A Companion to „Physics of gases and the phenomena of heat"

Slides 2–13 - discovery of the atmospheric pressure.

In 1644 the Italian mathematician Evangelista Torricelli, who was a student of Galileo, performed his famous experiment with a tube filled with mercury (called quicksilver at that time). However, he described it only in a private letter to his friend Michelangelo Ricci. Because of that information of Torricelli's results was very slowly disseminated throughout Europe. In July 1647 similar experiment was performed independently in Warsaw by Valeriano Magni, an Italian monk and scholar who was in the service of the king of Poland. The small brochure with the description of the experiment which Magni published in Warsaw in September of the same year was the first publication on the subject (see Slide 3, lower left picture).

Torricelli suspected that the weight of the mercury column in his tube was balanced by the pressure of air in our atmosphere. However, a convincing experimental proof of that hypothesis was needed. French scholar Blaise Pascal planned the experiment (Slides 5-6), which was performed by his brother-in-law Florin Périer (Slides 7-11). One must admire care with which Périer did his task: he prepared two identical tubes with mercury, left one set in the town, and took the second set to performe multiple measurements during climbing the mountain Puy-de-Dôme near Clermont. One must also admire the excitation of experimenters when they had seen changes of the height of mercury column with the elevation. Having learned from Périer about the extent of the effect Pascal was able to repeat it in Paris.

Aristotle denied the existence of vacuum (see „Greek science"), hence many scholars opposed the view that there could be vacuum above the column of mercury in Torricelli's tube. An amusing example of such a disbelief is shown in Slide 14. Its author was of the opinion that light could not propagate in a vacuum.

Slides 15-23 show some examples of experiments with vacuum performed by Otto Guericke, a German civil servant, the mayor of Magdeburg, who was interested in physics and constructed the first vacuum pump (about 1650). He gave detailed account of his experiments in the book *Experimenta nova (ut vocantur) Magdeburgica de vacuo spatio* (*New experiments, so-called Magdeburgian, on empty space*) published only in 1672 (because of many duties Guericke did not have time to prepare the publication earlier).

Guericke was also a showman and performed a large scale experiment in the presence of emperor Ferdinand III and the Imperial Diet in Regensburg in 1657. He prepared two hollow copper hemispheres of 36 cm diameter each („Magdeburg hemispheres"), milled so that their edges fitted precisely, and together formed a sphere. Next, the air from the interior was pumped out through a stop-cock in one of them which was then closed. Now he harnessed a team of eight horses to each hemisphere and the two teams were driven in opposite directions. It appeared that force of sixteen horses was not sufficient to separate the hemispheres (Slide 23). When air was allowed into the enclosure the hemispheres were easily separated. In 1663 Guericke performed the experiment with twenty four horses. You may be interested to know that the original hemispheres used by Guericke have been preserved and are on display in the Deutsches Museum in Munich.

Guericke's results had been known long before his book appeared in 1672 because he permitted other authors to publish accounts of his inventions. Guericke's vacuum pump was described in *Mechanica hydraulica-pneumatica* published by Gaspar Schott in 1657.

That information stimulated the British scholar Robert Boyle to construct similar pump. Boyle came from a very rich family and could afford to build for himself a private laboratory in Oxford. He hired a young assistant Robert Hooke who designed and built several vacuum pumps. Boyle and Hooke performed numerous experiments on air pressure and the phenomena in rarefied air. In particular they were able to confirm the conjecture of Galileo that in a vacuum all bodies fall with equal acceleration (Slides 24-25). The most important quantitative result obtained in Boyle's laboratory was the relation between the volume and the pressure of the enclosed air. It was found that these quantities were inversely proportional to each other (in other words: the product of the volume of air and its pressure is a constant). Boyle published the results of his experiments in *New Experiments Physico-Mechanical touching the Spring of the Air* published in 1660; the second edition in 1662 (Slide 24, lower left picture).

Boyle published the results in form of a table (Slide 26). The measured values of the volume V and pressure p_{obs}, are shown in the first and second column, whereas the third column lists the values of the pressure p_{calc}, calculated by assuming its inverse proportionality to the volume V. Boyle simply stated that the values of p_{obs} and p_{calc} agree well. In modern times we prefer to display the experimental results graphically (Slide 27).

Boyle proposed an explanation of the results by assuming that air consisted of very small „coiled particles" (Slide 28).

More than ten years later Edmé Mariotte in Paris also found experimentally the relation between the volume and pressure of air, and probably he did it without knowing Boyle's results. Mariotte's experiments have been even more precise than Boyle's, and the results were published in 1679. The first quantitative law in the physics of gases is now known as Boyle's law in Anglo-Saxon and several other countries, while the French call it Mariotte's law (*le loi de Mariotte*); in a number of countries the accepted name is Boyle-Mariotte law (Slide 29).

Slide 31 shows a schematic time table of important events in the study of the phenomena of heat. In this chapter we discuss only the invention and evolution of thermometers during the XVIIth century.

„Heat" and „cold" were opposing qualities introduced in Antiquity (see: „Greek physics"). There was no attempt to assign numbers to these qualities. Later the great physician Galen seems to have introduced the idea of „degrees of heat and cold" for the use in medicine but he did not use measuring instruments.

Slides 32 and 33 contain excerpts from the writings of Francis Bacon and Galileo. Both had been convinced that heat was caused by a motion of some kind. Galileo believed in the existence of heat or fire particles which he called *ignicoli*.

It is not clear who was the inventor of the thermometer. The names of the four contenders are shown in Slide 34. The dates given there are uncertain, except for 1612, the year in which Santorio Santori, an Italian professor of medicine in Padua, provided the description and usage of that instrument in his book *Commentaria in artem medicinalem Galenis* published in Venice. Santorio must have been using such an instrument earlier. It is certain that he was the first to use it in his clinical studies.

The thermometric substance in the first thermometers was simply air. It was contained in a glass bulb at the top, and a tube dipping into an open vessel with water (see Slide 35).

When the temperature of bulb containing air at a pressure lower than the of the atmosphere rises, the level of water in tube falls. When the temperature falls, the air contained in the bulb contracts and the level of water in the tube rises. An arbitrary scale of „degrees" attached to the tube could be used to measure the differences of the level of water on different occasions.

Later (1631) the first liquid thermometer was constructed by Jean Rey.

Slide 36 shows the famous air thermometer built about 1660 by Otto Guericke in Magdeburg. The instrument was about ten feet tall and was made of copper and brass. Guericke attached it to the wall of his house. The figure on the left shows the mechanism, that on the right the instrument as seen by the passers-by. The scale had only seven markings, from „great frost" (*Magnus frigus*) to „great heat" (*Magnus calor*). The thermometric liquid in Guericke's thermometer was alcohol.

The earliest proposals for the fixed points which were needed to compare various thermometers are listed in Slide 37.

Slide 38 illustrates the audacious attempt by Santorio to compare „the heat of the Sun with the heat of the Moon". He had used his air thermometer which was of course too primitive to yield any sensible results. Nevertheless, his attempt published in 1625 allows us to count Santorio among the pioneers af astrophysics. His approach contrasted with popular but groundless fables of astrologers about the „heat" of celestial bodies (Slide 40).

It is worth knowing that Francis Bacon who is quoted twice in this Chapter, was an influential scholar and politician in England during at the turn of the XVIIth century.