# Francis Bacon, Royal Society of London and Landmark Experiments (II)

By the time the 16th century was ending, cracks were appearing in the grand edifice of Aristotelian science. The view of the cosmos laid down by Aristotle, buttressed by medical theories of Galen and the astronomy of Ptolemy and the theology of Christianity was being challenged. The old teleological ways of explaining the workings of nature were no longer very convincing: natural phenomena, including even human bodies, were being imagined as machines. New Worlds were being discovered: not just the New World of the Americas, but never-before seen worlds seen by telescopes and microscopes.

This was a period suspended between medievalism and modernism.

A new vision of knowledge was needed that could justify the new vision of the cosmos that was emerging. A need was felt to tear down the old and to put knowledge on an entirely new foundation. A new kind of explanation was needed if the old teleology of purposes and desires of natural world was to be discarded.

So in early 17th century, two major philosophical developments took place which were influential in bringing a new energy and vigor to science:

1. Experimentalism of Francis Bacon in England
2. Mechanical Philosophy of Rene Descartes in France.

Elements of these philosophies became institutionalized in the Royal Society of London. Nearly all the key pioneers of science after Galileo were associated with the Royal Society.

**Who was Francis Bacon (1561-1626)**

Francis Bacon was not a scientist. Yet, he made a huge contribution to the scientific revolution by outlining and advocating an experimental approach to understanding nature. His philosophy of scientific method was a major influence on the founding of the Royal Society of London.

Bacon was a slightly older contemporary of Galileo.

He was born into a distinguished family: his father was the keeper of the seal for queen Elizabeth and his mother was an accomplished scholar in her own rights. He was educated at Trinity College and studied law at Grey’s Inn.   
Entered parliament and was considered one of the most powerful orator and writer. He fell out of favor with the Queen, but rose to very high position under the next monarch, ending up as a Viscount of St Albans.

His career took a steep dive, however. He was caught accepting bribes from those who came to seek justice from him. He was fined 40,000 pounds and imprisoned in the tower of London. After this disgrace, he withdrew from public life and wrote full time on philosophy. It is in this period he produced his great works, *The Great Instauration*, the *Novum Organum* and the *Nova Atlantis* which established his reputation as THE philosopher of the Sct. Rev.

He died a famous death. He was driving through snow one night and it occurred to him to do an experiment to see if snow can preserve meat, i.e, prevent if from spoiling. So he knocked at the door of a farmer and asked the farmer’ wife to kill and clean a chicken for him. He stuffed the chicken with snow to do his experiment. Apparently, he caught a terrible cold and pneumonia in the process – and died. So this great philosopher of experimentation died while doing an experiment!

#### Francis Bacon’s critique of the ancients:

The driving force behind Bacon’s philosophy was his alarm at the **lack of progress** since ancient times in so many branches of science. Ancient learning seemed to Bacon, for the most part, the shallowest understanding dressed up as various rhetorical devices, so that it merely put up a show of profundity.

He saw the wisdom of Greeks as “the property of boys: it can talk, but it cannot generate; it is fruitful of controversies, but barren of works.”

#### Bacon’s Great Instauration

*The Great Instauration*, published in 1620, represented the culmination of Bacon’s efforts to reconstruct the foundation of sciences. This was supposed to be his masterpiece that would synthesize various elements of his philosophy. It was supposed to be a book in six parts, of which Bacon could only complete two before his death.

What does “instauration” mean? This is a noun not used very commonly any more. In Bacon’s time, it meant “ the act of starting something for the first time; introducing something new.” It also had another meaning: renewal; restoration; renovation and repair. So Great Instauration in this case means “ the great new beginning”, or “the great renewal”.

Two parts he did complete – and which were published as separate books – are of great importance in history of science.

Part I: is called “The Advancement of Learning.” It is an expanded version of an essay by the same name he had written some time ago. This book is a survey of different branches of knowledge with a purpose of assessing their condition and deficiencies.

Part II: This part was completed and is called the *Novum Organon*, or the *New Organon* and contains the core of Bacon’s new philosophy of science.

(what does Organon mean? It is a Latin word for “Instrument.” O*rganum* was the name of a medieval compilation of Aristotle’s writings. Thus Bacon was offering to replace Aristotle with a new instrument or method.).

