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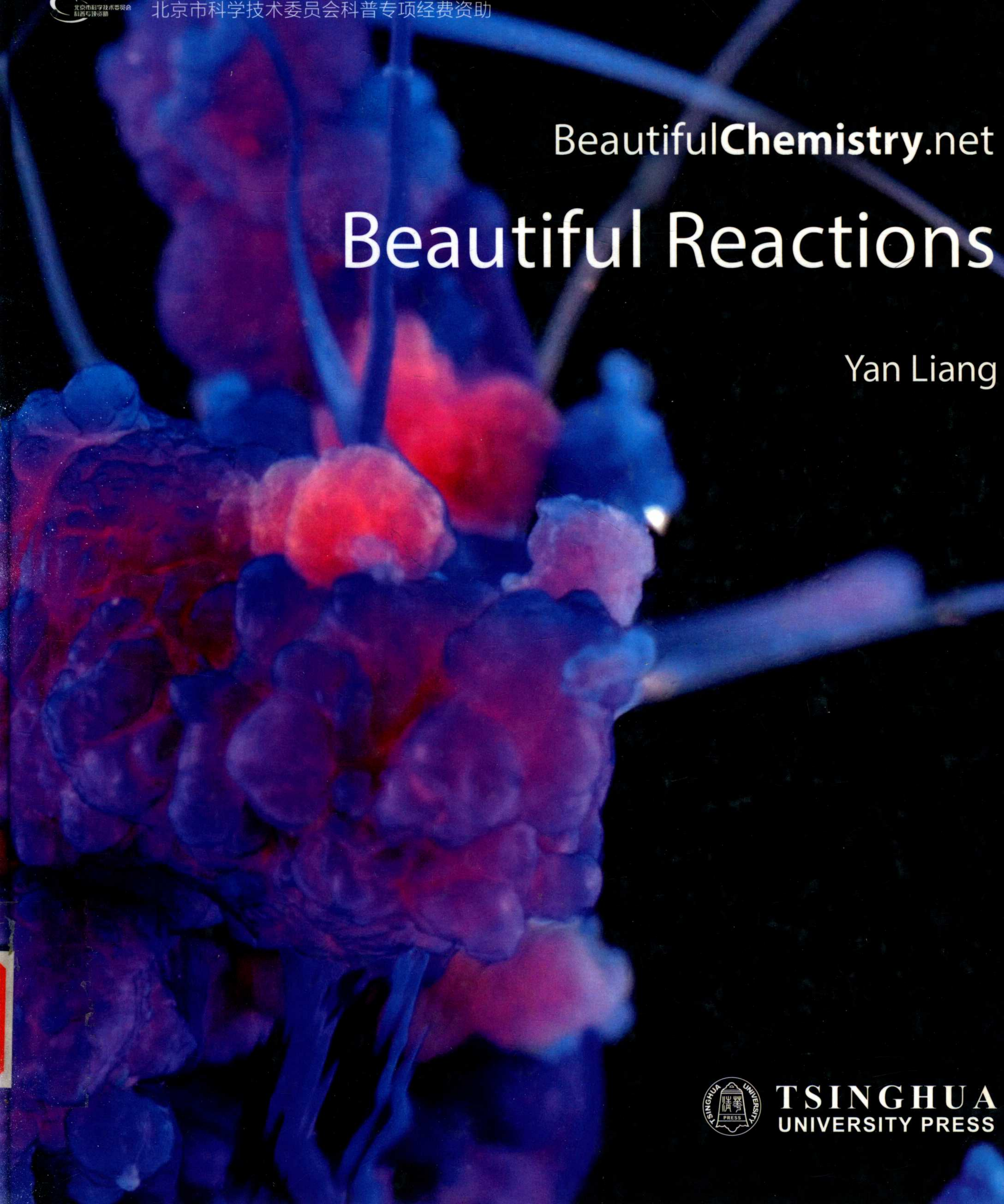
BeautifulChemistry.net

Beautiful Reactions

Yan Liang

TSINGHUA UNIVERSITY PRESS



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Beijing

内 容 简 介

本书历史部分选取了1660—1860年间波义耳、普利斯特里、拉瓦锡等12位著名的化学家，用精美的手绘图片和简洁的文字对他们使用过的重要化学装置进行了介绍。欣赏部分用CG图像复原了历史上15套重要的化学反应装置，另外还包括了拍摄的化学反应4K视频的精美截图。

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To my wife and daughter

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For the books. We would like to thank Mr. Hui LIU for his generous donation, with which we were able to complete the high-quality CG images and animations of historical chemical instruments. We would also like to thank Dr. Rongting ZHOU, chair of the Department of Sci-Tech Communication and Policies at USTC, for his kind support to our project. Finally, we would like to thank the artists from Shanghai Imagehost Digital Technology Co., Ltd (IHDT) for their amazing CG production and constant striving for perfection.

