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Antoine-Laurent Lavoisier

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For a millenium, till the time of Lavoisier, Alchemy was practised. Alchemy was unscientific, but its practitioners developed useful experimental methodologies, materials and medicines. In the seventeenth century 'phlogiston' theory was introduced to explain the results of combustion. Lavoisier, through his extraordinary logical capabilities developed systematic experimental procedures by adopting proper weighing and measuring methods. This brought about radical change in scientific thoughts and ushered in the era of modern chemistry. Lavoisier was not only a great scientist, but a revolutionary thinker, a social reformer, a good administrator, a helpful and sociable person and an institution builder. Despite these uncommon qualities, the frenzy of the French Revolution consumed his life in a very tragic way.

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The second half of the eighteenth century may be considered as the beginning of modern chemistry. During this time the reign of alchemy, which was first practised by Arabs in the latter half of the first millennium and early second millennium and then passed over to European alchemists, ended gradually. Many scientists contributed to the alchemy's change over to chemistry. Among them Robert Boyle (1627–1691) and Antoine Lavoisier (1743–1794) are particularly given the credit for this transformation and each one of them is considered as the 'Father of Modern Chemistry'.

Alchemy was born and grew because of human's fascination for the glittering gold and desire to live forever. The alchemists worked to find a way for converting base or inferior metals to gold and also a way for keeping humans away from disease and death. Philosophically speaking, it is to work towards achieving purity and perfectness. Alchemists believed that there were secrets to be uncovered in order to acquire the ability to perform these

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transformations. They thought that this ability is present in a universal medium called the 'elixir of life' or the 'philosopher's stone', which may be likened to '*Amritha*' and '*Parusha* stone' in Indian myths and holy texts. Naturally the rich and the royals and the poor too were interested. The European Royals in the Middle Age patronised alchemists who therefore flourished.

Though alchemy's objective was noble, its practitioners were not all noble. There were some charlatans and frauds alongside the noble. Alchemy had no logical basis, but worked on a trial and error basis, and on the conjunction of astrology and magic. However, alchemy was not all black magic. There were several intelligent, genuine and honest alchemists such as Geber, Nagarjuna, Robert Boyle and many others whose achievements are significant and became the foundation for future chemistry. Alchemists developed and used many apparatus, instruments and experimental procedures that may be considered as the forerunners of their modern counterparts. They practised extraction, distillation, fermentation, smelting, mettalurgy, mixing, prepared powders and identified plants of medicinal value, made alcohol, acids, alkalis, perfumes and many things else. Despite these achievements and the association of several famous names, alchemy has no place in modern chemistry because of its mysterious origin, mythical beliefs, unscientific practises and unscrupulous self-servers. The advent of modern science paved the way for the gradual disappearance of alchemy and finally its demise in the eighteenth century.

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Late in the seventeenth century, the German alchemists Johann Joachim Becher and Georg Ernst Stahl propped up the 'phlogiston theory'. According to this theory, a colourless, odourless and weightless substance called 'phlogiston' is present in all materials and it is given off when they are burnt. The remaining ash was 'dephlogisticated' material and considered to be the element. On the basis of this the products of combustion of phosphorus, coal and sulphur were elements and not these! There were many well-known scientists of that time who strongly believed in the phlogistic theory. Joseph Priestley's faith in 'phlogiston' was so strong that his close friend Lavoisier could not convince him of the fallacy in that theory and change his mind. It may look strange and stupid to us now, but for the scientists of the eighteenth century it was a scientific truth, because their understanding of the elements was incorrect. Another reason was that they neither used proper balances nor cared to take correct weights of starting materials or products. Therefore the interpretation of the results was based on assumptions in most experiments. That is why the phlogiston theory flourished. In such critical and confusing circumstances, it was Antoine-Laurent Lavoisier who made every possible effort to infuse sanity and proper scientific thinking by driving away the phlogiston devil successfully.