The *Great Instauration* opens with a drawing of a ship sailing and heading beyond the Pillars of Hercules in the Strait of Gibralatar which used to be thought of as the limit of the known world. Underneath the ship, the motto of the book: “ Many shall pass to and fro and science will be increased.” The traditional expression of the limits of knowledge – *ne plus ultra (latin)* or “no farther” was replaced by *“plus ultra”* – “farther yet.” (see the picture in ppt)

He wrote many other books and essays. The other book that is relevant to history of science is his sci-fi utopia called the *New Atlantis*. ***New Atlantis*** is a [utopian](http://en.wikipedia.org/wiki/Utopian) novel, published in Latin (as *Nova Atlantis*) in 1624 and in English in 1627. In this work, Bacon portrayed a vision of the future of human discovery and knowledge, expressing his aspirations and ideals for humankind. The novel depicts the creation of a utopian land where "generosity and enlightenment, dignity and splendour, piety and public spirit" are the commonly held qualities of the inhabitants of "Bensalem". The plan and organization of his ideal college, "[Salomon's House](http://en.wikipedia.org/wiki/Salomon%27s_House)" (or Solomon's House) envisioned the modern research university in both applied and pure sciences. (from Wikipedia)

We will very briefly look at Bacon’s critique of the old, Aristotelian ways of knowing and look at the new method Bacon prescribed.

Bacon’s critique of Aristotle:

* Aristotle and his followers practice a haphazard, uncritical collection of data;
* The ancients, Bacon said, generalized too hastily. Given a few observations, they leap at once to the most general principles and then use these principles to deduce generalizations of lesser scope.
* The Aristotelians don’t pay attention to negative instances – that is, they ignore evidence that goes against their pet theories.
* They fail to define adequately such important predicates such as “attraction,” generations, element, heavy, moist etc.
* They reduce science to deductive logic by overemphasizing the deductions from first principles which they don’t question. Bacon stressed that deductive arguments are valid only when their premises (first principles) are derived from testable experience.

The positive doctrine of Novum Organum : The Scientist as a bee

The idols have to be broken: any new science will have to begin from, and be controlled by, observations untainted by the idols. We HAVE TO APPROACH NATURE WITH AN INNOCENT OR UNCORRPUTED EYE.

But presupposition-less observation does NOT mean investigation carried out in random or disorganized way.

Bacon compares the rationalists to spiders who spin an intricate web out of their own substance, and the empirics to the ants who go around collecting all kind of observations. He says we should learn from the bees who synthesize:

*Those who have handled science have been either the men of experiment or the men of dogma. The men of experiment are like the ant, they only collect and use; the reasoners resembles the spiders who make cobwebs out of their own substance. But the bee takes a middle course: it gathers its materials from the flowers of the gardens and of the fields, but transforms and digests it by a power of its own.*

*Not unlike this [the bee] is the true business of science: for it neither relies solely or chiefly on the powers of the mind, nor does it take the matter which it gathers from natural history and mechanical experiments and lay it up in the memory as a whole as it finds it. [Rather, science] lays it up in understanding altered and digested.*

***Therefore, from a closer and purer league between the two faculties, experimental and rational … much may be hoped****.”*

Basically, Bacon was arguing that like a bee that goes from flower to flower to making honey, a scientist is to constantly go-back-and-forth between facts and theories, using observations to generate hypotheses and hypotheses to generate new observations, and even using new observations to correct old hypotheses… all this in a never-ending process.

*Knowledge as power*

True knowledge, according to Bacon, must serve the “kingdom of Man”, i.e. help improve humanity’s condition, bring power to people so that they are no longer at the mercy of nature, but become its masters.

This **mastery** over nature can only come about through correct **understanding** of nature’s laws.

Thus, Bacon sees human beings are both masters and servants of nature: they must first understand nature’s laws, obey those laws so that they can master it. As he said, “nature to be commanded must be obeyed.”

Values artisan’s knowledge

#### Mechanical Philosophy:

What is mechanical philosophy? There were many varieties of it, but the essential idea was that all phenomena of nature are produced by particles of matter in motion. It is the random, purposeless motion of these particles of matter that account for everything in nature. This philosophy rules out teleology, purposes etc.

Rene Descartes in France was the chief architect of this philosophy. It was accepted by Robert Boyle and Isaac Newton.

Rise of Academies of science

1. Emergence of a community of scientists: By the close of the 17th century, science had begun to differentiate from natural philosophy and there had emerged a significant number of people (men, almost entirely) who we would recognize as scientists. They were not working in isolation, but thanks to the printed books, they were reading and writing to each other. A community of scientists was beginning to emerge.

Scientific knowledge was no longer the province of university scholars, but was widely diffused through a new class of laymen who were educated and had the leisure to explore new ideas. Moreover, a new class of learned men was emerging among the craftsmen and the artisans who had developed sufficient theoretical and empirical knowledge by working with their hands.