Beauty of Science

The Origin

Preface

About BeautifulChemistry.net

BeautifulChemistry.net started as a collaboration between University of Science and Technology of China (USTC) and Tsinghua University Press (TUP). The goal of this project is to bring the beauty of chemistry to the general public through digital media and technology. For example, we used 4K UltraHD cameras and macro lenses to capture chemical reactions in astonishing detail without the distraction of beakers or test tubes. At the molecular scale, we used computer graphics (CG) to showcase some of the most beautiful chemical structures selected from a large volume of scientific literature.

BeautifulChemistry.net was launched on September 30th, 2014. By the end of 2015, over 310 thousand people (68 thousand from the US) had visited our website, generating over 6 million page views. Our chemical reaction videos had been viewed over 5 million times. BeautifulChemistry.net was covered in many influential English media, such as *Time, Huffington Post, Business Insider, Colossal, Gizmodo, C|Net, Creators Project, Slate,* and other major media in China, France, Russia, Italy, Argentina, Hungary, Greek, Netherlands, and other countries. Through licensing, our chemical reaction footages appeared in more places, such as BBC's *Newsnight,* Discovery Channel's *Day Planet,* MITx online course, and the website homepage of the Chemistry Department at Columbia University. In addition, our project won many awards including the Experts' Choice award in the video category of the 2015 VIZZIES Visualization Challenge organized by NSF and *Popular Science.*

About the books

Building on the success of BeautifulChemistry.net, we prepared two books: Beautiful Chemical Reactions *(Reactions* for short*)* and *Beautiful Chemical Structures (Structures* for short*)*. *Reactions* is recommended to all readers, including those without much experience in chemistry, who will enjoy the wonderful colors and shapes generated during chemical reactions. Structures is recommended to readers with some chemistry background, who will enjoy a stunning collection of the most beautiful chemical structures.

To expand the scope and depth of the content in these books, we add in each book over 50 pages of History section. In *Reactions*, we focus on the history of chemistry from 1660 to 1860 through explaining the chemical instruments used by 12 famous chemists: Robert Boyle (1627—1691), John Mayow (1641—1679), Stephen Hales (1677—1761), Henry Cavendish (1731—1810), Carl Wihelm Scheele (1742—1786), Joseph Priestley (1733—1804), Antoine Lavoisier (1743—1794), Alessandro Volta (1745—1827), Humphry Davy (1778—1829), Michael Faraday (1791—1867), Justus von Liebig (1803—1873), Gustav Kirchhoff (1824—1887). In these 200 years, chemistry transformed from practical art and mysterious alchemy to a physical science with great precision. In Structures, we look at how scientists discovered the invisible molecular world through 10 topics: Chemical Symbols, Atomic Structure, Chemical Bonds, Crystal Structure, Organic Molecules, Polymers, Biomacromolecules, Nanoparticles, Carbon Nanostructure, and Surface Structure.

In addition, each book includes a Gallery section. In *Reactions*, readers can find photorealistic CG reproductions of 15 important historical chemical instruments and chemical reaction pictures extracted from our popular 4K videos. In *Structures*, readers can find beautiful visualizations of 58 chemical structures and the screenshots of a CG animation to showcase the unique beauty of chemical structures. Brief explanations of all 58 structures can be found in the Notes section of *Structures*.

During the preparation of these two books, we paid a lot of attention to the quality of the illustrations. For example, the hand drawings and CG *renderings* of historical chemical instruments in the History and Gallery sections of *Reactions* were the results of countless hours of literature research to find every little detail of these instruments and the labor of love from our art team. Together with concise and accurate texts, we hope these illustrations can effectively communicate the knowledge and beauty of chemistry.