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Early Life and Education

Antoine was born in Paris on 26th August, 1743, to a well-to-do family. His father Jean Antoine Lavoisier was a prominent advocate, and his mother, Emilie Punctis was the daughter of an advocate of the parliament. Antoine had a sister, Marie, born two years after him. Emilie died when Antoine was five years old. It became the sole responsibility of the father to take care of the children who missed their mother's care and love. Realizing that he cannot devote full time for this, Jean Antoine moved with the children to his mother's place. Emilie's sister, Constance Punctis, too thought it important to bring up the children in the best possible way. She loved them so much that she decided to stay unmarried in order to give them her complete attention. Antoine and Marie grew up with the love and care of their father and aunt.

Antoine's aunt was of good wordly wisdom and knew that he should be given good education. She admitted him to College Mazarin, which was famous for science and mathematics with such teachers as Nicholas Louis de Lacaille, the astronomer, Jean-Etienne Geuttard, the geologist, Bernard de Jussieu, the botanist and Guillaume Francois Roulle, the chemist, on its faculty. In addition to studying science and mathematics Antoine studied law and obtained a bachelor's degree in that subject. With this, he could have gone into the legal profession, but he never entered it. Instead, because of his much greater interest in

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mineralogy and chemistry, he continued his studies in these subjects.

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As a student, Antoine was very good in his studies and received many prizes and awards. During his college days he used to assist his teachers in conducting experiments and sometimes he conducted them independently. On the basis of his work in geology and his proposed plan to provide lighting to big cities, Lavoisier was admitted to the Royal Science Academy of France as a member in 1768, when he was only 25 years of age. As part of the ceremony he made his first lecture at the Academy entitled, 'An analysis of gypsum and its calcinations into plaster of Paris'. Lavoisier is thus 'father of plaster of Paris'.

The Political and Social Condition

During the period of mid-eighteenth century France was ruled by Louis XV and then Louis XVI. The kingdoms and principalities in Europe of that time were strife-ridden and constantly fighting wars with each other. It was the pre-industrial era and the economic conditions of most of these states were not satisfactory. There used to be regular unrest among people within the principalities and kingdoms. France was no exception to this. Due to famine condition over a long time, the farmer's life had become particularly difficult. This had an adverse effect on trade. Despite hardships, the farmers and traders had to pay taxes as in good times, as the government was not willing to cut its expenditure.

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The government had outsourced to private companies, the task of tax collection on its behalf. It was the duty of these companies to collect taxes and pay the proceeds to the government. The companies received certain percentage of the collected amount for their service. The person appointed for this job was called 'fermier', or a 'tax farmer'. A fermier was entitled to collect all kinds of taxes. They included taxes on peasant households and land area taxes for military expenditure, revenue tax (50% of incomes from land, trade, industry, property), taxes on salts (most hated), tariffs on products like wine, tobacco and speciality products, octroi, church tax called 'dime' and others. Also customs charges, including duty on imported goods, were collected by tax fermiers. Many fermiers were greedy and corrupt and misused their position to gain illegitimate money to lead a luxurious life at the cost of hapless farmers and traders. They were naturally hated by tax payers, particularly the poorer sections of farmers and traders. There were a few honest among them, and one such was Antoine Lavoisier.

Lavoisier conducted experiments on his farms to increase the crop yields and dairy productions, and passed on the improved farming practices to the farmers without any charges.

Government Job and Personal Life

Although Lavoisier belonged to a well-to-do family, he could not get all the needed finances to pursue his interest in chemistry. Therefore in order to earn money to meet the expenses for setting up the laboratory and conducting the experiments, he joined as deputy to fermier-general Baudon and worked as tax collector. After sometime Lavoisier himself became an independent fermier. He used to perform the duty of a tax collector during the day and in the evening /night he would engage himself in his experiments. Unlike the other tax collectors Lavoisier conducted his 'fermier' job with honesty and sincerity. He never abused his authority to exploit the tax payers. On the other hand he helped farmers. He conducted experiments on his farms to increase the crop yields and dairy productions, and passed on the improved farming practices to the farmers without any charges. Many times he would help them by spending his own money.

