THE DISCOVERY OF OXYGEN

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It is essential for life on Earth. It is also the most abundant element in the earth's crust and the second most abundant element in the earth's atmosphere. It is necessary for both combustion and respiration. How was it discovered? When was it first recognized as a chemical element? How did it get its name?

One of the earliest known experiments on the relationship between air and combustion was conducted by a Greek physicist, engineer, and writer called Philo. Born in 280 BC, Philo was a resident of Byzantium (the ancient name for Istanbul). He observed that a few seconds after a burning candle was covered by an upturned vessel (sealed at its base with water), the flame went out and there was a dramatic rise of water in the upturned vessel (see **Fig. 1**). He included a detailed description of this experiment in a treatise called *'Pneumatica'*. Philo inferred that the rise in water level was caused by a partial vacuum in the glass container. Fire was believed to be an element at the time. Philo incorrectly surmised that the vacuum was caused when some amount of 'this' element was lost from the glass container in the form of light.

In the early part of the 16th century, the Italian polymath Leonardo Da Vinci replicated this experiment and concluded that some of the air trapped in the upturned vessel had been used up for combustion by the burning candle.

In 1659, the Irish scientist and inventor Robert Boyle and the British polymath Robert Hooke (who was at the time working as Boyle's assistant) developed an efficient vacuum pump (see **Fig. 2**). When they used this to pump out all the air from a jar inverted over a burning candle, the candle died out. The same happened when the candle was replaced with a glowing ember of coal. However, if they allowed some air into the jar while the ember was still hot, it would start glowing again. Based on these observations, Boyle and Hooke concluded that the presence of air was essential for combustion.

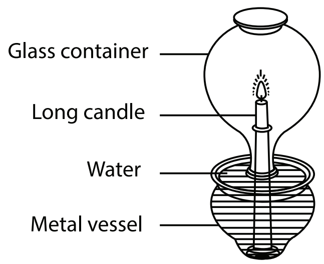

Fig. 1. Philo's experiment on combustion. Philo mounted a long candle (made of animal fat) to the base of a shallow wide-mouthed metal vessel. He poured water into the metal vessel and lit the wick of the candle. As the candle was burning, he inverted a glass container with a narrow mouth and a long neck over it in such a way that its mouth touched the water in the metal vessel.

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Building on their work, the British chemist John Mayow conducted two sets of experiments. In one set, he replicated Philo's setup with a burning candle. In the second set, he replaced the burning candle with a mouse. Mayow found that after some time, the candle went out in the first experiment and the mouse died in the second one. He also found that a portion of the air in both inverted jars had been displaced by water. Mayow referred to this portion of air as *spiritus nitroaereus* (or simply *nitroaereus*) and concluded that this portion was necessary for both combustion and respiration. He described these experiments and observations in his book *Tractatus Quinque Medico-Physici* (or 'Five Medico-Physical Treatises'), published in 1674. In another experiment, Mayow observed that heating antimony increased its weight. From this, he concluded that the *nitroaereus* must have bonded to antimony. He also hypothesised that our lungs separate the *nitroaereus* from air; this is sent into our blood, where it reacts with certain substances to produce the energy that fuels muscle activity. Mayow's ideas as well as detailed descriptions of his experiments were published in 1668 in a book titled 'The Respiration'.

During the 17th and 18th centuries, many scientists attempted to isolate Mayow's *nitroaereus*. This included Robert Hooke, the Danish physician Ole Borch, the Russian scientist Mikhail Lomonosov, and the French chemist Pierre Bayen. However, none of them recognized *nitroaereus* to be a chemical element. This may have been because the phlogiston theory was believed to be the most plausible explanation for combustion and rusting at the time. This theory was first propounded in 1677 by the German alchemist Johann Becher, and modified in 1731 by the German chemist Georg Ernst Stahl. It stated that all combustible substances were made up of two parts—one of these parts (named phlogiston) escaped when the substance was burnt, while the other part, considered the true form of the substance, remained behind as ash (named calx). This implied that combustible substances (like coal and wood) consisted mainly of phlogiston; whereas non-combustible substances (including iron, which is prone to rusting) contained negligible amounts of phlogiston. Strangely enough, according to the phlogiston theory, air was believed to play no role in combustion.

