7 ROBERT BOYLE AND EXPERIMENTAL METHODS

For teachers

Lesson Title: *Robert Boyle and Experimental Methods*

Area of Learning: states of affairs, evidence

Aims. Pupils should be able to: know the difference between the Baconian inductive method which advocates the use of experiments and the older Aristotelian deductive approaches; gain factual knowledge of and be able to describe the intellectual culture of a past; make links and note differences and similarities between 'scientific' enquiry in the 21st century and in seventeenth - century England; identify sources and extract information from sources

Vocab: axiom, quantitative, logical, deductive, inductive, methodology, experimental, hypothesis, theory, preconceived, air pump, receiver, thorax, microscope, technology, vacuum, respiration, transcription, annotate, provenance, retort

Time frame: material for between one to two hour-long lessons

Possible School Visit: some teachers may further wish to explore the history of scientific instruments; an ideal school trip would be to the Whipple Museum of the History of Science in Cambridge http://www.hps.cam.ac.uk/whipple/collect.html

Resources: worksheet given below

Pupil tasks. Pupils work through each section of the worksheets. Teachers may prefer to go through some sections with the whole class, or leave some groups to work through various sections on their own and pool answers in a whole-class question and answer session.

The materials for this lesson present ideal opportunities for cross-disciplinary links with science. The source detailing what some children might view as Boyle's rather cruel experiment with the frog and respiration could also form the starting point for wider citizenship or PSHE discussions on animal rights, vivisection and use of animals for medical research etc. Teachers could liase with science teachers to ensure pupils understand very basic issues relating to pressure, vacuums, respiration etc so that they will be equipped to understand the air pump and the frog experiment.

Attention should be drawn to the technology that made available certain scientific instruments in the seventeenth century laboratory. The location of Boyle's lab – the fact that it was usually attached to his place of residence (first at his mansion in Stalbridge, then Oxford and then at his sister's in Pall Mall) could be highlighted. Not only does this contrast greatly with modern-day preferences for lab locations, it also highlights the fact that Boyle's eminence in science owed much to his aristocratic wealthy family background that enabled him to afford such luxuries.

For Pupils
A. Robert Boyle, Francis Bacon and the Experimental Method

Francis Bacon (1561-1626).

Portrait of Francis Bacon, 1626

Bacon was one of the most influential theorists of science in the 17th century. He rejected the intellectual method of Aristotle and his followers and their logical deductions about the workings of the world from preconceived theories. Instead, he argued that conclusions should be drawn from the fullest possible collection of information obtained by experiments, and Boyle was deeply influenced by this inductive approach to science. Bacon wrote about his ideas in a book called the *Novum Organum* (New Method).

'There are two ways … of seeking and finding truth. The one method **(A)** leaps from sense and particulars to the most general axioms and from these principles … invents … all intermediate axioms. The other method **(B)** collects axioms from sense and particulars gained by various experiments, so that … in the end it arrives at the most general axioms. This latter is the only true one, but it has not been tried before.' (Adapted from L. Jardine and M. Silverthorne eds., *The New Organon* (Cambridge, 2000), p.36)

1. Using work you completed in earlier lessons, remind yourself what inductive and deductive methods were, and who used them. Read the extract from Bacon's *Novum Organum* and state whether methods (A) and (B) are inductive or deductive. Explain your answer, using the word 'because'.

B. Task

1. Describe an experiment you did in either a chemistry or biology lesson. Why and how did you do it? What equipment did you use? Was your experiment successful or a failure? How did you record your results? What conclusions did you draw? Did you set up a *control* experiment? Why did you need to do this?
2. In the light of your answers to the above, do you think you used a Baconian, experimental, inductive method – or did you use a deductive approach based on Aristotelian principles? Explain your answer, using the word 'because'.
3. In the light of your answer to number 2, how important do you think Bacon's ideas were?

C. Robert Boyle's Laboratory and Experiments

Read this passage about Boyle's laboratory using a dictionary to help you. Note where Boyle's laboratory was usually located. Do you think this was a good idea?