In 1771, Lavoisier married thirteen year old Marie-Anne Pierette Paulze, the daughter of his fermier company partner. Marie-Anne was a bright woman beyond her age. She became an invaluable partner in all of Lavoisier's activities. She helped Antoine in his scientific work with good understanding and skill. She illustrated the experiments with beautiful sketches of the apparatus, and recorded the results for analysis and publication. She later learnt the English language and translated English articles to French in order to facilitate Lavoisier to follow Priestley's and others'work published in English. She gained good knowledge in science and actively participated in scientific discussions contributing her

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ideas in explaining experimental observations and developing scientific theories about them. Thus she deserves to be called 'the mother of modern chemistry', if Lavoisier can be called 'the father of modern chemistry'. However, in eighteenth century Europe, the women suffered gender bias and Marie-Anne did not get the recognition she deserved.

In 1775, Lavoisier was appointed as the commissioner of the Royal Gun Powder and Saltpetre Committee. He took steps immediately to improve the composition of gunpowder and increase its production. With this the public were happy because from then on they did not face the searching of their basement for confiscation of their saltpetre stock by the government. During this time Lavoisier built a very good laboratory in Europe, which served as a centre for the European scientists to come together to exchange their views and ideas.

[1]This aspect is discussed further in Mallesh *et al*, *Resonance*, Vol.16, No.3, p.254, 2011.

Lavoisier served as secretary to the agricultural committee with great ability and thoroughness. He prepared brochures and instruction manuals to help farmers for reaping bountiful harvests. These instructions were based on his experiments carried out on his own farms. Lavoisier helped farmers in other ways also. For example, he taught them how to keep their accounts, and extended financial help to needy farmers, and in 1788 famine he distributed grains bought with his own money. Lavoisier used his wealth and authority to help the public and to finance his scientific activities.

Such a kind and generous person, sympathetic and helpful to the public, supporter of scientific activity, who paved the way to modern chemistry, and never exploited his authority for self-gain or indulged in self glory, had to face the ire of the activists during the French Revolution known to have started in 1789 triggered by the 1788 famine. The famine made the existing bad economic condition and social unrest worse.

The French Revolution was the result of complex social, political, religious and economic reasons. The French society was under turmoil for many years. The 1788 famine was probably the proverbial last straw. The events that happened during the Revolution were quite complex and it is impossible to narrate it in a few sentences. However, the goal of the Revolution was to abolish the monarchy and establish the rule of common people through the formation of a Republic. Though monarchy was abolished on 21st September, 1792, along with declaration of the Republic and the King Louis XVI was executed on 21st January, 1793, the turmoil went on for many years. The Revolution could not be contained by the monarchy and it spread like wildfire. Death and destruction became the order. The revolutionary activists mercilessly dealt with all those who had worked for the government. By 1791, Fermier generals were suppressed. They were accused of every kind of misconduct by the revolutionary writer Jean Paul Marat. Lavoisier was no exception to this. Because he held public offices, interacted freely with agriculturists and general public, and was in the forefront of scientific activity, Lavoisier was one of the most visible Fermier-generals. The revolutionary activists were not in a mood to distinguish the good from the greedy. He was even charged of trying to change good quality gun powder stock with low quality one as the Royal Gunpowder Commissioner and was forced to resign from the post and sent out of the Royal Arsenal. For activists, Lavoisier was just another Fermier-general who collected taxes and misused his position as Gunpowder Commissioner. Therefore in their view he deserved the same punishment as the greedy ones.

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By 1792, the revolutionists had taken over the government. All the Fermier-generals including Lavoisier were arrested by the security forces. At the time of his arrest on December 24th, 1793, Lavoisier was conducting an experiment in his laboratory on respiratory gases using a test subject sealed in a silk bag and breathing through a tube into a gas collection flask. It was a terrible irony; the arrest warrant falsely accused Lavoisier that he was mixing tobacco with water and other chemicals to prevent it from drying up fast, which would put the health of the public at risk.

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A revolutionary tribunal was set up with Jean-Baptiste Coffinhal as its president to try the arrested. The tribunal members had made up their minds about what the punishment should be even before the trial began. On May 7th, 1794, Lavoisier was brought before the tribunal. Most charges against him were false; the trial was over in just two days and was given the capital punishment. His supporters appealed not to execute a noble person and a genius,as it would be a great loss to science and society. But the tribunal president remarked "The Republic has no need for scientists or chemists". The indiscriminate and over enthusiastic activists in their hatred of everything that symbolised French monarchy condemned Lavoisier to die and he was executed, along with his father-in-law Jaques Paulze on the guillotine on May 8th, 1794. The life of a scientific revolutionary was brought to an abrupt end by political and social revolutionaries. He was just 51 years old. It is one of the greatest tragedies in the history of science. A few days after Lavoisier was executed the mathematics genius Joseph-Louis Lagrange remarked, "It took only an instant to cut off that head, and a hundred years may not produce it".

