# Dawn of Science

## 15. The Invisible Weight

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***Of vacuum, air pressure and some showmanship.***

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Previous parts:
*Resonance*, Vol.15: p.498, p.590, p.684, p.774, p.870, p.1009, p.1062. Vol.16: p.6, p.110, p.274, p.304, p.446, p.582, p.663, p.770.

Though air is a pervasive and powerful agent around, a serious understanding of how air (and gases in general) behaves developed only in the seventeenth century. This followed collective efforts of several persons especially that of Jan Baptista van Helmont (1579–1644) from Belgium, Otto von Guericke (1602–1686) from Germany, Evangelista Torricelli (1608–1647) from Italy, and Blaise Pacal (1623–1662) from France.

Of these, Helmont's work is probably not so well known. Rather surprising (and a bit unfair), because it was he who first recognized the important fact that air was not a single entity and that more than one air-like substance could be produced by ordinary chemical processes. Like several others before him (notably Paracelsus), Helmont was a physician interested in chemistry. Most of his work revolved around finding a 'philosopher's stone' and other alchemical endeavours and was worthless.

In the midst of these, however, he discovered something important. He noticed that his experiments produced several 'vapours' which had no definite shape (and took the shape of the containers in which they were kept), behaved like air physically, but had very different chemical properties compared to normal air. In particular he made a detailed study of the vapour produced by burning wood. He called it 'gas sylvestre', Flemish for 'gas from wood'. (Incidentally, he coined the term 'gas' which essentially meant 'chaos' in Flemish, but the term did not catch on for over a century and was reintroduced by Lavoisier!). He listed the properties of this gas and stressed the fact that it was different from air. In a way, this was the first time three states of matter (solid, liquid and gas) were recognized clearly.