1. The non-role of the universities: this community of scientists was largely located outside the walls of the universities. This may seem strange to us, because science is done in universities today. But in the 17th century, universities were not hospitable to the new sciences. As Richard Westfall puts it, “ the scientific revolution was created despite the universities and not because of them.”

The universities in Europe at that time were seeped in Artistotelian dogma. They were largely created by the Catholic Church in high middle ages when the old Greek classics were beginning to be rediscovered. The great synthesis of Aristotle and Plato with the Christian dogma has deeply entrenched Aristotle in the universities. Even though they were sufficiently autonomous of the church, the universities by and large continued to work within the Chrisitian-Aristotlian tradition.

New scientific thinking was therefore not much welcome in universities. With the notable exception of Newton, nearly all the major figures of the Sct. Rev. were \*\*trained\*\* in universities but did their scientific work outside

Galileo is a good example: it is true that he taught at the universities of Pisa and Padua and did his work on mechanics in the latter. But in the end, he chose to leave Padua and become a court mathematician for the Grand Duke of Tuscany. Indeed, later when he got into trouble with the Church, most of his opposition came from the university-based scholastics who defended the old model of Ptolemy and Aristotle.

Unlike Galileo, Newton spent his whole life as a university professor – he held the Lucsasian chair of mathematics at Cambridge University. But according to Westfall who has written the most well-known biography of Newton, he was quite isolated at Cambridge and his work on optics was not understood by this students and colleagues. It was his contact with the Royal Society later that fuelled his creativity.

## Scientific Societies:

As they were not welcome inside the universities, the emerging community of scientists sought to create their own institutions. Thus the idea of the “scientific society” was born. [you can skip over the details of this section)

1. **Accademia dei Lincei (The Academy of the Lynx):** is the first known scientific organization. It flourished in Rome in the early part of 1600s. At its peak, it had 32 members, but it had grand plans to created branches in other parts of Europe equipped with printing presses, botanical gardens, and laboratories.

Galileo was a member of the Lincei. In his *Dialogue*, he identifies himself as an “ Academician” with reference to his membership in this academy. Two of Galileo’s early books were published by Lincei, but it did not approve of G’s later theories about the earth and the sun.

The Lincei served more as a meeting place for scientists who did their own work. They only met to discss their findings and other interesting matters.

1. **Accademia del Cimento (the Academy of experiment)** was devoted to refine the experimental method. It concerned itself with the further development of the scientific ideas of Galileo, and his famous student, Toricelli and others. This academy actually did experiments in its own laboratories that had been created by large funds made available by its patrons (the grand dukes of Florence and Naples) who used the wealth of the Medicis to obtain the services of the finest craftsmen and gathered the best scientific equipment of the time.

This academy tried the following kind of projects: it tried to verify Galileo’ s theory of projectiles, time keeping properties of pendulums, testing new forms of thermometers, hygrometers and barometers, improving the design of optical instruments, the results of Torricelli and Pascal were confirmed, attempts were made to construct an air pump (based upon the work being reported by Boyle).

The academy brought out a book (eng. Essays of Natural Experiment) which can be considered as the first book of experimental reporting in history.

1. The Mersenne Circle in Paris(functioned from around 1630-1660): Outside Italy, informal groups similar to the Lynx academy sprouted. In France, Father Mersenne (d 1648), a Minim Friar [Minim was a sect of monks within the Catholic Church], set up a group that included scientists and philosophers including Descartes, Pascal, Fremat, Gassendi. Mersenne was a great communicator and brought the news of science outside france. In fact, it is through this groups that the ideas of Galileo were taken up by people like Descartes, Gassendi and Pascal, who went on to develop the mechanical philosophy. Mersenne was personally involved in publication of Galileo’s book the Discourses outside Italy when G. was in house arrest.
2. Montmor Academy: After the death of Mersenne, the weekly meetings of the Mersenne circle began to take place in the house of Habert de Montmor , a man of great wealth who had been a patron of mechanical philosophers. These meetings were presided over by Gassendi. Members were required to be “ curious about natural things, medicine, mathematics, the liberal arts and mechanics.” The Montmor academy gradally became a fashionable salon where foreign scientists (Christian Huygens from the Netherlands) were invited to read papers, events attended by the dignitaries of the church and the royals.
3. Academia Royale des sciences (the Royal Academy of Science) of France: as the fortunes of the Montmor academy began to decline, it was given the royal charter in 1666 under the king Louis XIV. This was inspired by the English example of the Royal Society.