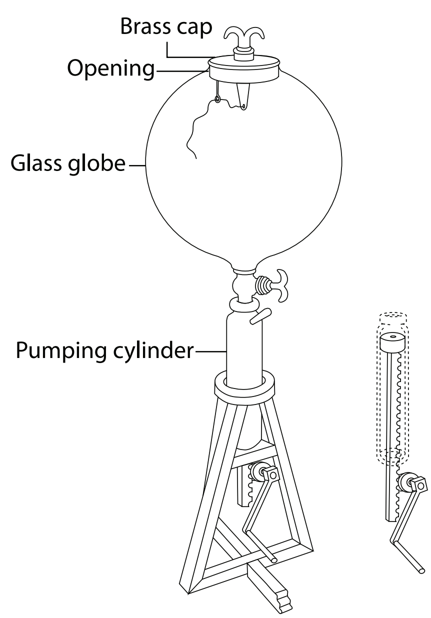

Fig. 2. A replica of the Hook-Boyle air pump. Built by Robert Boyle, with the help of Robert Hooke, this air pump or vacuum chamber had a spherical glass globe and a brass pumping cylinder. Objects could be put into the globe through an opening on top, which could then be sealed with a brass cap. This pump was useful in conducting experiments on combustion and respiration in a closed system.

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Mayow's *nitroaereus* was first isolated by the Swedish pharmacist Carl Wilhelm Scheele. Between 1770-1773, Scheele experimented with heating oxides of mercury, silver, and gold. He observed that the gas that was released in these experiments supported both combustion and respiration better than common air (see **Fig. 3**). He used the term *'Feuerluft'* or fire-air to refer to this gas as it was then the only substance that was known to support combustion. Records suggest that Scheele made this historic discovery in June 1771. However, he sent a detailed description of it to his publisher only in 1776. This was published in 1777 in Scheele's only book, *'Chemische Abhandlung von der Luft und dem Feuer'* (or 'Chemical Treatise on Air and Fire').

Meanwhile, Mayow's *nitroaereus* had been isolated by another scientist. On 1st August, 1774, a British preacher called Joseph Priestley observed that a gas was released when he focused a magnifying glass to focus the sun's rays on a lump of reddish mercuric oxide kept in an inverted glass tube sealed with mercury. On studying this gas, Priestley found that it did not dissolve in water. The flame of a candle burned more brightly in the presence of this gas than it did in common air, and a mouse remained alive in it for four times longer than it did in a similar quantity of air. Priestley tried inhaling the gas and recorded experiencing a lightness in his chest that lasted for some time. A firm believer in the phlogiston theory, Priestley surmised that air consisted of two components—'dephlogisticated air' (now known to be oxygen) and 'phlogisticated air' (now known to be nitrogen). According to

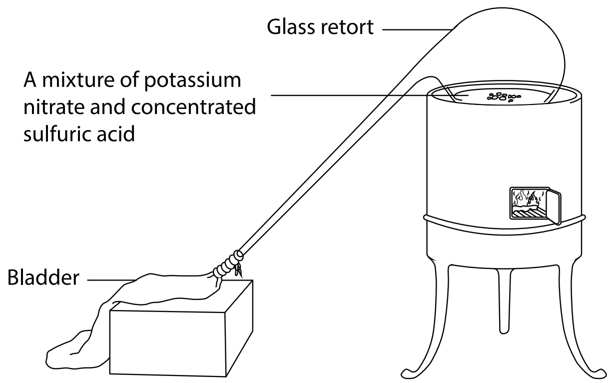

Fig. 3. Scheele's instruments for producing oxygen. In one of his experiments, Scheele placed a mixture of potassium nitrate and concentrated sulfuric acid in the glass distillation apparatus, called a retort. When heated, this mixture released a colourless and odourless gas, which was collected in a bladder tied to the mouth of the retort.