**Keywords**
Otto von Guericke, Magdeburg, Torricelli, barometer.

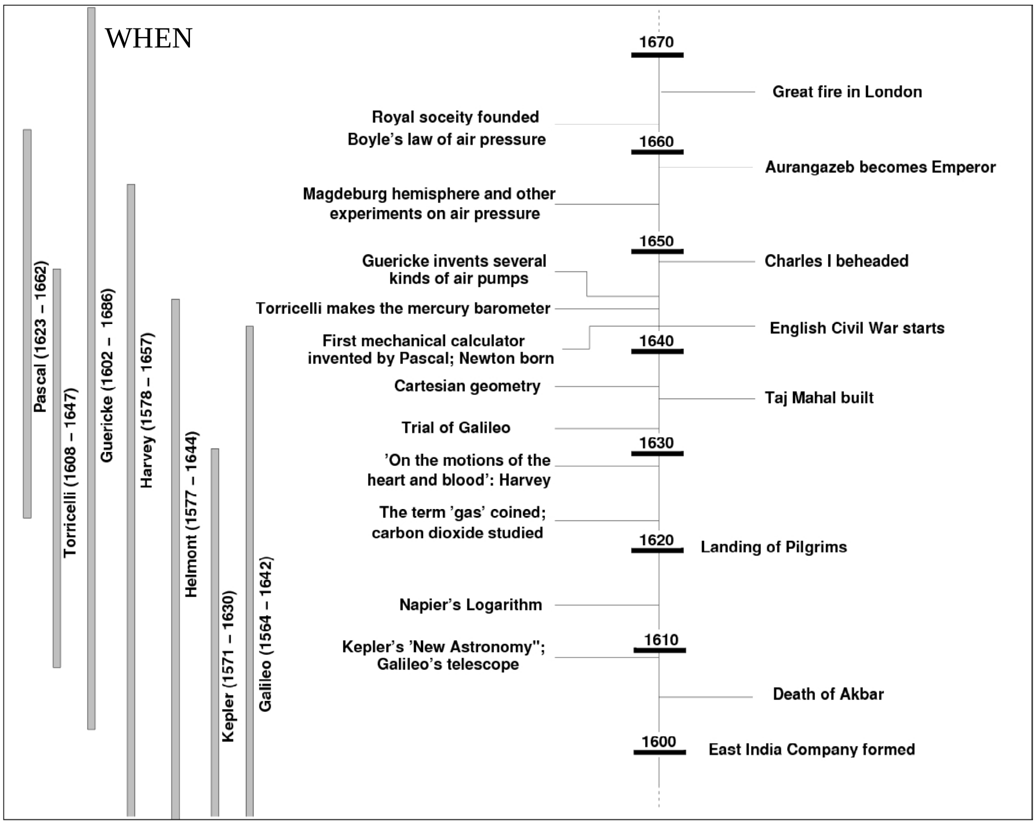


*Figure 1.*

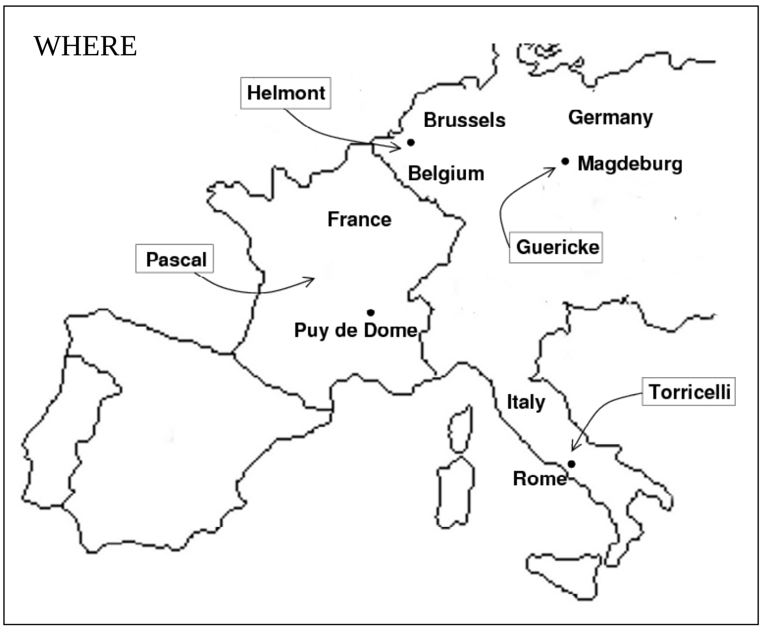


*Figure 2.*

***Figure 3.***
***Otto von Guericke.***
Courtesy:
http://en.wikipedia.org/wiki/
Otto_von_Guericke

The life and work of Guericke was a lot more colourful than that of Helmont. An engineer by profession, he entered politics in 1627 in the midst of the Thirty Years' War. His home town, Magdeberg, was ransacked by the Imperial Army in 1631 and Guericke barely managed to escape. He joined the army of Gustav II Adolphus of Sweden who turned the tide of the war. Guericke returned to Magdeburg in 1646 and became mayor of the city when it was rising from the ruins.

Meanwhile, Guericke got interested in the possibility of producing a vacuum. The prevailing view on the subject, again, was the one advocated by Aristotle: 'Nature abhors a vacuum'. Aristotle had worked out a theory of motion in which a body would move faster if the surrounding medium became less dense. Bodies had to move with infinite speed in vacuum, which, Aristotle thought was impossible; hence, he concluded that a vacuum could not exist. Guericke was unimpressed by this argument and decided to settle it by direct experiment. He built an air pump, similar in design to the water pump which had been used for centuries, and used it to evacuate air from a closed chamber.

With his flair for showmanship, Guericke put this pump to good use. He showed that candles would not burn in such a vessel and animals could not live in vacuum. After these simple demonstrations, he got more dramatic. He tied a rope to a piston and had 50 men pull the rope as he produced a vacuum on the other side with his pump. Very soon, the 50 men could not pull the piston out against 'the force of the vacuum'.