## Science Societies in England and the birth of the Royal Society

The complete name: The Royal Society of London for Improving Natural Knowledge.

Motto: Nullius in verba (“take nobody’s word for it”)

The Royal Society is the oldest continually running science society in the world. It began as a group of 12 scientists who came to be known as the “Invisible College” which began to meet, sometime around 1645, at a variety of locations, including each other homes, but mostly at Gresham college in London. The members of the invisible college included Samuel Hartlib, John Wilkins, Chsristopher Wren and Robert Boyle. The group discussed the “new science” of experiments as promoted by Francis Bacon. They just did not talk about new science; they actually carried out experiments on their own and reported the results to each other. In other words, they were amateur gentlemen scientists.

This group split into two – because of the distances the members had to travel. The London branch kept on meeting at Gresham College while the Oxford branch at Oxford. They went through political turmoil during the English revolution, but continued…

In the late 1650s, the invisible college was largely in located in Gresham College. One evening, on Nov. 28, 1660, after a lecture by Christopher Wren, members went to a bar and decided to organize formally as a “College for the Promoting of Physcio-Mathematical Experimentall (that is how they spelled it] Learning” which would meet weekly to discuss science and run experiments. Initially, this was a self-financed group, with each member paying a membership fee. The notes kept from the founding say the following:

“This Company would continue their weekly meetings on Wednesday, at 3 of the clock at Mr Rooke’s chamber at Gresham College(some more details follow)…..*toward the defraying of the occasion expenses, everyone should, at his first admission, pay down ten shillings and besides engage to pay one shilling weekly, whether present or not, whilst he shall please to keep his relation to the Company…”*

It is estimated that 10 shillings at that time were about 500 British pounds today. It was not a trivial sum of money. The members were obviously people of wealth who could afford to pay. y

Two years later, on July 15, 1662, they were given the royal charter by Charles II, and the Royal Society of London was born.

The founding members sought the royal charter so as to enhance the prestige of their group and to gain legal rights to buy land , employ staff and to publish books. They also assumed that with “Royal” added to its name, they might be able to attract rich gentlemen who could afford to pay the fees.

Even though they became officially a “Royal Society”, the king gave them no money, no buildings or any other facility. The Society continued to depend upon membership fees. This influced how it functioned: in order to keep the members educated and entertained, it started to hold demonstration of experiments (which were carried out for the most part by Robert Hooke, who was appointed the curator of experiments). This began a tradition in the larger society of travelling “scientists” holding demonstrations in cafes and other public places.

## The English and the French Royal Societies compared:

The French Royal Society was born just four years after the British. But they displayed entirely different ways of doing science: the French model was that of BIG SCIECNE under state control, while the Brits favored a more private enterprise.

In the French case, the royal patronage allowed big science which required a lot of money: length of one minute arc, expedition to south America, …. Etc

In Britain, the Royal was only in name: no funding, no labs, no great observatories, no nothing…

The RS continued as a private club with a more varied membership: while the French collected elite scientists from around the world, the British RS opened the doors to anyone who was doing experiments.

The Royal Society of London was deeply influenced by Henry Oldenberg (1620-1677) who was a great bridge builder: He started the journal Philosophical Transactions of the Royal Society, the oldest scientific journal that exists today. This became a forum for publications of all kinds of research: through this journal and through Oldenberg’s efforts, the Dutch microscopist A. V. Leeuwenhoek, the Italian Malpigighi and many others disclosed their discoveries to the world.

Bacon’s influence on the Royal Society:

Two elements of Bacon were enthusiastically embraced by the members of the RS:

1. His insistence on deriving generalizations from facts that can be tested. And his insistence upon ACTIVE observation, by putting nature to the test of experiments.
2. His vision of science as a collective effort which serves human needs. The Royal Society was deeply influenced by Bacon’s *New Atlantis* in which he created a fictional “Foundation” which was run by “Fellows” who operated farms, factories, labs for the improvement of society.

Three remarkable features of the Royal Society

1. Internationalism: The scientific community at this stage, by and large, set a good example of internationalism.

The Royal Society welcomed scientific ideas and scientists from all across Europe and even the emerging United States which was fighting a war of independence against Britain. For eg., it welcomed Benjamin Franklin, the American inventor and scientist when the two countries were at each other’s throats.

Other scientific societies also showed this kind of unity across national boundaries: the French society , for e.g., welcomed the British Humphrey Davy. The French Royal Society right from the beginning brought in international talent: Christian Huygens from Netherlands, Roemer from Denmark, Cassini form Italy.