Contents

History

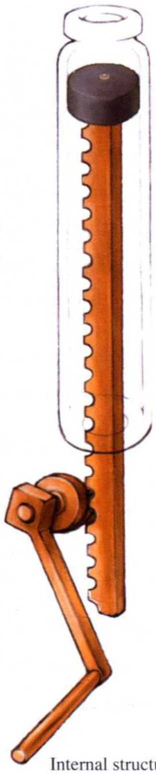
Robert Boyle
1627—1691

Robert Boyle

1627—1691

Robert Boyle was born on January 1st, 1627 in Waterford, Ireland. He emphasized on the importance of conducting experiments in scientific research and was a scientist with outstanding experimental skills. He optimized many scientific instruments and made contributions to many areas of research. Boyle is regarded as the founder of modern chemistry. He considered chemistry as a physical science, not just a practical art or mysterious alchemy, although he was a believer in alchemy. Through experiments, he proved that the ancient Greek theory of four elements was invalid, and proposed a concept of elements close to the one we have today. He believed that all matters were composed of minute particles and the universe worked like a sophisticated machine. His thoughts deeply influenced many scientists including Newton. Boyle died on December 31st, 1691 (aged 64) in London, England. The main scientific contributions of Boyle are:

- Discovery of Boyle's Law (at constant temperature, the absolute pressure and the volume of a fixed amount of gas are inversely proportional).
- Design of a new vacuum pump and conducted experiments inside vacuum, and finding that in vacuum sound could not transmit and a candle could not burn.
- Preliminary explanation to combustion and metal calcination.
- Emphasis on the importance of chemical analysis, invention of experimental methods to identify chemicals and measure purity, the use of vegetable colors to identify acid and base.