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him, dephlogisticated air contained little or no phlogiston of its own and could readily absorb phlogiston from flammable substances. This caused such substances to burn more brightly in the presence of this component. Priestley shared details of this discovery in a research paper titled 'An Account of Further Discoveries in Air'. First published in 1775, this paper was later included in Priestley's book (in six volumes) titled 'Experiments and Observations on Different Kinds of Air'. Since Priestley's findings were the first to be published, the discovery of oxygen is credited to him.

The famous French chemist Antoine Lavoisier also claimed to have independently isolated this component of air. This claim was met with disbelief. Not without reason. Lavoisier had a reputation for taking credit for work by lesser-known scientists. In this case, Scheele had written a letter to Lavoisier on 30th September 1774, describing his discovery. Lavoisier denied receiving any letter from Scheele. Believed to have disappeared, the letter was found in 1890 in the Archives of the French *Académie des Sciences* by the French chemist Edouard Grimaux. Similarly, it was known that Priestley had visited Lavoisier in October 1774. This was just before Priestley had published his own discovery. During this meeting, Priestley had shared his experiments and inferences regarding this newly isolated component of air with Lavoisier.

While the validity of Lavoisier's claim is still disputed, it is indisputable that he was the first to conduct accurate quantitative experiments on oxidation as well as provide a correct and satisfactory explanation for it. This was particularly significant because both Scheele and Priestley had interpreted their findings in light of the erroneous phlogiston theory. Lavoisier dismissed this theory as nonsense and suggested that the component isolated by Scheele and Priestley was a unique chemical element. He shared these ideas along with detailed descriptions of his various experiments on combustion in in 1777, in a book titled *'Sur la combustion en général'* (or 'General Thoughts regarding Combustion'). Like Priestley, he suggested that common air was a mixture of two components. Unlike Priestley, he suggested that each of these components was a chemical element. He referred to the element that was essential to combustion and respiration as 'vital air' (Priestley's dephlogisticated air) and to the other element as 'azote' (Priestley's phlogisticated air). Again, unlike Priestley, Lavoisier correctly assumed that vital air reacted with metals and nonmetals during combustion. He also observed that irrespective of the material that was burnt, the product was always more acidic than the reactant. Based on this observation, Lavoisier incorrectly assumed that vital air was a necessary constituent of all acids. This led him to replace the term 'vital air' with 'oxygen' (derived from two Greek words: *'oxy'* meaning 'sharp' from the taste of acid, and *'genes'* meaning 'that which forms or produces').

Nearly 35 years after the term oxygen was coined, the British chemist Humphry Davy showed that Lavoisier had been mistaken. It was not oxygen, but hydrogen that was a necessary constituent of all acids. However, by this time, the term oxygen was widely accepted and used. This was partly due to the popularity of a book called 'The Botanic Garden', which used this term in a poem in praise of the gas. Published in 1791, this book was authored by the British physician Erasmus Darwin, the grandfather of Charles Darwin. This was also the name that was entered into the English dictionary, despite protests from several British scientists who believed that it was inappropriate that a French scientist was allowed to name a gas that was first discovered by a British scientist (Priestley). As we all know, oxygen remains the name by which we know this gas by even today.

Key takeaways

- Many early experiments showed that air was required to support combustion and respiration.
- Two scientists—Carl Scheele and Joseph Priestley—independently isolated the component of air that supported combustion and respiration.
- Antoine Lavoisier was the first to recognize that this component of air was a chemical element. It was also he who coined the name 'oxygen' to refer to it.

Notes:

1. This article was first published in Srote, May 2014, pg. 10-12. This version includes some modifications. URL: https://www.eklavya.in/magazine-activity/srote-magazine/370-srote-2014/srote-may-2014.
2. Source of the image used in the background of the article title: Solar particles colliding with oxygen gas to produce a Green Aurora Borealis display. Credits: Tobias Bjørkli. URL: https://www.pexels.com/photo/aurora-borealis-at-night-1663376/. License: CC0.

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