1. A **relative** lack of class differences: although most members were clearly well-to-do, it was not necessary to be well-born to be a part of the RS. It was a place were an ordianry draper from a foreign country (Leeuvenoek) and a mere lab-attendant (Robert Hooke, more on him below) could become celebrities.

3 . Its long life: it is a remarkable achievement for a private foundation to be in existence for more than 350 years.

# Landmark Experiments under the auspices of the Royal Society of London:

Life and work of Robert Boyle and Robert Hooke:

Robert Boyle was one of the founding members of the Royal Socieity: He was among the 12 who called themselves the “Invisible College,” which later became the Royal Society of London. He later partnered with Robert Hooke, his very able and creative laboratory assistant. Hooke eventually became the Curator of Experiments for the RS and was elected as a Fellow of the RS. These two brilliant scientists – and life-long friends – represent the best of the RS.

Who was Robert Boyle

Robert Boyle (b. 1627) came from an extremely wealthy family. He was born in Ireland, the seventh son and fourteenth child of [Richard Boyle, 1st Earl of Cork](http://en.wikipedia.org/wiki/Richard_Boyle,_1st_Earl_of_Cork). Robert received private tutoring in Latin, Greek and French and when he was eight years old, following the death of his mother, he was sent to [Eton College](http://en.wikipedia.org/wiki/Eton_College) in England. After spending over three years at Eton, Robert traveled abroad with a French tutor. They visited [Italy](http://en.wikipedia.org/wiki/Italy) in 1641 and were in [Florence](http://en.wikipedia.org/wiki/Florence) during the winter of that year that [Galileo Galilei](http://en.wikipedia.org/wiki/Galileo_Galilei) passed away.

When in Florence, Boyle became deeply interested in the new telescopic evidence . He taught himself Italian to be able to read Galileo’s books.

This experience got Boyle interested in reading the works of Galileo which got him interested in science.

Boyle returned to England in 1644 with a keen interest for scientific research.His father had died the previous year and had left him huge estates and properties. Being a man of independent wealth, Boyle decided to devote his life to [scientific](http://en.wikipedia.org/wiki/Science) research.

In 1654, Boyle left Ireland for Oxford to pursue his work more successfully. An inscription can be found on the wall of [University College, Oxford](http://en.wikipedia.org/wiki/University_College,_Oxford) the [High Street](http://en.wikipedia.org/wiki/High_Street,_Oxford) at [Oxford](http://en.wikipedia.org/wiki/Oxford) (now the location of the [Shelley Memorial](http://en.wikipedia.org/wiki/Shelley_Memorial)), marking the spot where Cross Hall stood until the early 19th century. It was here that Boyle rented rooms from the wealthy apothecary who owned the Hall. At Oxford, he soon took a prominent place in the band of inquirers, known as the "[Invisible College](http://en.wikipedia.org/wiki/Invisible_College)", who devoted themselves to the cultivation of the "new philosophy". They met frequently in London, often at [Gresham College](http://en.wikipedia.org/wiki/Gresham_College), and some of the members also had meetings at [Oxford](http://en.wikipedia.org/wiki/Oxford).

In 1663 the Invisible College became the [Royal Society of London for the Improvement of Natural Knowledge](http://en.wikipedia.org/wiki/Royal_Society_of_London_for_the_Improvement_of_Natural_Knowledge), and the charter of incorporation granted by [Charles II of England](http://en.wikipedia.org/wiki/Charles_II_of_England), named Boyle a member of the council. In 1680 he was elected president of the society, but declined the honour because his religious faith did not allow him to take oaths. (He was a devout Protestant Christian).

He made a "wish list" of 24 possible inventions which included "The Prolongation of Life", the "Art of Flying", "perpetual light", "making armor light and extremely hard", "A ship to saile with All Winds, and a Ship not to be sunk", "practicable and certain way of finding Longitudes", "potent druggs (sic) to alter or Exalt Imagination, Waking, Memory and other functions and appease pain, procure innocent sleep, harmless dreams etc". They are extraordinary because all but a few of the 24 have come true. (from Wikipedia with some corrections).

Boyle’s contributions to science are enormous. They range from:

* his experiments on the air pump
* his gas laws
* his work on alchemy
* his philosophical writings on mechanical philosophy
* his writings on religion.

In this lecture, we will only concentrate on the first two. Alchemy is really not within the scope of this course, as we simply don’t have the time.