The Revolution ended officially in 1799. It is estimated that 25,000 to 40,000 executions were carried out during that period, in which both the guilty and the innocent were beheaded on the guillotine. Even some leaders of the Revolution and its active participants had to face execution if they were perceived to be deviating. The French Revolution was one of the bloodiest in the history of mankind.

Scientific Achievements

Several eminent scientists such as Davy, Priestly and others who were contemporaries of Lavoisier were staunch phlogistonists.

The time in which Lavoisier lived was a transition time for chemistry. Alchemy was rubbing shoulders with modern chemistry. The phlogiston theory propounded towards the end of the seventeenth century by the German alchemists Johann Joachim Becher and Georg Ernst Stahl, was flourishing. Several eminent scientists such as Davy, Priestly and others who were contemporaries of Lavoisier were staunch phlogistonists. Lavoisier rejected the idea completely. However, all of them conducted experiments in (more or less) similar fashion and recorded their observations systematically. It was in the interpretation of the results that they differed drastically. The laboratory facilities they had were very simple compared to those in the modern laboratories. But in those days they served well and what was achieved then is no less important than what is achieved in the most sophisticated laboratories.

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One of the greatest contributions of Lavoisier was to drive away the 'ghost of phlogiston' and to show that chemical changes occur by combination or decomposition of measurable things and not imaginary things like 'phlogiston'. According to the proponents of phlogiston theory a colourless, odourless and weightless substance called phlogiston, present in every material was released while it burnt and the 'ash' that remained was considered as 'dephlogisticated' material. It was assumed that the dephlogisticated materials were pure elements based on the fact that most of the pure metals (gold, silver, mercury, copper, zinc, tin, lead, etc.) were indeed obtained by strongly heating or burning their ores with charcoal. This idea was applied indiscriminately to other materials such as the products of combustion of phosphorus, carbon, sulphur, etc., as well. The chemists of that time had no clear idea about the difference between elements and compounds. It was only in the beginning of the eighteenth century that the confusion started to recede due to the work of Dalton (*Resonance*, 2010, Vol. 15, p.2–7), Avogadro (*Resonance*, 2006, Vol. 11, p. 2–7), Berzelius and others.

Lavoisier showed that the combustion products of phosphorus, carbon, sulphur and other non-metallic substances behave like acids. He went an important step further and proved that oxygen is consumed by substances during combustion and that oxygen was an element. It was a turning point and the beginning of a proper understanding of chemical changes. In a few years Humphrey Davy, Louis Joseph Gay-Lussac and Louis-Jacques Thenard enlarged the idea of acids and showed that it is possible to form acids without oxygen based on their experiments with

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hydrochloric acid, chlorine and hydrocyanic acid. In 1784 Joseph Black included Lavoisier's experiments and theoretical explanations as part of science studies in his lectures. Thus Lavoisier's contributions were widely accepted and opened up a new pathway for the progress of science.

Lavoisier was aware of the importance of accurate measurement in obtaining correct results from scientific experiments. In order to achieve this he developed good balances and introduced metric system for weighing. Because of the dependable weighing procedure, Lavoisier was able to prove that the products of the combustion of the elements actually have more weight than before. He explained that the weight gain was because a part (later found to be oxygen) of the air combined with the substances during combustion, and the total weight was the sum of the weights of oxygen and the substance burned. But the pro-phlogiston scientists explained such facts by attributing a negative weight to phlogiston. They were eventually proved wrong by Lavoisier who repeated the experiment of Priestly on mercuric oxide systematically (see later).

Oxygen was discovered in 1774 by Joseph Priestly of England and Carl Wilhelm Scheele of Sweden. Priestly called it "dephlogisticated air" or air that had lost phlogiston, while Lavoisier first referred to it as "air in its purest form" and later named it as "oxygen" (Greek: *oxus* = sharp, acid; *ginomai* = become, cause to be).