Robert Boyle had his own laboratory attached to the large house he shared with his sister in Pall Mall, London, where he lived from 1668. Here he did all his experiments on an almost daily basis. He had a number of lab assistants helping him, such as Frederic Slare, son of a German emigrant who, using the experience he gained working for Boyle, became a significant chemical experimenter in his own right. The instruments Boyle worked with included the air pump, thermometer, barometers and retorts which were made of glass with metal and wood supports. Much of his work consisted of heating substances, distilling them in retorts and observing, weighing and sometimes tasting the results. As a source of heat he used a small furnace called an athenor. Other materials he worked with included oil of vitriol (sulphuric acid), aqua fortis (nitric acid) and sal ammoniac (ammonium chloride - this is what the popular modern headache remedy 'smelling salts' is made of).

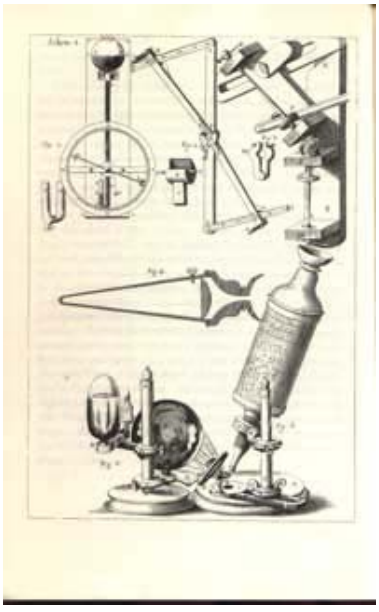


Illustration from Robert Hooke's *Micrographia* (1665) showing various instruments. In addition to the famous microscope through which Hooke made the observations in that book, the instrument shown at the top left is a wheel barometer, such as Boyle might have used.

1. Think about the equipment you can see in your school laboratory. What materials is it made of? What heat and chemicals are used?
2. Write a few sentences comparing the equipment that could be found in a seventeenth century scientist's laboratory and that used in a modern lab such as the one at your school.

D. Robert Boyle's Air Pump

In particular, Robert Boyle decided to do experiments using air because, as one contemporary commentator put it, it was the 'most necessary' to all living things for it was used for respiration. In order to do these experiments on the air, Boyle used an Air Pump, or pneumatic engine. It was an elaborate device which was very expensive to produce - the 'big science' of its day. It was designed and made for Boyle by Robert Hooke in 1659. It comprised a glass chamber which Boyle called a 'receiver', which could be sealed and from which the air could be pumped out. By placing substances or creatures such as frogs, snakes or chicks in the chamber, it was possible to observe the effects on the animals of removing or reintroducing the air.

A picture of the Air Pump occurs in Boyle's printed work *New Experiments Physico-Mechanical, Touching the Spring of the Air and its Effects* (1660). This is shown below:

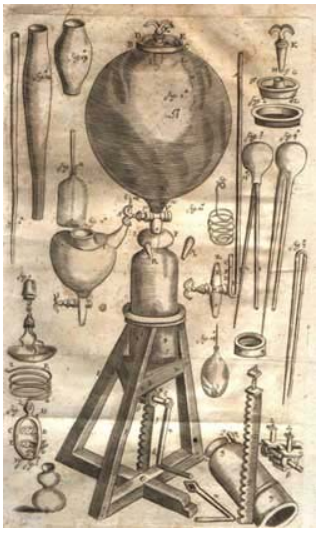


Illustration from Boyle's book *New Experiments Physico-Mechanical, Touching the Spring of the Air and its Effects* (1660) .

A scholar called William Wotton started a book called the *Life of Boyle* around 1700. This survives in manuscript form and describes how the air pump worked. An extract appears below. The letters in brackets correspond to some of the letters on the diagram. As you read through the source, look at the large print of the air pump on a separate sheet (page 8 of the lesson materials) and try to locate the letters and numbers mentioned.