Intellectual influences on Boyle:

1. Galileo : remained for Boyle the “greatest master”. He wrote admiringly of how Galileo did not just spin theories but had focused upon **particular** aspects of mechanics and understood them through ingenious experiments and mathematics.
2. Bacon. Boyle followed Bacon’s new logic that inverted the order of discovery: rather than begin with speculations about the universal causes, philosophers should first compile a vast amount of information about the natural phenomenon under study and build theory out of that. In other words, he accepted wholeheartedly Bacon’s advice that **facts must be established first before theories can be constructed.**

Boyle saw himself as a Baconian bee: he wasn’t offering a whole system, but rather devising experiments and to “report observations faithfully” so that in due course of time, this experimental knowledge would provide grounds for building theories.

### Who was Robert Hooke

Hooke was born in 1635 in a relatively impoverished family: his father was a curator of a church with very little income. He had many health problems and suffered from a malformation of the spine.

He had a great aptitude for making things with his hands (something he shared with Issac Newton, actually). As a child he had made working models of ships and clocks with wood. He landed in London with the total inheritance of 40 pounds in his pocket. He was hired as a lab attendant by a local doctor, Thomas Willis, who dabbled in experiments and who ended up introducing him to the Royal Society. There he met Boyle, who recognized his talent and his genius. Hooke became Boyle’s right-hand man, and his friend.

Hooke was made the Curator of Experiments at the RS in 1662. (Boyle continued to pay his salary, because the RS had very little money). In June 1663, Hooke was elected as a Fellow of the R, without charging him the usual subscription. The same year, Oxford U. gave him an MA, even though he did not even have his BA. All this marked his acceptance by the scientific elite.

Hooke was a scientific researcher in his own right and not just a technician working at Boyle’s instructions. Like Boyle, he has many contributions in optics, astronomy and gravity. In fact, Newton got into priority disputes with Hooke on many issues (which we will look at when we discuss Newton). In this lecture, we will only look at Hooke’s work with Boyle and his totally original work with the microscope which made a huge mark on the Royal Society.

**Boyle’s experiments with the air pump**

Here two more of Aristotelian beliefs will be demolished:

--that vacuum does not exist.

-- that air does not have weight, derived from air’s natural tendency to fly away from the earth.

Before Boyle, the Italian mathematician and an admirer of Galileo, Evangelista Torricelli (1608-47) had already established that water rises in a column not because it (nature) hates vacuum but because of a simple equivalence in nature: the column of water in a closed tube reached its resting height when its weight equaled the weight of the air pushing against its base. His invention of the barometer was designed to show the weight of the atmosphere/air. Torricelli had established that as he put it, “ we live submerged at the bottom of a vast ocean of air.” ( in other words, air has mass, weight and it exerts pressure.)

Ingenious experiments with Torricelli’s barometers had also established that pressure of the air varies with altitude. The French mathematician Blaise Pascal 91623-62) and his brother-in-law, Florin Perier carried out a very famous experiment: Perier prepared two barometers. He left one at the base of a mountain (called Puy-de-dome), and the other he carried with him as he climbed about 3000 feet up the mountain. He found that the level of mercury stood three inches lower at the mountain top. The level reached back once he returned to the base of the mountain. They showed that at higher elevations, with less of the “ocean of air” pressing from above, the weight of the air resting on the Hg in the barometer was reduced.