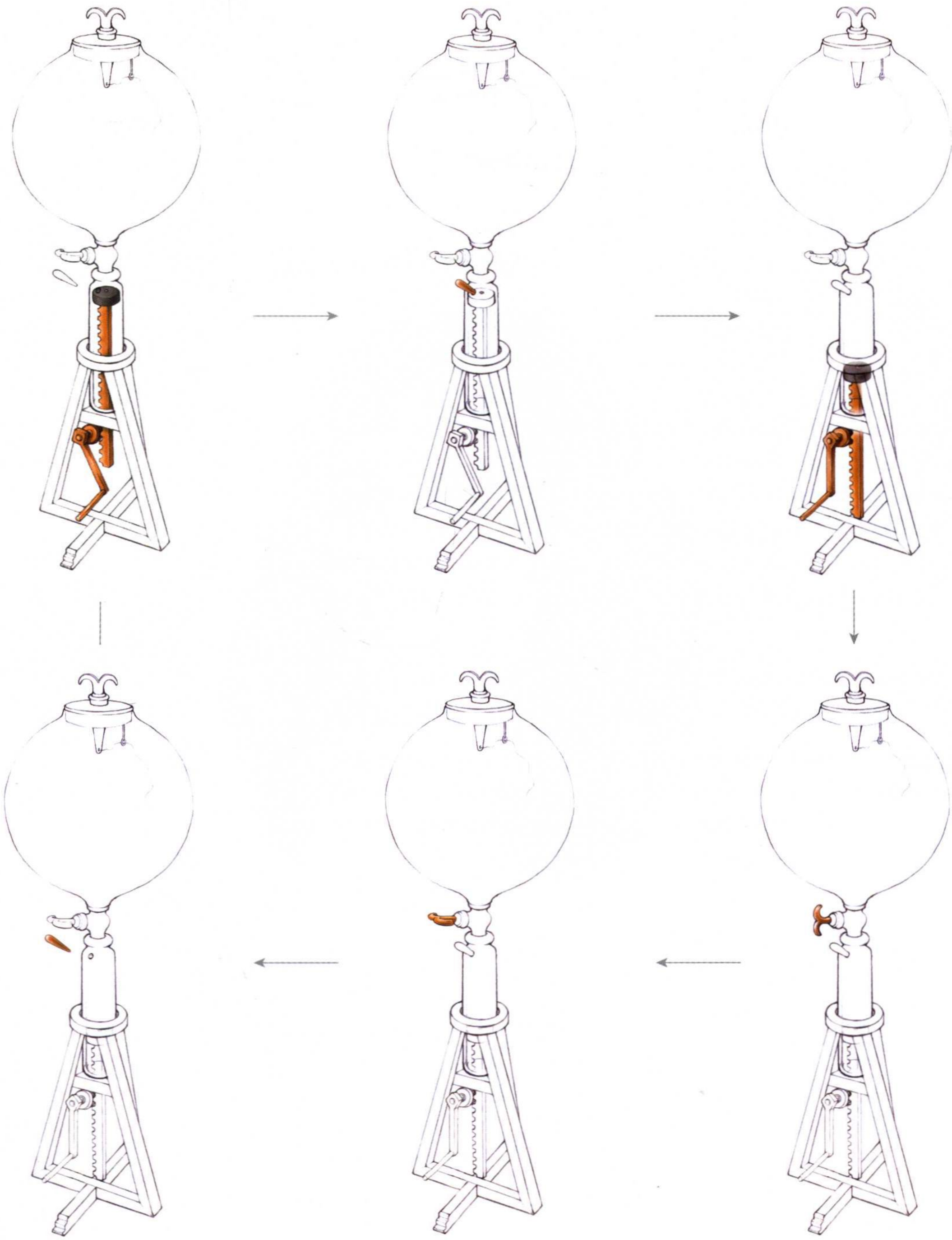


Internal structure
of the pumping cylinder.

The drawings on the left show Boyle's vacuum pump described in *New Experiments Physico-Mechanical, Touch the Spring of the Air, and Its Effects* published in 1660 (a photorealistic CG reproduction can be found on page 60). Boyle's got a lot of help from his assistant Robert Hooke for designing and constructing the pump. The first vacuum pump was invented by Otto von Guericke in 1654. In 1657, von Guericke conducted the famous experiment with the Magdeburg hemispheres, demonstrating the power of atmosphere pressure. Boyle and Hooke made a lot of improvements upon von Guericke's design, making the pump easy to use. Also, they could conduct experiments inside the pump.

Boyle's vacuum pump is made of a spherical glass globe with a diameter of 38 cm and a brass pumping cylinder connecting with it. The globe has an opening on the top. Objects used in experiments can be transferred into the globe through this opening and later sealed by a brass cap and lute. The air pumping process is controlled by the valve connecting the pump and globe and a small brass plug on the pump, as shown graphically in the opposite page (please pay attention to the colored component in each step).

In *New Experiments Physico-Mechanical, Touch the Spring of the Air, and Its Effects,* Boyle described 43 experiments, covering physics, chemistry, biology and other subjects. For chemistry, he discovered that a candle and charcoal could not burn inside vacuum, which was the opposite to Boyle's original hypothesis. Based on the four-element theory, as "gas" was pumped out, "fire" in the inflammable objects should release much easier. After Boyle, many scientists tackled the combustion problem and led to the famous chemical revolution.



