A Companion to Physics of the XIXth century - part 1

This chapter is divided into two parts: development of electrical science (Slides 3-41) and development of optics (Slides 42-87).

In Slide 3 we see the time table of the most important discoveries together with the names of their authors in the period 1600-1900.

The well known French scientist Jean Baptiste Biot published the *Traité de physique expérimentale et mathématique* in four volumes. He expressed the common view that physics should be limited to ”studying the phenomena produced by the actions of invisible, intangible, and imponderable principles such as electricity, magnetism, caloric, and light.” Electricity and magnetism accounted for only one-fifth of the volume of Biot’s textbook, however, the greatest progress during the XIXth century occurred in just these two parts of physics.

The original Volta’s pile was unstable because of its vertical construction and it was limited to rather small number of cells. In 1808 William Cruickshank in England realized that the elements of the pile could be arranged in a trough. The horizontal construction made possible building very large electric batteries such as e.g. the pile built by the Royal Society in London, and the huge pile constructed at École Polytechnique in Paris (Slide 5). The London pile had 2000 double plates of zinc and copper arranged in 200 groups, each of 10 cells. The electrolyte was made out of 108 parts of nitric acid and 25 parts of sulphuric acid in 1168 parts of water.

The most important results obtained with the use of electric batteries were: decomposition of water into hydrogen and oxygen during electrolysis (Nicholson and Carlyle, 1800), discoveries of metallic sodium and potassium resulting from electrolysis of their solutions in water (Davy, 1807), and discovery of the electric arc, observed first in 1801 and used for spectacular public demonstration of electric light (Davy, 1808). However, already in 1807 Thomas Young expressed scepticism concerning the understanding of electric effects (Slide 6), and soon it was felt that no further progress could be made in that domain (Slide 7).

Meanwhile the French scholar Siméon Poisson published the first mathematical theory of electrostatic phenomena (Slide 8).

No one predicted the great revolution in electrical science which began in 1820 with the unexpected discovery of the action of the electric current on a magnetic needle by Hans Christian Oersted. In the following years the science of electromagnetism was created and developed by several great scholars whose portraits are shown in Slide 9.

Hans Christian Oersted (1777-1851) was professor of physics at the university of Copenhagen. In April 1820 he first noticed the effect while giving a lecture to his students. On July 21 of the same year he published an account of his results in a small brochure in Latin (Slide 10). It was probably the last important physics publication written in that language because everywhere else physics papers and books had already been published in national languages. Slides 11-17 contain excerpts from Oersted paper and from his later article in the „Edinburgh Encyclopedia".

Oersted had sent many copies of his brochure to scientists and societies in Denmark and abroad. One of the copies was received by Auguste De La Rive in Geneva during the congress of naturalists in that town. The participants of the congress learned about Oersted's discovery and witnessed the repetition of his experiment. One of the participants, François Dominique Arago, returned to Paris and on September 4 reported the news during the meeting of the Academié des Sciences. He repeated Oersted's experiment during the next meeting on September 11 (Slide 18). One of the academicians, André Ampère, who was known earlier because of his mathematical papers, in a sudden flash of genius conceived an idea of how to extend and exploit the stunning finding of the Danish scholar. He showed that a circular current behaves as a magnet and deduced that magnetism arises from electricity in motion. In nine reports to the Academié des Sciences starting from September 18 he founded a new science of electromagnetism (Slides 20-25). His formula for the force between two currents was quite complicated (Slide 25) - it is now written in a much simpler form by using the vector product, not yet known in Ampère's times. Meanwhile Jean Baptiste Biot and Félix Savart performed measurements of the force acting on a magnetic needle by an electric current (Slide 19).

James Clerk Maxwell expressed admiration of Ampère's achievement and called him „the Newton of electricity" (Slide 26).

Following Oersted's discovery there have been numerous unsuccessful searches of the inverse action, i.e. production of an electric current by magnetism. However, the searches were made of a static effect! Arago experimented with a copper disc and his results introduced new complications. It had been known that iron was the only substance attracted by a magnet, yet copper appeared to be magnetic when whirled around a pivoted magnet. A pivoted magnet was caused to follow the motion of the copper disc. Moreover a copper wire carrying a current attracted iron fillings!

Michael Faraday (Slide 28) was born in a very poor family and he got very little formal education. At thirteen he began his apprenticeship as a bookbinder. He soon developed a taste for reading books, particularly those on scientific subjects. After reading the article on electricity in the old *Encyclopaedia Britannica* he began making simple experiments with a home-made voltaic pile. One day he decided to attend the lectures given by Humphry Davy at the Royal Institution. He took full notes of the lectures, bound them with his own hands, and sent to Davy with a letter in which he asked for a possibility of working as a laboratory assistant at the Royal Institution. Davy was impressed by Faraday's enthusiastic account of the lectures and agreed to employ him. Faraday learned very fast and soon became a well qualified experimenter. After resignation of Davy in 1825 he became the director of the Royal Institution.