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| **Otto von Guericke** (November 20, 1602 – May 11, 1686) was a [German](http://www.wikipedia.org/wiki/Germany) scientist, inventor, and politician. His major scientific achievement was the establishment of the physics of [vacuums](http://www.wikipedia.org/wiki/Vacuum). Guericke was born to a patrician family of [Magdeburg](http://www.wikipedia.org/wiki/Magdeburg), [Germany](http://www.wikipedia.org/wiki/Germany). He served as the mayor of [Magdeburg](http://www.wikipedia.org/wiki/Magdeburg) from 1646 to 1676. Air pressure and the vacuum In 1650 he invented a [vacuum pump](http://www.wikipedia.org/wiki/Vacuum_pump) consisting of a piston and an air gun cylinder with two-way flaps designed to pull air out of whatever vessel it was connected to, and used it to investigate the properties of the vacuum in many experiments. Guericke demonstrated the force of [air pressure](http://www.wikipedia.org/wiki/Air_pressure) with dramatic experiments. He had joined two [copper](http://www.wikipedia.org/wiki/Copper) hemispheres of 51 cm diameter ([Magdeburg hemispheres](http://www.wikipedia.org/wiki/Magdeburg_hemispheres)) and pumped the air out of the enclosure. Then he harnessed a team of eight horses to each hemisphere and showed that they were not able to separate the hemispheres. When air was again let into the enclosure, they were easily separated. He repeated this demonstration in 1663 at the court of [Friedrich Wilhelm I of Brandenburg](http://www.wikipedia.org/wiki/Friedrich_Wilhelm_I_of_Brandenburg) in Berlin, using 24 horses.  With his experiments Guericke disproved the hypothesis of "[horror vacui](http://www.wikipedia.org/wiki/Horror_vacui_%28physics%29)", that nature abhors a vacuum, which for centuries was a problem for philosophers and scientists. Guericke proved that substances were not pulled by a vacuum, but were pushed by the pressure of the surrounding fluids. Other research Guericke applied the [barometer](http://www.wikipedia.org/wiki/Barometer) to weather prediction and thus prepared the way for [meteorology](http://www.wikipedia.org/wiki/Meteorology). His later works focused on electricity, but little is preserved of his results. He invented the first [electrostatic generator](http://www.wikipedia.org/wiki/Electrostatic_generator), the "Elektrisiermaschine", of which a version is illustrated in the engraving by [Hubert-François Gravelot](http://www.wikipedia.org/wiki/Hubert-Fran%C3%A7ois_Gravelot), c. 1750.  Guericke died on May 11, [1686](http://www.wikipedia.org/wiki/1686) in [Hamburg](http://www.wikipedia.org/wiki/Hamburg), [Germany](http://www.wikipedia.org/wiki/Germany). The [Otto von Guericke University of Magdeburg](http://www.wikipedia.org/wiki/Otto_von_Guericke_University_of_Magdeburg) is named after him.  Also, before Boyle, in 1657, a German scientist by the name of [Otto von Guericke](http://en.wikipedia.org/wiki/Otto_von_Guericke) had created an air pump in which he showed that vacuum can be created. |

Robert Boyle was familiar with both Torricelli’s and Guericke’s work. He decided to make his own air pump to do further experiments regarding the nature of air. So he enlisted the help of Robert Hooke.

Significance of empirical demonstrations:

CYCLOTRON: Demonstrations at the RS  
“Boyle’s air pump, together with Hooke’s microscope constituted the show piece of the RS. … when distinguished visitors were to be entertained, the chief exhibits were always experiments with the pump. “

As early as 1661, the Danish ambassador was “entertained with experiments on Mr. Boyle’s air-pump.” And in 1667, Margaret Cavendish, Duchess of New Castle, the first woman to be admitted to RS, was treated to a similar display. The King of England himself was entertained …

But there was serious business beyond entertainment….

These instruments were seen as **enlarging the human sense….** “the task was to remedy the infirmities of the human senses with instruments and , as it were, “the adding of artificial organs to the natural,” (Hooke), the aim was the “enlargement of the dominion of the senses” (Hooke).

Things would be seen that were previously unseen: the mosaic structure of a fly’s eye, spots on the sun, .. other things, essentially invisible would be given a visual manifestation: the pressure of the air…

This new world indicated not only the potential of sct. Instrument to enhance the senses, it also served as a warning that the sense were inherently fallible and required such assistance as the experimental philosophers could offer.

The microscope – made visible what was not accessible to the naked eye…

The air pump – made visible relations between particles of air..

Scientific instruments imposed a correction and a discipline on the senses…

The Boyle-Hooke air pump, the so-called "machina Boyleana" or "Pneumatical Engine" was ready in 1659, he began a series of experiments on the properties of air. An account of Boyle's work with the air pump was published in 1660 under the title *New Experiments Physico-Mechanicall, Touching the Spring of the Air, and its Effects (Made, for the Most Part, in a New Pneumatical Engine)*..

The air pump was intended to produce a vacuum in its great glass receiver. It was also meant to serve as a space where experiments could be conducted: the glass receiver had a removable brass cover through which instruments and objects could be introduced before the air was removed. So one could study the behavior of objects/apparatus while varying the pressure of the air.

All told, Boyle and Hooke conducted 43 experiments with their air pump.