John Mayow

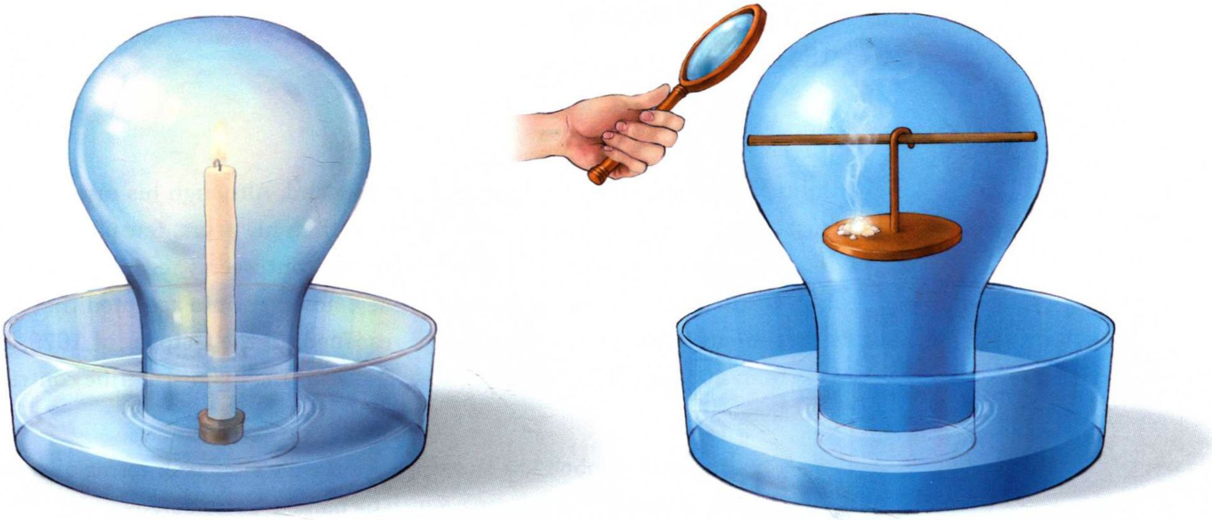
1641—1679

John Mayow

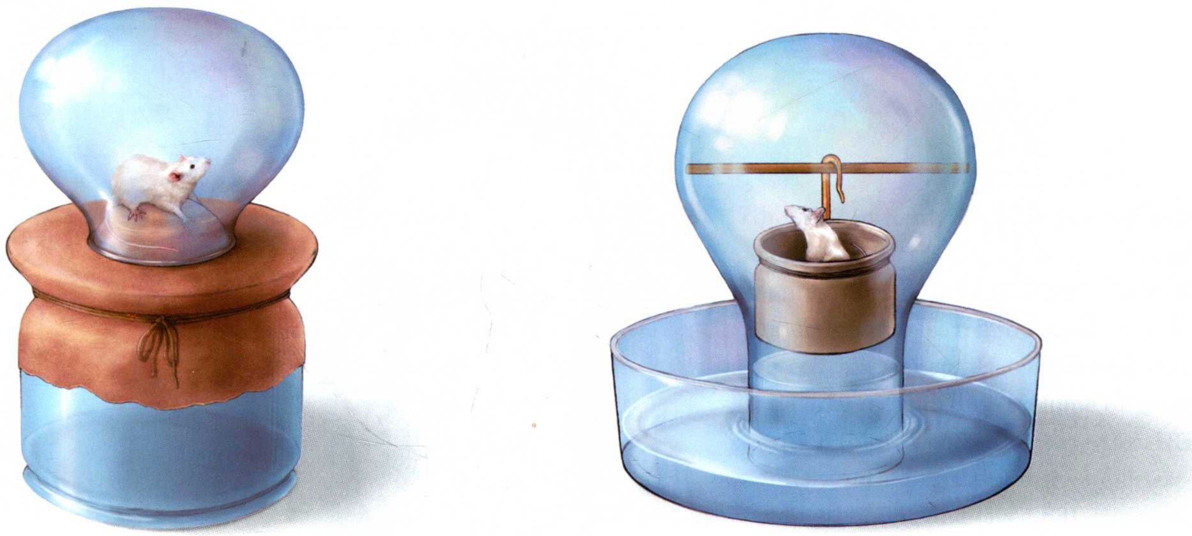
1641—1679

John Mayow was born in about 1641 in England. Although his research on combustion and respiration was more advanced than his peers, few paid attention to his work during his time. There was even some controversy regarding his contribution to chemistry among historians. Today, however, it is accepted that Mayow's experiments were innovative and well-reasoned. In the October of 1679, Mayow, less than 40 years old, died in London, England. The main scientific contributions of Mayow are:

- finding that combustion and respiration were similar in terms of consuming a part of the air (i.e. oxygen), which he named "nitro-aereus".
- pointing out that "nitro-aereus" entered animal lungs during respiration, and that muscle contraction and body heat were results of chemical reactions between "nitro-aereus" and substances in the body.



Above are Mayow's apparatuses for studying combustion described in his *Tractatus Quinque Medico-Physici* published in 1674. He discovered that inside a container sealed by water, a burning candle (left) and combustion of inflammable substance ignited by fire glass both consumed a portion of the air, leading to the increase of water level inside the containers. When this part of air was used up, combustion stopped. Mayow named the air that supported combustion "nitro-aereus". His experiments were advanced in his time. For example, at the beginning of the experiment, he used a U-shaped syphon to equalize the pressure inside and outside the container. For the burning candle experiment, the syphon was quickly removed after the container was in place. This procedure made the experiment more accurate.



Above are Mayow's apparatuses for studying animal respiration described in his *TractatusQuinque Medico-Physici* published in 1674. He discovered that animal respiration was similar like combustion, both of which consumed a portion of the air. In the left apparatus, the respiration of a mouse caused the bladder membrane to bulge inside. In the right apparatus, the respiration of a mouse caused the water level to increase inside the container. When the part of air that support respiration was used up, animals died. Mayow thought that respiration and combustion were similar as both processes consumed the "nitro-aereus" (*i.e.* oxygen). Mayow argued that during respiration the nitro-aereus reacted with substances inside blood, providing body heat for the animals. This was an advanced view of respiration during that time.