In 1831 Faraday made the greatest discovery of his life, when after several failed attempts he finally found electromagnetic induction (Slides 29-30). It must be stressed that Faraday had to construct his instruments including coils and galvanometers (Slide 31). The famous coil used on August 29, 1831 has been preserved at the Royal Institution. It is still in working condition and had been used in public experiments performed during the Faraday Centenary in 1931. On October 17, 1831 Faraday used a cylindrical coil made from a hollow paper cylinder covered with copper wires connected to the galvanometer. Into this coil he inserted the end of a cylindrical bar magnet and thrust it quickly in the whole length of the cylinder. He was able to observe a sudden deflection of the galvanometer's needle. On withdrawal of the magnet bar there was again a deflection of the needle.

Faraday's results led quickly to the construction of the electric dynamo. The first „Magneto-electric machine" was built in Paris by Hypolyte Pixii (Slide 33), and soon after that machines converting mechanical into electrical energy became common sources of the electric current.

Faraday invented the way to observe and then publish the „delineation of lines of magnetic force by iron fillings." These are his own words:

„Nothing is simpler than to lay a magnet upon a table, place a flat piece of paper over it, and then sprinkling iron fillings on the paper, to observe the forms they assume. Nevertheless, to obtain the best and most generally useful results, a few particular instructions may be desirable. The table on which the magnet is laid should be quite horizontal and steady.(...) The fiilings should be distributed over the paper by means of a sieve more or less fine.(...) The designs thus obtained may be fixed in the following manner, and then form very valuable records of the disposition of forces in any given case. (...) Raise the paper upwards from the magnet, to be deposited on a flat board or other plane surface. A solution of one part of gum in three or four of water been prepared, a coat of this is to be applied equably by a broad camel-hair pencil, to a piece of cartridge paper, so as to make it fairly wet, but not to float it, and after wafting it through the air once or twice to break the bubbles, it is to be laid carefully over the fillings, then covered with ten or twelve folds of equably soft paper, a board placed over the paper, and a half-hundred weight on the board for thirty or forty seconds. (...) If, after that, the paper be taken up, all the fillings will be found to adhere to it with very little injury to the forms of the lines delineated; and when dry they are firmly fixed."

A copy of the original picture published by Faraday in 1852 is shown in Slide 32.

Faraday's achievements had been highly esteemed by Maxwell (Slides 34 and 35).

Unknown to Faraday, the American scholar Joseph Henry independently performed similar experiments on electromagnetic induction (Slide 36). He discovered self-induction (1832). To honor this discovery the unit of induction had been named „henry".

Georg Simon Ohm was the teacher of mathematics in German secondary schools. He was also interested in physics and performed experiments to quantify electric resistance (Slides 37-39). He used wires of equal diameter and different length. His choice of observables was unfortunate so that his first „law" published in 1825 had a logarithmic form. Later he used thermoelectric source of current and proper observables (Slide 39). In 1834 Heinrich Lenz established the „Lenz rule" for the direction of the induced current (Slide 40).

Coulomb's law of interaction between static electric charges had to be generalized to aacount for the interaction of charges in motion. It was done by Wilhelm Weber (1846). His formula (1846) included a constant c which had dimension of velocity and had been experimentally determined to be equal approximately 3 x 10^{10} cm/s, close to the velocity of light. Most physicists of that time, except Maxwell, decided that it was just a numerical coincidence. Maxwell decided to explore the consequences of that agreement of the quoted numerical values. It led him to the new theory of electromagnetism (see „Physics of the XIXth century - part 2”).

Slide 43 shows the time-table of important discoveries in optics between 1600 and 1900. Because of the great authority on Isaac Newton his „corpuscular” theory of light ruled supreme over the whole of the XVIIIth century, while Huygens „wave” or rather „impulse’ theory had been largely forgotten. Slide 44 presents an excerpt from the article on light in the first edition of *Encyclopaedia Britannica* (1771).

The visible spectrum had been extended on both ends by discoveries of the infrared radiation (Herschel, 1800), and the ultraviolet radiation (Ritter and Wollaston, independently in 1801). The most important discovery was made by Thomas Young, the English polyhistor who „knew almost everything”, and made important contributions to several disciplines, including Egyptian hieroglyphs, mathematics, medicine, and physics. He published the general law of interference of light in 1802 (see Slide 46, and additional explanation in Slides 48 and 49).Young wanted to resurrect the wave theory of light (Slide 50). He met with violent attack by Lord Henry Brougham who condemned Young for trying to destroy the greatness of Isaac Newton (Slide 51).