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He went on to do an even more dramatic experiment, involving the famous 'Magdeburg hemispheres'. These were two hemispheres which fitted together along a greased edge. When the hemispheres were put together and the air inside was evacuated, the hemispheres could not be separated even by two teams of horses. And when he let air enter inside, they fell apart by themselves. Guericke, the showman that he was, arranged a demonstration in 1654 for the Emperor, Ferdinand III. The Emperor was highly impressed.

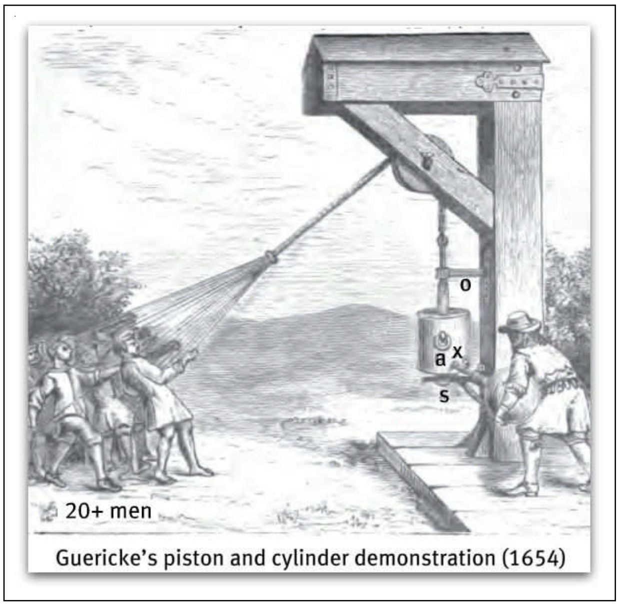



***Figure 4. Guericke demonstrates the effect of vacuum.***
Courtesy: http://www.eoht.info/photo/1758074Guericke's+piston+and+cylinder+demonstration

Did Guericke understand why these demonstrations were successful? May be he did, but the clear enunciation of the basic principles came from Torricelli. A mathematician from the University of Rome, Torricelli was deeply attracted by Galileo's books. So much so that he went to meet Galileo and volunteered to serve as a secretary during the last three months of Galileo's life. Galileo pointed out to him a peculiar problem which needed explanation.

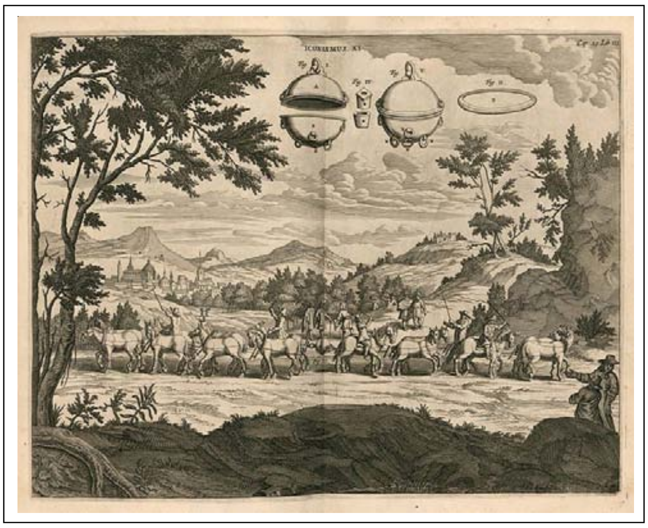


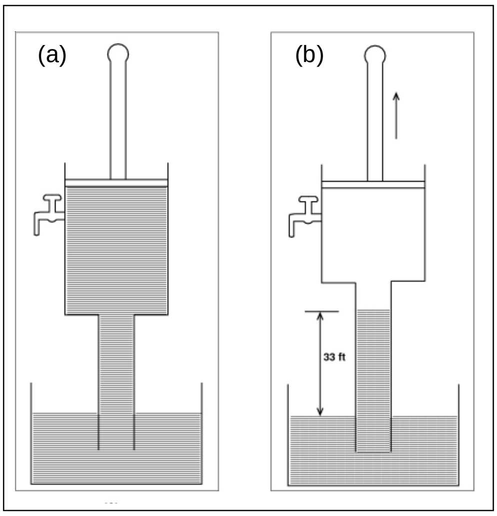
***Figure 5. The Magdeburg experiment.***
Courtesy: http://en.wikipedia.org/wiki/Magdeburg_hemispheres)

Galileo found it strange that nature abhorred a vacuum to a certain limit but gave up after that.