'The engine consisted of two parts, a receiver (A) made of glass and a pump to draw the air out of that receiver. At the top was a round hole (BC). A cover (DE) was fitted upon the hole. In this, was fitted a stopple (FG) and in the middle of the stopple was a hole into which a handle like a stopcock was fitted. The pump was fixed in a wooden frame of 3 legs upon the ground. The pump consisted of four parts, a cylinder, a sucker (44), a handle (7) and a valve (K). To the sucker was fastened a

thick and narrow plate of iron, smooth on one edge and indented on the other (55). The engine worked in the following manner. Salad oil was put into the top of the receiver to create an air seal. The operator then forced the sucker into the cylinder by turning the handle (7) forcing the air contained in the receiver *out* through the valve. By this operation the cylinder was emptied of its air, since what was in before was driven out through the valve and there was no other passage for fresh air to come in. Thus by repetition of the motion of the sucker upwards and downwards, and by turning the key and stopping the valve, more or less air might be drawn out of the receiver' (Adapted from M. Hunter, *Robert Boyle by Himself and His Friends* (London, 1994), p. 116-117)

1. How do historians know what Robert Boyle's Air Pump looked like?
2. How do historians know how Boyle's Air Pump worked?
3. Take the large A4 sized picture of the Air Pump printed out by your teacher. Use William Wotton's account and annotate the diagram, trying to label at least 5 parts of the air pump.
4. Using Wotton's account, try to describe, in basic terms, how the air pump worked.
5. When air was extracted from the receiver, what is the term given to what was left inside?
6. Would the glass of the receiver have needed to be very thick? Use your knowledge of physics to explain your answer.

E. Robert Boyle's Experiments Using the Airpump

Source One: Boyle's air pump demonstration at the Royal Society, 1661: John Evelyn's *Diary*, 3, 284-5, 25 April 1661.

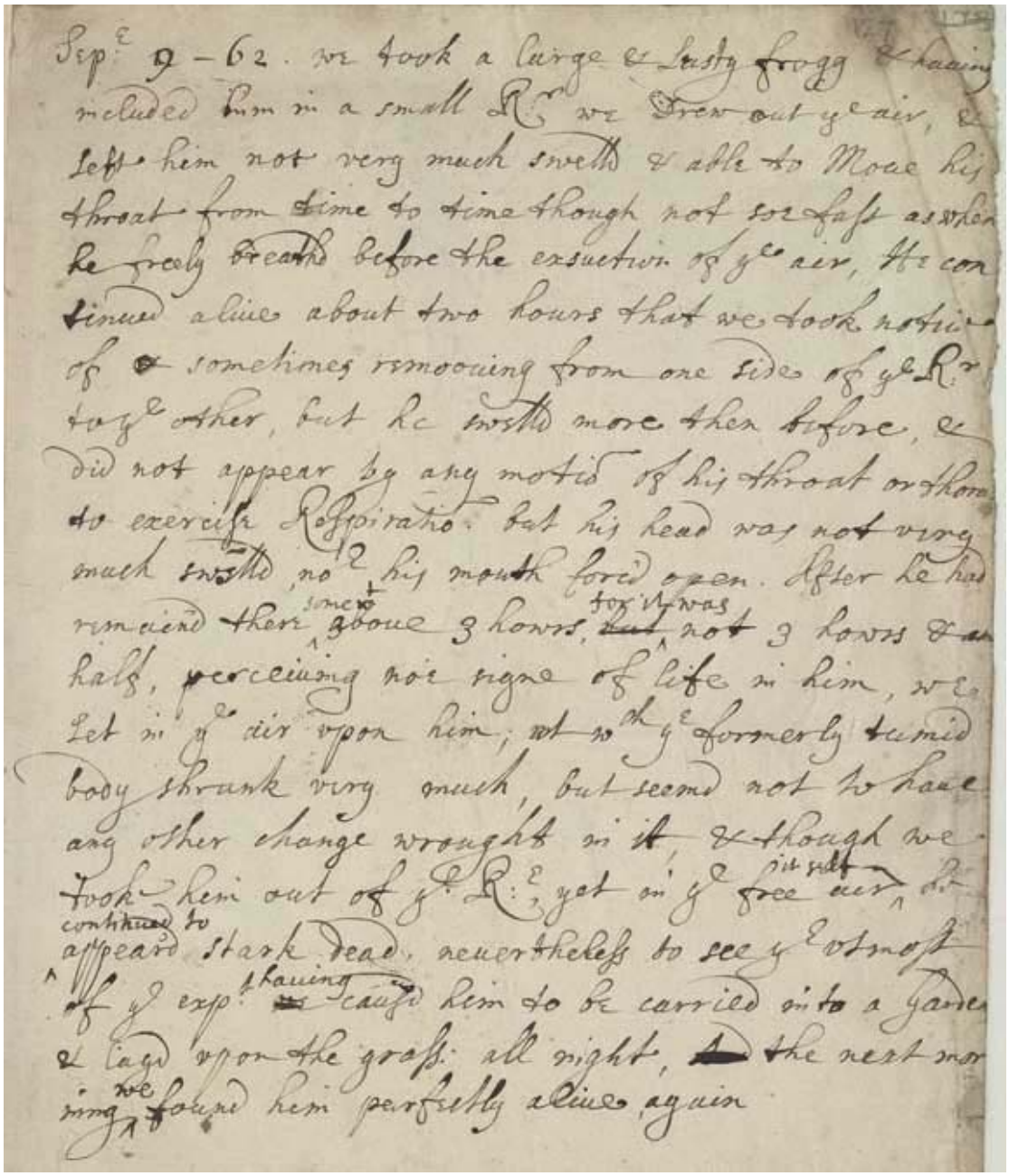
I went to the Royal Society where there were several experiments using Mr Boyle's pneumatic engine (Air Pump). We put in a Snake and chick and sucked out the air. But we could not kill it by exhausting the air, we only made it extremely sick and the chick died of convulsions in a short space of time.

