A Companion to „Optics from Kepler to Newton"

Slide 2 shows a time-table of most important events in the history of optics in the years 1600-1900. In this chapter we discuss the development of optics in the XVIIth century.

Johannes Kepler tried to establish the law of refraction of light. He knew about previous measurements by Witelo but decided to perform his own measurements by using a simple instrument shown in Slide 3 (lower right corner). He then tried to represent the results of measurements by several simple formulas but he failed (usual symbols are used: α is the angle of incidence, and β - the angle of refraction). The account of his trials is included in his book *Ad Vitellionem paralipomena* (*Additions to Witelo*) published in 1604.

When Kepler learned from Galileo about his telescopic discoveries he devised another form of telescope (Slide 4). He could do it without knowledge of the exact law of refraction of light because for very small angles he could assume simple proportionality between angles of incidence and of refraction; we know now that $\sin \alpha \approx \alpha$ for small angles. Kepler's research is presented in his book *Dioptrice* (1611).

(Slide 5) The correct relation $\sin \alpha = n \sin \beta$ has been found independently by three scholars. The English maverick Thomas Harriot achieved it before 1610 but did not inform anyone about it; only recent analysis of his manuscripts revealed details of his experiments. The Dutch physicist Willebrord Snell found the law of refraction experimentally in 1621 but died before publishing this result; several years later Christiaan Hyugens found his manuscripts and made his discovery public. That's why in many countries the law of refracton of light is called Snell's law. René Descartes came to the law of refraction by theoretical arguments, which are summarized in Slides 6-11, and he was the first to publish the result in *La Dioptrique* (1638). Please notice that at that time refraction of light was described as shown in Slide 5, lower right picture.

French laywer and mathematician Pierre Fermat gave the proof that the law of refraction is a consequence of the principle of the shortest time for the passage of light (see Slide 12).

Making use of the law of refraction of light Descartes was able to provide the first quantitatively correct explanation of the rainbow (both primary and secondary). His analysis was published in *Les météores* (1638) - see Slides 13-15.

Slide 16. In the second half of the XVIIth century new important results concerning light were obtained.

Danish astronomer Ole Roemer, who was employed in the astronomical observatory in Paris, performed systematic observations of Jupiter's satellites and explained irregularities in the times of their eclipses by assuming that light did not propagate instantaneously as commonly believed for centuries (Slides 19-21). He did not give any value for light's velocity because his aim was simply to explain that it could not be infinitely large. Many modern authors fail to understand Roemer's aim and try to quote some invented values (see Slides 22 and 23).

Many scholars, such as Robert Hooke, could not accept Roemer's conclusion (Slide 24), whereas others, e.g. Huygens and Newton, agreed with it. Huygens invented an ingenious mechanism explaining propagation of impulses in an elastic medium (Slides 25-27).

Discovery of the diffraction of light by Grimaldi described by him in 1665 in the book *Physico-mathesis de lumine, coloribus, et iride* (Slides 28-29) was taken by some physicists as the result of sloppy experimention! (Slide 30).

The origin of colours arising from the passage of white light through media remained a mystery for centuries. Early attempts to explain this phenomenon were quite naive (Slides 33-35). Robert Hooke included his theory in the best-selling book *Micrographia*, which contained mainly very detailed drawings of small objects observed under the microscope which he constructed. His explanation of colours involved a conjecture that white light propagating through homogenous and transparent medium had its wave-front perpendicular to the direction of propagation; refraction at the boundary of two media was supposed to destroy that arrangement which led to appearance of colours (see the picture in Slide 35).

