A Companion to Physics around 1900

It is usually believed (with little justification, as we shall see) that it was just in the year 1900 that the transition from the classical to the quantum physics occurred. For that reason the state of physics around the year 1900 deserves a special discussion.

At the end of the XIXth century most physicists and chemists were convinced that there was not much remaining for research in the exact sciences. True enough, there were some facts difficult to explain by then existing theories, but they were regarded as just minor, insignificant details. This attitude is documented in Slides 2-10. Only Lord Kelvin seemed to have been aware of the fact that the understanding of physical phenomena remained imperfect and incomplete (Slides 11 and 12).

In Slides 13-25 a summary of the facts concerning cathode rays and X rays is given. The cathode rays were discovered in 1859 by Geissler and Plücker. At that time the vacuum obtained in glass tubes was already good enough to enable observation of colourful electric discharges in various very rarified gases. The induction coil which provided high voltage between the electrodes had been invented by Heinrich Rühmkorff in Germany. The observation that magnetic field changed the appearance of the glow within the tube led to conclusion that there must be some kind of rays emanating from the cathode. Another German physicist Johann Wilhelm Hittorf had proved that these rays propagated along straight lines, because an obstacle placed in their path casted a distinct shadow, but they were deflected in a magnetic field. Hittorf described the rays as *Glimmstrahlen* (“glow rays”). The present name, cathode rays, was coined in 1876 by yet another German physicist, Eugen Goldstein. British physicist Cromwell Fleetwood Varley put forward the hypothesis that cathode rays have a corpuscular nature. William Crookes, however, since 1879 propagated the view that cathode rays represent the fourth state of matter: radiant matter. The German physicists did not accept the corpuscular theory of cathode rays claimed by the British, but declared them to be some kind of light propagating in the ether.

It was inevitable that during the investigations of cathode rays in numerous laboratories (Slide 17) sooner or later someone would notice that the light-sensitive screens placed near the discharge tubes exhibit phosphorescence and that photographic plates become fogged and spoiled. In several cases physicists returned the plates to the producers and asked to replace them by new, undamaged plates.

On November 8, 1895, Wilhelm Conrad Röntgen unexpectedly discovered a new invisible and very penetrating radiation. For the next seven weeks he was constantly engaged at his laboratory. He wrote a report of his experimental results and on December 28, 1895, handed the manuscript to the President of the Physico-medical Society of Würzburg. His article entitled *Über eine neue Art von Strahlen* (*On a New Kind of Rays*) was immediately printed in the *Sitzungsberichte* of the society and also issued as a separate ten-page brochure (Slide 18). Röntgen listed the most important results concerning the properties of the new rays: their rectilinear propagation, capacity to penetrate various substances, power of inducing fluorescence of barium platino-cyanide and other substances (such as glass, quartz and calcite), action on photographic plates, and lack of noticeable interference, polarization, refraction by prisms and focusing by lenses. He concluded that perhaps the new rays represented longitudinal waves in the ether (Slide 20).

The news about the discovery of new rays spread immediately all over the world. Experiments were performed everywhere (Slides 21-24). The harmful effects of the X rays were not yet known and no safety measures existed. In a few weeks after the announcement of the discovery one could purchase complete equipment for the exciting studies (Slide 25).

It is important to know that the discovery of radioactivity was an accidental consequence of the discovery of X-rays (Slides 26-31). Henri Becquerel wanted to check the hypothesis of Henri Poincaré that emission of X rays may be connected with phosphorescence. By accident he picked up uranium-sulphide out of his rich collection of minerals. His first experiments seemed to confirm Poincaré's hypothesis, but after a few days it became obvious that uranium compounds emit invisible penetrating radiation by themselves. In the following weeks Becquerel presented numerous results of his experiments with „uranium rays". Unfortunately he made use of the unreliable method of visual inspection of photographic plates. Thus, some of his conclusions were erroneous (Slide 32), and led to the opinion that uranium rays represented a new sort of light (Slides 35-37). Becquerel himself decided to leave the field of radioactivity which seemed to be an „uninteresting" problem, and for two years, until March 1899, studied only the new phenomenon discovered in 1896 by Zeeman, that intense magnetic field produced changes in the structure of the spectral lines of a gas when subjected to its influence (Zeeman's effect). At that time there were also many unsubstantial claims of new rays (Slide 33) which added to the confusion.

There was little progress in the field of radioactivity and still in the spring of 1898 the uranium rays were considered to be short ether waves (Slides 38-39).