Source Two: Robert Boyle's description of an experiment involving a frog, September 9, 1662

We took a large and lusty frog and having included him in a small receiver we drew out the air not very much and left him very much swelled and able to move his throat from time to time - though not so fast as when he freely breathed before the exsuction (extraction) of the air. He continued alive about two hours that we took notice of, sometimes removing from one side of the receiver to the other, but he swelled more than before, and did not appear by any motion of his throat or thorax (chest) to exercise respiration. But his head was not very much swelled, nor his mouth forced open. After he had remained there somewhat above 3 hours, for it was not 3 hours and an half, perceiving noe signe of life in him, we let in the air upon him, at which the formerly tumid (swelled) body shrunk very much, but seemed not to have any other change wrought in it and though we took him out of the receiver yet in the free air it self, he continued to appeard stark dead nevertheless to see the utmost of the

experiment having caused him to be carried into a garden and layd upon the grass all night, the next morning we found him perfectly alive again. (BP 18, fol. 127r)

Source Three



(Royal Society Boyle Papers, 18 fol 127. © The Royal Society)

A picture of the manuscript page from which the above description of the frog experiment was taken l. Try to locate in the manuscript the passage that is underlined in the extract above. Note that the letter that looks like a ‘y’ in the manuscript is in fact an older form of a letter that no longer exists today, called ‘thorn’, which is usually printed as ‘th’. Also the ‘&’ (ampersand) is used for ‘and’.]

Read the sources above carefully, also looking at the caption describing their provenance.

1. How do sources one and two help historians know about how Boyle was using his air pump in the early 1660s?

2. How do historians know about how Boyle conducted his experiments? Give examples where possible.

3. What, according to Boyle, initially happened to the frog's body when the air was extracted from the receiver?

4. Use your knowledge of physics and biology to explain why the frog's body reacted in this way.

5. Do you think Boyle's experiment on the frog and chick described in sources one and two were cruel? Do scientists do experiments on animals today? What are the advantages and disadvantages of experimenting on animals?

Robert Boyle's Air Pump
Illustration from his book *New Experiments Physico-Mechanical, Touching the Spring of the Air and its Effects* (1660)

Annotate this picture using the description from William Wotton's manuscript - *Life of Boyle*