The first modern, experimentally founded theory of colours was published by Isaac Newton. He constructed himself a small reflecting telescope. It aroused great interest in Cambridge and news about it reached the Royal Society in London, which expressed a wish to see and inspect it. Newton made another telescope, sent it to London and was prompted to publish the details of construction in the „Philosophical Transactions" which he duly did (Slide 36). The telescope was quite small: it was about 20 cm long and the mirror had a diameter of about 5 cm (Slide 37, lower right picture). The instrument was received with enthusiasm and Newton was elected member of the Royal Society. He soon sent for publication a small treatise *New Theory about Light and Colors* (please notice different spelling of the word colours) which appeared in February 1672 (Slide 37). Excerpts from Newton's text are presented in Slides 38 and 40-41, while Slide 39 shows his original drawing of his *experimentum crucis*.

Newton's paper met with applause because it was realized that the reported results are important. The Society asked Robert Hooke to judge the value of Newton's paper. Hooke presented his evaluation during the Society meeting on February 15, 1672, which Newton did not attend. Hooke spoke highly about Netwon's experiments but criticised their interpretation (Slides 44-45). Newton was an irritable man and after prompt confirmation of receiving Hooke's evaluation (Slide 46) spent the next three months to prepare the answer. It was sent to Oldenburg, the secretary of the Royal Society on July 11, 1672, and published in the „Philosophical Transactions" on November 18 of the same year (Slides 47-50). Three years later Newton sent to the Royal Society his next paper in which he explained the details of his theory of light. The text was read in December 1675 but not published (Slides 51-54). Newton elaborated his theory of light which accodring to him was „neither aether, nor its vibrating motion, but something of a different kind propagated from lucid bodies."

Treatise on light (*Traité de la lumière*) published by Christiaan Hyugens (Paris, 1690) was one of the most influential books on light in the XVIIth century. The excerpts presented in Slides 56-66 contain the most important conclusions of that treatise. Please pay special attention to Slide 59, in which Huygens theory of light is explained correctly as a „pulse theory" and not „wave theory" which many authors wrongly present in their textbooks. The „Huygens principle" is explained in Slides 59, 60 (left picture), and 61.

Huygens tried to provide an explanation of the phenomeon of double refraction of light in certain crystals (see Slide 31). He found out that the ordinary ray in calcite propagated as a spherical wave through the crystal. In order to account the behaviour of the extraordinary ray he described its propagation as „spheroidal" waves. He was, however, unable to explain certain phenomena which he discovered upon passing a ray of light through two crystals in succession (Slides 60-66).

Slides 67-70. Newton had waited with publication of his *Opticks* while his main critic Robert Hooke was alive, because he despised entering into further discussions with him. That's why the book appeared only in 1704. The original edition was in English, and two years later a Latin translation appeared. It included the summary of all Newton's experiments, starting from those published in 1672. The contents of *Opticks* is presented in Slide 68. At the rather abrupt end of Book 3 Newton explained that because of other duties - he was then Master of the London Mint - he was forced to leave the subject with only a number of Queries, some speculations and unanswered questions, the material for the future experiments by other physicists. In the later editions of *Opticks* the number of Queries grew to thirty one. Some excerpts of Queries are presented in Slides 71-75. Parts of Query 31 are of special interest because of remarkable hypotheses on the structure of matter and forces acting at different scales (Slides 73 and 74).

The different explanations of refraction of light in Huygens' and Newton theories are shown in Slides 76 and 77.

There had been a considerable progress in astronomy in the XVIIth century (Slides 79-82). Large astronomical observatories were erected in Paris and London (Greenwich). Rich citizen of Gdańsk, Poland, Johannes (Jan) Hevelius, built a large observatory on the roofs of his houses and later installed his longest telescope outside the city limits (Slide 79, lower right picture). At that time telescopes were made as long as possible to reduce the chromatic aberration which resulted in fuzzy and coloured images of celestial bodies. Hevelius published several important books, in particular he had drawn one of the first maps of the lunar surface (Slide 80, lower left picture). Christiaan Huygens finally resolved the mystery of Saturn rings, which was earlier presented in quite fantastic shapes by the astronomers using inferior telescopes (Slide 82, left picture).