It was believed that the 'element' water of Democritus' philosophy would turn into the 'element earth' when boiled. Lavoisier showed by a very simple experiment that this was wrong. He took a weighed quantity of water in a sealed glass flask and boiled it for many days. To the disappointment of the phlogistonists, it was found that the water neither lost weight nor became earth.

In 1789, Lavoisier published *Elementary Treatise of Chemistry*. Through this he propagated his oxygen theory and other concepts.

Lavoisier published his book *Opus of Physics and Chemistry* in 1774. He wrote several laboratory textbooks also. His wife Marie-Anne has drawn the pictures of apparatus, experimental set-up, etc., for the books. In addition, Lavoisier published a number of articles on chemistry, meteorology, geology and other subjects. In 1789, he published *Elementary Treatise of Chemistry*. Through this he propagated his oxygen theory and other concepts. In that book he has mentioned thirty three elements. (Several of them were not actually elements. Much later, Dalton prepared a table of only twenty elements).

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Disproving the Phlogiston Theory

In 1774, Lavoisier repeated the experiments done by Robert Boyle in the seventeenth century on the ashes of tin. Boyle had established that when tin was burnt, the product obtained weighed more than the metals he started with. According to phlogiston hypothesis, the weight of the ash is more, because the phlogiston of negative weight is released from the burning substance. Cavendish thought that phlogiston was an inflammable gas and considered it to be some kind of a substance. Many well-known scientists of that time firmly believed in its existence and used it to explain all kinds of scientific observations in a manner that suited them. But Lavoisier had absolutely no belief in it. So he started doing experiments systematically to prove his point.

Lavoisier heated tin in a closed vessel and after the reaction was over, he observed that air gushed into the vessel when opened. At about that time, Priestly visited Lavoisier in Paris and informed him about his discovery of "dephlogisticated air". At the same time Scheele sent a letter to Lavoisier (30.09.1774) describing the preparation of oxygen with a request to repeat his experiment. With the discovery of oxygen by Scheele and Priestly, Lavoisier became fully convinced about the non-existence of phlogiston and he produced unassailable experimental proof in 1777.

Lavoisier found the volume of air in the bell-jar had decreased from 50 cubic inches to 42 cubic inches. He collected the liberated gas and found it to be Priestley's dephlogisticated air and was 8 cubic inches in volume.

Lavoisier heated a known weight of mercury in a small dish covered with a bell-jar for twelve days. It turned into red ash and had more weight. He found the volume of air in the bell-jar had decreased from 50 cubic inches to 42 cubic inches. He thought that the remaining gas was impure air. (It was later called azote and then nitrogen). In the subsequent experiment he took the red product in a retort and heated it even stronger. He collected the liberated gas and found it to be Priestley's dephlogisticated air and was 8 cubic inches in volume. The regenerated mercury had the same weight as in the beginning of the experiment.

This simple experiment had a profound consequence. It showed that the ash obtained in the first step, when heated at a higher temperature the reverse reaction occurred and the starting substances reformed in the same quantities. In the modern way, these reversible reactions can be written in the following equations:

$$2\,Hg + O_2 \longrightarrow 2\,HgO$$
$$2\,HgO \longrightarrow 2\,Hg + O_2\,.$$

According to the phlogiston hypothesis, a reaction cannot be reversed. Therefore, it followed that the assumption of the existence of phlogiston was false. Thus Lavoisier drove away phlogiston from chemistry forever. Despite such strong evidence against it there were still many people, including his close friend Priestley, who believed in the phlogiston theory and did not convert to a nonbeliever. Ironically, the evidence for oxygen theory as against phlogiston theory came from the work of phlogistonists Davy and Priestley.

Lavoisier, who was constantly immersed in gaining knowledge and rational thinking, conducted hundreds of experiments. They included the analysis and studying the properties of gases, respiration in animals and humans, the metabolism of organic substances in the body and many other scientific studies. By adopting the metric system in weighing and an accurate balance, he showed the advantages of getting reliable results in interpreting and understanding scientific concepts. His contributions to the advancement of science are immense. But, alas! His life ended prematurely due to the thoughtless judgement of an overenthusiastic French revolutionist.

Suggested Reading

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