Meanwhile new discoveries of polarization of light (Slide 52) introduced changes in the views on the nature of light. The French Academié des Sciences made diffraction of light the subject of the prize for 1818. French military engineer Augustin Fresnel sent his essay for that contest. The jury called by the Academié consisted of Arago, Biot, Gay-Lussac, Laplace, and Poisson, all of whom with exception of Arago were followers of the corpuscular theory of light. Poisson, who was skilled mathematician, pointed out that Fresnel’s theory led to „absurd” conclusion that a bright spot should occur in the centre of the shadow of a disc illuminated by a light source. That „absurd” result had been verified by experiment and the jury had been forced to award the prize to Fresnel (Slide 54).

Fresnel and Young independently suggested that the light-bearing ether may have the additional degree of freedom and oscillate „transversely”, at right angles to the direction of propagation of the wave (Slide 55). That idea of Fresnel and Young about transverse light vibrations inaugurated a long period of studies of the properties of the hypothetical ether, a medium of very large elasticity, but transparent and presenting no resistance in the motions of heavenly bodies (Slides 56-57).

The Austrian teacher of mathematics Christian Doppler was interested in physics and astronomy. In 1842 he published a short essay *Über das farbige Licht der Doppelsterne* (*On the colours of the double stars*) in which he suggested that the colours of stars depend on whether they are approaching the observer or receding from him; he conjectured that stars moving towards us should appear bluer and those moving away, redder (Slides 58-59). Doppler’s erroneous assumptions had been corrected in 1848 by the French experimental physicist Armand Hippolyte Fizeau (see Slide 60 and the link to additional explanatory slides 78, 84-87).

Doppler's effect for light is described by the formula $\Delta\lambda/\lambda = v/c$, where $\Delta\lambda$ is the change in the wavelength λ, v - the velocity of the source, and c - the velocity of light. Usually the velocity of the source is much smaller that the velocity of light, so that it is extremely difficult to measure the effect in the laboratory even when multiple reflections are used to enlarge it (Slide 62-63). The Sun is rotating around its axis so that one part of the solar limb moves toward the Earth while the opposite part is receding (Slide 61). The effect, however, is very small and could not be measured with instruments available in the middle of the XIXth century. The first estimate of the velocity of stars was obtained by William Huggins who used the multiprism spectrograph of special construction. He succeeded to measure the red shift of spectral lines in the spectrum of Sirius, the brightest star in the sky, and found its velocity of recession to be about 48 km/s. Huggins correctly predicted that Doppler's effect will play a dominant role in astronomy (Slides 64-66).

The various applications of the Doppler effect are listed in Slide 67.

Dark lines in the solar spectrum were first noticed by William Wollaston (1802), who however, did not pursue this line of investigation. In 1815 Josef Fraunhofer published his extensive observations collected in the catalogue of 574 dark lines in the solar spectrum (now called Fraunhofer lines). At that time there was no explanation for their origin.

Two German scholars, chemist Robert Bunsen, and physicist Gustav Kirchhoff discovered that each chemical element has its own characteristic spectrum. Observations of its spectral lines in the light of the distant source provide the proof of the presence of that element in the source. Bunsen's and Kirchhoff's discovery of spectral analysis made possible studies of chemical composition of distant celestial bodies, which had been declared impossible by prominent philosophers, such as August Comte (Slides 70-72).

First laboratory measurements of the velocity of light were performed by Fizeau (1949) and Foucault (1850) - (Slides 73 and 74). It was proven that light travels more slowly in an optically dense medium, contrary to Newton's prediction (see Slide 77 in „Optics from Kepler to Newton").

The attempt to detect Earth's motion in the ether undertaken by Abraham Michelson and Edward Morley gave null result (1887). In spite of extremely careful measurements no displacement of spectral lines had been observed. That result of the Michelson-Morley experiment (Slides 75-76) became later one of the cornerstones of the special relativity theory .

The first verification of the Doppler effect was made for acoustic waves by Christopher Buys-Ballot in the Netherlands (Slide 79). He asked a group of professional musicians endowed with absolute hearing to try to detect changes in frequency of sounds played by another group of musicians on a moving railway platform. The data concerning that experiment are presented in Slides 80-84.

Additional explanatory slides 84-87 explain the conditions of observing emission and absorption spectra.

Please take special notice of Slide 87. Spectral lines are images of the spectrometer slit by light of a given wavelength. The slits almost always have a very thin rectangular shape, hence spectral lines are also very thin rectangles. But in the special case of the total solar eclipse the situation is different. Just before the phase of totality an extremely thin portion of the solar limb remains visible and serves as a thin crescent slit (lower left picture). When observed through a prism spectrometer (without its own slit!) the so-called flash spectrum is seen in which spectral lines have the shape of a thin crescent (lower right picture). Flash spectrum appears momentarily also just after the end of the totality phase.