The problem was as follows. Pumps used to raise water from one level to another worked on pistons. How these pumps worked was explained on the basis of Aristotle's principle: 'Nature abhors a vacuum. So when the piston is raised, a vacuum will be created inside the pump unless the water level inside rises. To avoid the vacuum, water rushes in.' There was however one problem. People who used these pumps knew that the pumps could raise water only to about 33 feet (10 metres). Even when longer pumps were used water just climbed up to about 33 feet and stopped (see *Figure* 6). Galileo found it strange that nature abhorred a vacuum to a certain limit but gave up after that. He suggested that Torricelli look into this strange behaviour.

It occurred to Torricelli that the entire phenomenon had a simple mechanical explanation. "Suppose air above us had some weight," reasoned Torricelli, "then it will push on the water surface and make it rise inside the pump when the piston is raised. However, suppose the total weight of the air could only support about 33 feet of water. Then no pump with piston can raise the water higher. All this talk about 'vacuum-abhorence' is irrelevant."

***Figure 6.***
***(a) Water rises inside the tube when the piston is moved up. (b) Water does not rise above 33 feet even when the piston is raised higher.***




Torricelli went further. Since mercury was known to be about 13.5 times heavier than water, air could only support a column of mercury which is 13.5 times smaller compared to water which works out to about (33 feet / 13.5 ), that is, 30 inches (76 cm). Torricelli filled a four-foot long tube (closed at one end) with mercury, put his thumb to close the other end and inverted the tube into a large dish of mercury. On releasing the thumb, mercury flowed from the tube into the dish, but not all of it. Nearly 30 inches of mercury remained in the tube, clearly proving Torricelli right.

This was in 1643 (seven years before Guericke's air pump) and must be considered a milestone in science. Not much for the intrinsic importance of the result, but for a clear and simple demonstration of the 'method of science'. The first step was in realizing that a specific, unexplained fact existed (namely, water pumps did not work for more than 33 feet), and the second step was in postulating an explanation (that air had weight equivalent to that of 33 feet of water). Several other explanations could have been offered but what distinguished the scientific one from the others was the crucial step: a prediction was made using a hypothesis (mercury could be supported for nearly 30 inches by the weight of air). And finally, the prediction was tested and verified. The Aristotalian explanation, 'nature abhors a vacuum' was not only wrong but also deficient in predictive power.

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The part above the mercury in the inverted tube was a vacuum (except small quantities of mercury vapour). This was the first human-made vacuum and is now called Torricelli vacuum in his honour.

There was, however, a question: If the weight of the air supported by the mercury in the tube, then the mercury level should drop when a barometer (which was how Torricelli's tubes were called) was taken up a mountain. This verification was designed by Pascal. Being a weak and chronically sick man, Pascal did not attempt the task himself but persuaded his brother-in-law to carry the barometers up the sides of Puy de Dome in France in 1646. The helpful relative climbed about a mile and found that the mercury had dropped by a few inches, as expected.

Pascal also literally introduced true French spirit into these studies. He made a barometer using red wine (which is lighter than water) and verified that a column of about 14 meters could be supported!

## Suggested Reading

[1] **Isaac Asimov, *Asimov's Biographical Encyclopedia of Science and Technology*, Doubleday, 1982.**

[2] **J Hakim, *The Story of Science*, Smithsonian Books, 2005.**

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