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WHO DISCOVERED OXYGEN?

KTO ODKRYŁ TLEN?

Summary: The history of research, leading to the discovery and isolation of oxygen is presented.

Keywords: oxygen, nitre, Hermann Boerhaave, Robert Boyle, Cornelis Drebbel, John Mayow, Joseph Priestley, Michael Sendivogius (Michał Sędziwój).

The discovery of oxygen was one of the greatest triumphs of modern science. With it came the recognition that air is a mixture of gases, of which about 20% is oxygen and 80% is nitrogen. This seemingly mundane fact has altered our lives in a fundamental way and has had a huge influence on the development of the Industrial Revolution.

The motor car and lorry, the aeroplane, engine powered ships, rockets, central heating systems, gas cookers and high explosives - none of these would have been possible without knowledge of the composition of air. To these we can add the Bunsen burner, found in school chemistry laboratories. Our world has been radically changed by all these inventions. This is because, through our knowledge of the composition of air, we have been able to optimise the burning of fuels and exploit them very efficiently in combustion engines.

In view of this profound effect that the discovery of oxygen has had, we would expect its mention to be accorded an appropriate emphasis and status in the chemistry teaching syllabuses in our schools. So let us examine a typical quote from a modern textbook to see how this most important discovery is presented to young people: *A new gas was discovered by the British chemist, Joseph Priestley* [1733-1804], *on 1st August 1786. Heating mercury in air he found that it combined with part of the air to form a solid which he called 'red calx of mercury'. When Priestley heated 'red calx of mercury', he obtained mercury and a new gas, which when he breathed it produced a 'light and easy sensation in his chest'. The gas was oxygen* [1].

How might a young student of chemistry respond to such a statement? Another person might imagine something like this: *Priestley was probably some sort of boffin who had a load of chemicals and apparatus, and he mixed the chemicals together to see what would happen. One day he did this experiment, which involved heating mercury and got some sort of gas. Maybe he bubbled it through water? 'Wow!!' he thought to himself, 'That's so cool! Maybe I've discovered something new?' That night, he was so excited about his new gas that he probably had a dream and so the next day he did some more experiments with some even more complicated apparatus. This time he got some of the gas in a jar, and smelt it. Then he got it to relight a glowing splint, and Bingo! He had discovered oxygen. He was so excited about his discovery that he went and told all his friends about it and so he became famous. Easy stuff, anyone can do it*!

The truth however, is far more complicated and far more subtle. In the 1660s the brilliant Irish natural philosopher Robert Boyle [1627-1691] had developed a great interest

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in air. This was because many experiments were being conducted by scientists in Europe, who had recently discovered remarkable facts about the way in which air behaves when subjected to changes of temperature and pressure. Boyle was particularly interested in the process of burning, and its relationship with air. It had become known in academic circles that when substances burn, an inexplicable change occurs in air - it becomes unable to support further combustion. Also, if small animals are left in enclosed spaces, they soon die. These changes were difficult to explain because air was considered to be an **element**, that is a simple substance, which could not be broken down any further.

Ingenious experiments were devised to try to explain what goes on when animals breathe and when objects burn. Boyle himself conducted countless experiments over many years, which he documented in his epoch-making book - *The Sceptical Chymist* (Oxford, 1661), in which he debated the exact significance of the concept of an **element**. This is because he had found the idea of the Aristotelian elements, Earth, Fire, Air and Water, which for some 2000 years had dominated natural philosophy, highly unsatisfactory.

Boyle also became fascinated by an unusual event – the journey of the world's first submarine in 1620. This had been designed for King James I by the secretive Dutch inventor, Cornelis Drebbel [1572-1633]. The wooden submarine had travelled underwater from Westminster to Greenwich with 12 rowers on board, and Drebbel was able to freshen the air in the vessel using a secret mysterious "liquor". This was the main focus of Boyle's interest: *Drebell conceiv'd, that 'tis not the whole body of the Air, but a certain Quintessence (as Chymists speake) or spirituous part of it, that makes it fit for respiration, which being spent, the remaining grosser body, or carcase (if I may so call it) of the Air, is unable to cherish the vital flame residing in the heart* [2].

