Historical background: Otto von Guericke

About 400 years BC Aristotle stated that no vacuum or void could occur naturally in the context of Democritus's proposed atomism theory. Aristotle gave many arguments for this thesis, for example that nature has a profound aversion against any emptiness. This discussion flamed up again in the 17th century. Beneath the work of Galilei, Torricelli and Pascal in Italy and France, the mayor of Magdeburg, a town in the center of Germany, conducted several experiments concerning the vacuum. This man, Otto von Guericke (1602-1686), was convinced that there has to be a void of air in a room if one releases air or water of it. At first he tried to pump water out of a wooden barrel, but without results. The Vessels soon broke under the strong force of the atmospheric pressure.

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However, the biggest achievement of Guericke was the development of the air pump. With its help he pumped air out of a metallic vessel and produced a vacuum in it. Finally he managed it to build such stable vessels, which allowed him to conduct some remarkable experiments. He demonstrated his famous experiment with two metallic hemispheres – the Magdeburg Hemispheres – in front of the German emperor and his Reichstag in Regensburg in 1661. This opportunity allowed him a great official approval and acceptance of his claims about the vacuum. On the engraving by the Jesuit Caspar Schott, who published Guericke's *Experimenta nova (ut vocantur) Magedeburgica de vacuo spatio* (fig.2) in 1672, one can see eight horses on each side of the hemispheres. Under the supervision of several onlookers, the horses try to pull the two copper hemispheres apart, but they failed. The force of the outer atmospheric pressure was stronger than the activity of 16 horsepower. Although the real diameter of the hemisphere was about 43cm and not as big as the picture led one to assume, this masterly enacted experiment and its impact answered one important question about the world: There is a void and one can produce and analyze it with suitable instruments.

Figure 1. Experiments with a wooden barrel and metallic hemispheres. (Guericke 1672, 74)

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Figure 2. Title page of Guericke's 'vacuo spatio'. One can see among other thing the air pump on the left. (Guericke 1672)

He changed this experimental setup and the underlying principle in several various types. Instead of the 16 horses he also used a few men and later masses to determine a numerous value of the force that holds a similar cylindrical vessel (fig. 4 and 5) together or rather the force of the outer

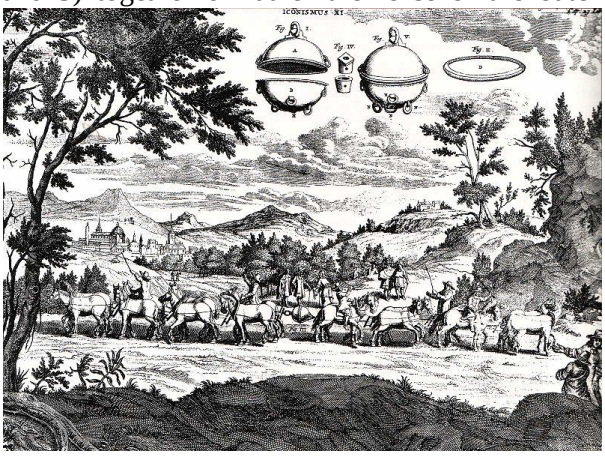

Figure 3. Engraving by Casper Schott, 1658. (http://commons.wikimedia.org/wiki/File:Magdeburg.jpg, 19.2.2013)

atmospheric pressure that bears against the vessel.

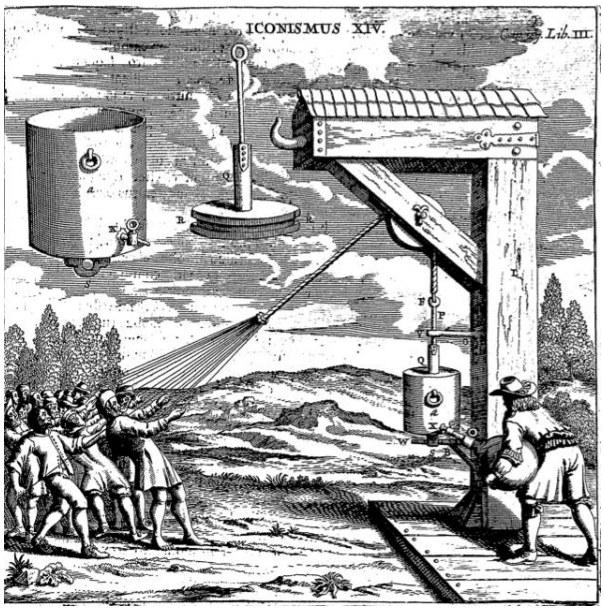

Figure 4. Experiment to demonstrate the vacuum's force. (Guericke 1672, 109)

In Figure 4 one can see also the reasoned production of the scenery: With the help of the cylindrical vessel and an evacuated sphere one single man is able to compensate the applied force of about ten men on the right.

However, what one cannot see is the work that has to be done, to conduct this experiment. Schott illustrates in his *technica curiosa* a setup, which separates the room with the airpump and the experimentation room (fig. 6).