The breakthrough was due to Maria Skłodowska, born in Warsaw, who went to Paris to study physics and chemistry at the Sorbonne (Slide 40). There she met Pierre Curie, married him and decided to study „uninteresting" field of uranium rays (Slide 41). In her brilliant experiments she made use of the precise electric method of measurements (Slide 44), and discovered radioactivity of thorium and also that uranium oxide and chalcolite (phosphate of copper and uranium) are much more active that uranium itself. Maria Skłodowska-Curie boldly suggested that these two uranium compounds must contain new radioactive elements (Slides 42-49). Pierre Curie joined her and after a few months they discovered polonium and radium (Slides 50-57) in spite of scepticism expressed by several physicists (Slides 54-56). The new element polonium was named after the country of origin of Maria Skłodowska-Curie (Slide 52). It is amusing to note that the editors of „Nature" got it all wrong and wrote that the name polonium was coined after the country in which the pitchblende was found (Slide 53).

Maria Skłodowska-Curie published the first review paper of the new field of physics (Slide 58). Slide 60 shows a time table of events in the period 1896-1899. The field of radioactivity became fascinating (Slide 62) and attracted many scholars (Slides 50 and 63-68).

Slides 69-86 present the events which led to the discovery of the electron. It had been quite complicated story which unfortunately is often incorrectly presented in textbooks (Slides 70-72). The English physicist Joseph John Thomson, professor of experimental physics in the Cavendish Laboratory in Cambridge, played the central rôle in investigations of the electricity flow through rarefied gases. In October 1897 he presented the results of his extensive studies of cathode rays (Slides 73-75). German physicists Walther Kaufmann and Emil Wiechert also performed measurements of the mass-to-charge ratio, *e/m*, of the cathode rays (Slide 60). Thomson, however, tried to find a connection of the cathode rays corpuscles with the problem of the structure of atoms (Slides 77-80). Several physicists expressed scepticism as to the conclusions of the cathode rays studies (Slide 76) but gradually the corpuscular theory of matter became accepted by most scholars. The vortex theory of matter (Slides 81-83) popular at the end of the XIXth century had been rejected. Thomson had been always talking about „corpuscles" and he never used the term „electron" (Slides 84-85). He became to be seen as the „discoverer" of the electron only after the World War II (Slide 86).

Slides 87-106 present the state of physics in the year 1900. The number of active physicists of that time, estimated in three different ways, was about 1100. Thus the world of physics was quite small, and most physicists were acquainted with each other. It was possible to organize the First International Congress of Physicists which took place in Paris in August 1900. It assembled more than 800 participants from 18 countries. The sessions of the Congress have been divided into seven sections: 1. General problems and metrology; 2. Mechanics and molecular physics; 3. Optics and thermodynamics; 4. Electricity and magnetism; 5. Magnetooptics, cathode rays, uranium rays etc.; 6. Cosmic physics; 7. Biological physics. The first four dealt with classical physics, the fifth - with new developments which did not belong to classical physics, and the last two sections concerned peripheral subjects, which would evolve into astrophysics, geophysics and biophysics in the years to come. Many lectures were given by the best known physicists of that time. The texts of the reports were published in three thick volumes in 1900. They constitute the most complete representation of any science at a given epoch yet made. According to all observers the First International Congress of Physics had been a brilliant success. The participants left Paris convinced of the great success and power of physics, which was found capable to explain so many complicated phenomena of the physical world. The Paris Congress was, however, the last of its kind because rapid growth of physics made it impossible to organize the second congress in which all of physics could be represented.

The origin and reception of quantum theory is illustrated in Slides 108-125. In the beginning the physicists struggled with the problem of the black body radiation. The theoretical concept originated with Gustav Kirchhoff who introduced the notion of a black body, which completely absorbs radiation of all wavelengths falling upon it, so that $a(\lambda, T) = 1$. Kirchhoff discovered the law that the ratio of the emissive power $e(\lambda, T)$, and absorptivity $a(\lambda, T)$, is a certain universal function $f(\lambda, T)$ of the wavelength and the temperature of the body.(Slides 109-110). The experiments made use of the black body model (Slide 111). There were numerous attempts to find the mathematical formula which would describe the experimental results (Slides 108, 112-113, 114). The breakthrough came in October, 1900, when Max Planck found that a small numerical change in the Wien's formula led to very good representation of the measurements by Kurlbaum and Rubens. He presented his phenomenological formula for black body radiation intensity on October 19, 1900, at a meeting of the German Physical Society in Berlin. He spoke in a discussion after the talk of Kurlbaum, who presented the results of measurements. Planck's lecture had a little ambitious title: *On an improvement of Wien's spectral formula* (Slides 116-118). He spent the next weeks trying to find a physical explanation of his formula. Planck finally concluded that emission and absorption of light is not a continuous process but occurs in portions equal h*ν*. He announced that conclusion on December 14, 1900. That day is regarded to be the beginning of the quantum physics (Slides 122-124). The acceptance of quantum theory was quite slow (Slide 125). We shall see in the following (Slides 150-152) that Planck himself regarded his solution of the black body problem as only a mathematical trick.