If Drebbel had indeed been able to freshen air, then it would make sense to see what he himself had to say on this matter. Drebbel was not a prodigious author. He wrote two short works, in one of which, writing on the origin of thunder, we find this interesting passage: *Thus is the body of the saltpetre broken up and decomposed by the power of the fire and so changed in the nature of the air* [3]. Not far from this statement is printed a diagram of a retort flask being heated. Several versions of this (the only illustration in the book) were published. In the accompanying diagram, published in the 1688 Dutch edition of Drebbel's *Treatise on the Elements of Nature*, two men are seen gazing at bubbles emerging from the spout of the flask in what is presumably a trough of water. The reaction seems to be the thermal decomposition of nitre (potassium nitrate), the gaseous product of which we would recognise today as oxygen.

So where did Drebbel get this extraordinary idea? Extraordinary, since it implies that he knew how to make the substance that we recognise as oxygen today. During the years at the turn of the 16^{th} and 17^{th} centuries, Drebbel had been employed at the court of Rudolph II in Prague [4], alongside a plethora of other alchemists, doctors, astronomers, magicians and astrologers. Thanks, partly to its location and partly to the welcoming disposition of Rudolph II, the sciences and arts flourished at the Royal Castle in Prague. One of the court alchemists with whom Drebbel would undoubtedly have had contact was the secretive Polish alchemist Michael Sendivogius (Michał Sędziwój) [1566-1636].

Sendivogius, born in Łukowica in Southern Poland on 2^{nd} February 1566, had established himself as a competent practitioner of the alchemical arts. In 1604 his first major work was published, the *De Lapide Philosophorum Tractatus Duodecim, é Naturae fonte, et Manuali Experientia deprompti. Autor sum, qui DIVI LESCHI GENUS AMO.*

Anno M.DC.IV. It turned out to be a remarkably successful and influential work: between 1604 and 1787 it went through 56 editions in 7 languages, and was published under a shortened title: *Novum Lumen Chymicum.* Both Isaac Newton [1643-1727] and Antoine Lavoisier [1743-1794] studied it.

The principal reason for the great interest in this work, which was "*Taken out of the Fountain of NATURE AND MANUAL EXPERIENCE*", unlike many other alchemical works, was that Sendivogius drew attention to a hitherto unrecognised aspect of air: that it plays a vital role in the processes of life. He was also able to link this to the chemistry of an important salt **potassium nitrate -** (**nitre** or **saltpetre**, a key component of gunpowder). The following passages from the English language edition of *A New Light of Alchemy* (London, 1650) illustrate the direction in which his research took him:

Man was created of the Earth, and lives by virtue of the air; for there is in the Aire a secret food of life, which in the night we call dew; and in the day rarified water, whose invisible, congealed spirit (i.e. nitre [Z.S.]) is better than the whole Earth.

…it is the water of our dew, out of which is extracted the Salt Petre of the Philosophers, by which all things grow, and are nourished.

O our Heaven! O our Water! O our Mercury! O our salt-nitre abiding in the sea of the world! O our vegetable! Our water that wets not our hands, without which no mortal can live, and without which nothing grows, or is generated in the world!

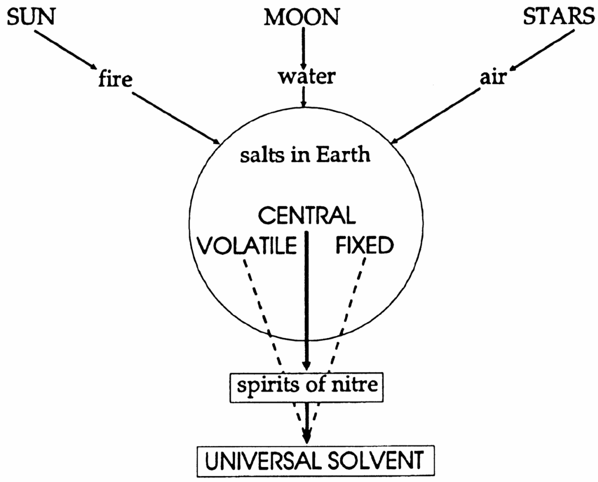

Fig. 1. A diagrammatical representation of Sendivogius' central nitre theory [5]

1. Nature produces the Central Salt which plays a vital role in the life cycle of plants and animals. 2. Man uses the Central Salt to produce the universal solvent, from which the universal seed of metals can be formed, which enables the transmutation of base metals into gold to be accomplished. 3. The Central Salt provides a link between "what is up there" and "what is down below". The Central Salt, or potassium nitrate, therefore provides the key to all phenomena relating to life. Modern chemical interpretation: central salt = potassium nitrate, volatile salt = ammonium chloride, fixed salt = potassium carbonate, spirits of nitre = nitric acid, universal solvent = aqua regia (a mixture of concentrated nitric and hydrochloric acids)

A careful study of his writings reveals that his theory of an aerial component that is necessary for life has a sound chemical basis. Above is shown, in diagrammatic form, a representation of his theory which combines the traditional alchemical world-view which is based on analogy, with that which can also be interpreted in terms of modern analytical chemistry.