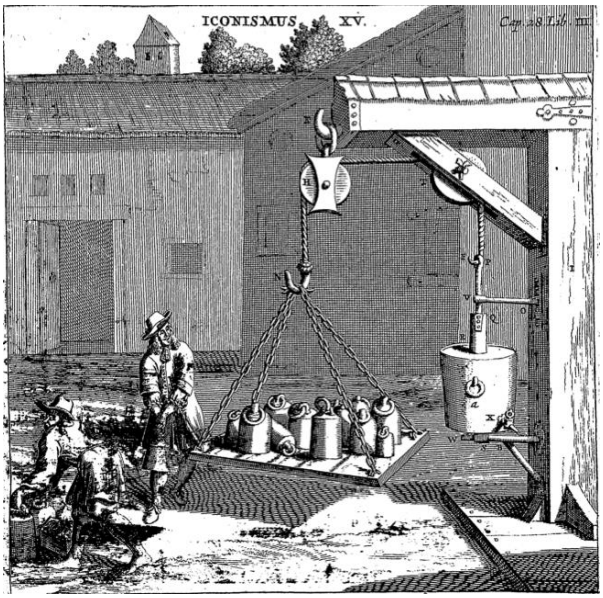

Figure 5. Experiment to determine a value for the vacuum's force. (Guericke 1672, 111)

The air pump below the experimentation room and the men, who operated it, were not visible to the audience, which could take a seat at the bench

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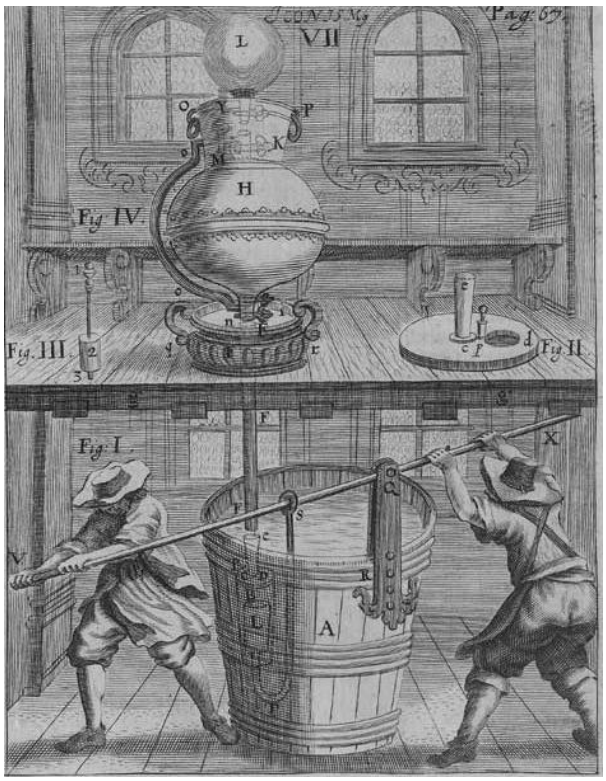

Figure 6. Guericke's air pump, 2nd design. (Schott 1664, Pars secunda - Experimenta Magdeburgica nova, Caput XXV, Iconismus VII)

in the upper room. While probably a single experimenter demonstrates the phenomena with apparently no effort, the faceless pictured, hard working two men are remaining invisible (for more details see Hentschel 2008).

Figure 7. The sulfur globe. (Guericke 1672, 129)

However, for Guericke the phenomenon of the vacuum was not limited to the earth. He rather thought, that the void inside the hemispheres resembles the same thing, which fulfills the universe. The theories of Nikolaus Kopernikus (1473-1543) and Johannes Kepler (1571-1630) questioned Aristotle's Dogma about the celestial spheres in a similar manor, but many problems were still unsolved. The explanation of the movement of the planets without the spheres of Aristotle and a result a conclusion out of Kopernikus' work caused another issue: If the fixed stars are as far away as Kopernikus proposed, which substance is in between them? Many preliminary explanations didn't withstand a further examination, e.g. Kepler's approach to explain the movement of the planets by means of a force, which was similar to the magnetic force. Guericke's research tied in with this discussion as well. Around 1663, he constructed a sulphur globe that could be rotated and rubbed by hand. Due to this contact electrification the ball got electrically charged and could attract light objects such as down feathers.

Moreover the small objects cling to the globe. For Guericke this was the explanation, why the atmosphere of the earth doesn't float away and everything object on the Earth's surface rotated with it. His approach to explain either the movement of the earth's atmosphere or the movement of stars was based on analogies and a animist viewpoint. The sulfur globe was designed to represent the earth. In Guericke's opinion the globe had the ambition to assemble or attract all associated or harmful material in its surroundings.

Casper Schott was the first person, who published Guericke's experiments as an appendix to his own work *Mechanica hydraulico-pneumatica* of 1658. As a result his experiments were known among other Jesuits, as well as lay experimenters and technicians. While Schott was a great supporter of Guericke and exchanged many letters on new problems and investigations with him, Schott's Mentor Athanasius Kircher was not. Kircher was an eminent Jesuit scholar and believed, that God fills everything and therefore, a vacuum could neither be possible between the earth and the fixed stars nor inside of a metallic vessel. A 'gap' in God's creation was unthinkable.

However, Guericke pursued another goal different from other natural philosophers or scientists. Instead of the traditional argumentation he didn't rely on the writings of famous scholars, but on experimental evidence. His contemporary scholar Blaise Pascal (1623 - 1662) shared his opinion on that. He wrote, that "experiments are the exclusive principle of physics and that experiments are the genuine Masters, whom one have to follow in physics." (Attali 2007, 167) The question how knowledge was developed or how to conduct science in general got in this relation a new viewpoint. Guericke tried to isolate the phenomenon of the vacuum. With the help of several instrument he was able to reproduce this phenomenon well-directed and on the first view very easy. Beneath his experimental skills it was both his elaborate enacting of experiments, their publica-

tion and the appreciation of contemporary researchers.

The Magdeburg hemispheres and Guericke's air pumps are the references of a meaningful and extensive change in the history of science.

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