Some significant experiments:

* Creation of vacuum itself counted as an experiment.
* He proved that Galileo’s premise about falling objects was correct in a vacuum, Boyle showed, all objects fall at the same velocity. Without air resistance, a feather falls at the same time as a heavier object
* In the experiment number 17, he inserted Torricelli’s mercury barometer and then began to evacuate: he showed that the level of mercury fell, just as it falls when the barometer is taken to an altitude where the air pressure is low.
* Boyle tested the effects of "rarified" air on combustion, magnetism, sound, and barometers, and examined the effects of increased [air pressure](http://en.wikipedia.org/wiki/Air_pressure) on various substances.
* He listed two experiments on living creatures: "Experiment 40," which tested the ability of insects to fly under reduced air pressure, and the dramatic "Experiment 41," which demonstrated the reliance of living creatures on air for their survival. In this attempt to discover something "about the account upon which Respiration is so necessary to the Animals, that Nature hath furnish'd with Lungs", Boyle conducted numerous trials during which he placed a large variety of different creatures, including birds, mice, eels, snails and flies, in the vessel of the pump and studied their reactions as the air was removed.[[3]](http://en.wikipedia.org/wiki/An_Experiment_on_a_Bird_in_the_Air_Pump#cite_note-2) Here, he describes an injured lark:

*…the Bird for a while appear'd lively enough; but upon a greater Exsuction of the Air, she began manifestly to droop and appear sick, and very soon after was taken with as violent and irregular Convulsions, as are wont to be observ'd in Poultry, when their heads are wrung off: For the Bird threw her self over and over two or three times, and dyed with her Breast upward, her Head downwards, and her Neck awry.*

Boyle’s gas law:

The law itself can be stated as follows:

For a fixed amount of an ideal gas kept at a fixed temperature, *P* [pressure] and *V* [volume] are inversely proportional (while one doubles, the other halves)

In 1662, Boyle showed that he could compress air.

He trapped air in the closed end of a 17-foot, J shaped tube by blocking its escape with a quantity of mercury.

He doubled the quantity of mercury, thereby doubling the pressure, the air column was cut to half.

He tripled the quantity of mercury, the air column decreased by one-third.

The air column expanded as he reduced the pressure.

This was Boyle’s experimental proof of the inverse relationship between pressure and volume.

Boyle argued that air could not be compressed in this manner unless it was composed of corpuscles that had empty space between them. So when pressure is increased, these corpuscles can move closer together.

This laid the basis for the kinetic theory of gases.

Boyle’s work on Alchemy: Skceptical Chemyist.

Trying to modernize alchemy, not discard it. But he challenged the idea of:

* That gold could be made from lead by removing impurities. He said gold was heavier than pb, so could not be made by removal of anything
* The four elements. He proposed a kind of atomic model – corpusclars.

HOOKES work with the Microscope.: published in *Micrographia,* the first book ever published by the Royal Society.

It became a best seller, bringing money and fame to the RS.

In this book, Hooke printed the drawings he himself had made of the creatures he saw under a microscope (see the power-point for pictures).

3. Microscopy

What the telescope was to astronomy, the microscope was to biology.

Microscopes were constructed around 1600 by three Dutch spectacle makers, Hans Janssen, his son Zacharias and Hans Lippereskey. Many naturalists used these instruments to look at insects and such, but the work of three biologists is of historical significance

**Marcello Malpighi (1628-94),** university of Bolonga med school., a friend of Giovanni Borelli (who we met above). Both were influenced by Galileo and Descartes.

He made many remarkable discoveries with the microscope. Dissecting frogs, the differentiated the fine structure of the lungs – the membranous alveoli at the ends of tracheo-bronchial ramifications. His book, De pulmonibus (*On the Lungs*) published in 1661 described the fie texture of blood vessels – the missing link in Harvey’s theory – and thus provided the decisive proof of blood circulation.

**Robert Hooke** was well known for his work with Robert Boyle on the air pump, and a great experimentalist. He believed with Francis Bacon that the defects of human reason could be rectified only by “the real, the mechanical and the experimental philosophy” which was grounded in the senses. His microscopic studies presented in his book *Micrographia* (1665) had exquisitely drawn pictures of plants and insects including such things as lice and fleas.

**Anthony von Leeuwenhoek (1632-1723 )** was not a trained biologist or a medical man. He was a draper from Delft who made microscopes in his spare time.

Starting around 1671, AvL made about 247 microscopes, all of a particular design using a signle lens: all used a tiny bead of glass a magnifying lens. The fact that there was only one lens, reduced spherical and chromatic aberrations, while the tiny size of the lens allowed high magnification. The strongest of his scopes, preserved in Utrecht university could magnify to the power of 266 and had a resolving power of 1.35 x, meaning that two features separated by a mere 0.00135 mm could be distinguished. S

He turned his lens to just about every thing : wood, cells of plants, fine structure of animal bodies, red blood cells, blood capillaries, crystals responsible for gout, nerves, bones, teeth, hair… he examined the fine structure of 67 species of insects, 11 species of spiders, 10 crustacea.

His most important discovery was the observation of what he called “animalcules” in various fluids, e.g., bacteria, protozoa and human spermatozoa (see below).