One of the earliest (and certainly greatest) teachers of chemistry, the Fleming Hermann Boerhaave [1668-1738] saw Sendivogius' discovery as a crucial step towards the understanding of the nature of air. In his successful textbook of chemistry, *Elementa Chemiae* (Lugduni Batavorum 1732), he wrote: *air possesses a certain occult virtue which cannot be explained by any of those properties previously investigated. That in this virtue the secret food of life lies hidden, as Sendivogius clearly said, some chemists have asserted. But what it really is, how it acts, and what exactly brings it about is still obscure. Happy the man who will discover it*!

The Sendivogian theory paved the way for a new wave of experimental investigations, particularly at Oxford University during the mid 17th century. Both Robert Boyle and John Mayow [1641-1679], among others, advanced our understanding of the role of air in respiration and combustion, and brought the topic to the forefront of the scientific agenda of the day. In his *Tractatus Quinque Medico-Physici* (Oxford 1674), Mayow explained the processes of combustion and respiration in terms of particles - these had been introduced into the chemical philosophy by René Descartes [1596-1650] in the 1630s, and played a significant role in the development of the chemical philosophy during the 17th century.

In the *Tractatus Quinque* one can read: *Besides, the nitro-aerial salt, whatever it may be, becomes food for fires, and also passes into the blood for respiration, as will be shown below.* Also, *Further, it is impossible that these igneo-aerial particles are any perfect nitre, as is generally supposed - for it was already pointed out that not the very nitre as a whole, but only a certain part of it, resides in the air…* . It is possible to see the influence of Sendivogian ideas here, because of the references to nitre and air.

With hindsight, it is possible to see that Mayow was talking about processes that involve oxygen and oxidation reactions. He was very close to a formal recognition of oxygen.

And yet, another theory relating to the chemical reactivity of metals in the air, caught the imagination of chemical philosophers for almost 100 years. This was called the **phlogiston** theory, and it stemmed from observations of burning processes. It was put forward by two German chemists: Johann Joachim Becher [1635-1682] and Georg Ernst Stahl [1660-1734].

According to their theory, all substances contain a combustible principle called phlogiston (from the Ancient Greek, meaning "burnt up"). When substances are burnt, phlogiston is released into the air. There was a serious problem in explaining how metals became **heavier** when they were burnt, but this was overcome by suggesting that phlogiston had **negative** mass!

Without going into too many details, it is possible to see just how complex these issues were to scientists of the past. When Priestley discovered his new gas which supported both combustion and respiration, it should be no surprise that he called it **dephlogisticated** air. It was the French chemist Antoine Laurent Lavoisier, who was beheaded during the French Revolution, that gave the gas the name **oxygen** (*I give birth to acids*, *gr*. oksýs = acidic; *gr.* gennáō = to give birth) and explained its role in combustion and respiration in a manner which remains substantially unchanged today. For this, he is rightly called the "*Founder of Modern Chemistry*".

In view of the above, concerning the study of air and its role in vital processes, does the one sentence quoted earlier from a modern chemistry textbook, do **justice** to the discovery of oxygen? Does it do **justice to the science of chemistry**?

References

[1] Ramsden E.: Key Science, New Edition, Chemistry, Stanley Thornes, London 1997, 137.
[2] Boyle R.: New Experiments, University Publishing House, Oxford 1660, 364.
[3] Drebbel C.: Treatise on the elements of Nature, Publishing House, Amsterdam 1608, 65.
[4] Evans R.: Rudolph II and his world: A study in Intellectual History, Thames & Hudson, London 1997, 197.
[5] Szydło Z.: Water which does not Wet Hands - The Alchemy of Michael Sendivogius, Polish Academy of Sciences, Institute for the History of Science, 1994.

KTO ODKRYŁ TLEN?

Streszczenie: Przedstawiono historie badań, które doprowadziły do odkrycia i wyizolowania tlenu.

Słowa kluczowe: tlen, saletra, Hermann Boerhaave, Robert Boyle, Cornelis Drebbel, John Mayow, Joseph Priestley, Michael Sendivogius (Michał Sędziwój)