Slides 126-130 illustrate the need of time perspective in analysing historical facts. Too short perspective may lead to a distorted picture of events.

A short CV of Albert Einstein, who was one of the greatest physicists in history, is presented in Slide 131. In the miraculous year 1905 he published four papers in the „Annalen der Physik" (Slide 132). These papers made revolution in physics.

The first paper *On a Heuristic Point of View Concerning the Production and Transformation of Light*, „Annalen der Physik" 17, 132-148 (1905) introduced quanta of energy. It is important to see the difference between the achievement of Planck who assumed that **emission and absorption of light is not continuous but takes place in finite portions**, called quanta, and the brilliant idea of Einstein who introduced **energy quanta which move through space undivided**.

Thus, remember, please, that **Planck introduced only quantization of emission and absorption processes,** whereas **the idea of energy quanta was due solely to Einstein.**

The contents of Einstein's paper in shortly explained in Slides 134-137. Einstein was worried that there existed a difference in theoretical treatment of gases and other ponderable bodies (which have their state completely determined by the positions and velocities of an indeed very large yet finite number of atoms and electrons), and the electromagnetic state of a volume of space (which is described by continuous spatial functions). He found a way to combine the two approaches (Slide 135). It allowed to provide explanation of the unusual properties of the photoelectric effect (Slides 138-142), namely that the energy of photoelectrons does not depend on the intensity of illumination but does depend on the colour of the incident light (Slide 143). That contradicted classical physics in which the energy of the electromagnetic wave depends on its amplitude. Thus, if this energy was directly transferred to the electrons, their velocity should be proportional to the intensity of light.

One can sometimes read in the textbooks that classical physics was therefore unable to provide an explanation for the photoelectric effect. It is not true (Slides 145-147). Classical physicists invented various mechanisms to explain the source of the energy of photoelectrons, e.g. the „trigger hypothesis" according to which the light incident on the cathode only „liberated" the electrons which already had considerable energies inside matter. In 1912 Owen Richardson derived classically, i.e. without the hypothesis of energy quanta, the equation which was formally identical to Einstein's equation. He considered the electrons inside metals as a particular „electron gas" which evaporated under the influence of light.

Experimental studies of the photoelectric effect were very difficult and gave conflicting results (Slide 144). In 1916 Robert Millikan verified Einstein's equation with great precision (Slide 153) but expressed opinion that the theory behind it can not be maintained (Slide 154). As already mentioned earlier, Planck himself did not believe in energy quanta (Slides 150-152). Even after the Nobel Prize in Physics was awarded to Einstein (Slide 155), some influential scholars maintained that the quantum theory can not be regarded as an expression of physical reality (Slide 156).

The second paper of Einstein dealt with the Brownian motions. The same problem was attacked independently by the Polish physicist Marian Smoluchowski. The formula derived by Einstein and Smoluchowski in two different ways was soon verified experimentally by the French experimentalist Jean Perrin (Slides 157-159). Unfortunately Smoluchowski contracted dysentery and died in 1917. His premature death brought sadness to world physics community (Slide 160).

The third paper of Einstein *On the electrodynamics of moving bodies*, published in „Annalen der Physik" **17**, 891-921 (1905) introduced his theory of special relativity (Slides 161-167). Einstein's motivation is presented in Slides 163-166, and also in Slides 168-169 where the fragment from his autobiography is given. Einstein built his theory on two postulates (Slide 170) which led to unusual consequences (Slides 171-172). In particular, the simultaneity of events was proven to be relative. It can be illustrated with a simple animation (Slides 173-178). It is worth remembering that because of the relativity principle the effects of special relativity theory are reciprocal, as stressed in Slides 183-185. The effects of time dilation and length contraction are proportional to the square of the ratio of velocity of the object to the velocity of light in the vacuum [$(v/c)^2$]; this ratio is very small, of the order of 0,00000001 for the „Apollo" ships travelling to the Moon and back (Slides 186-189).

In the fourth paper published in 1905 Einstein derived the famous relation $E = mc^2$ (Slides 191-192). It had been since checked experimentally with very high precision (Slide 192).

In Slides 193-224 we have a summary of the work of other physicists who tried to build a new theory and explain the negative result of the Michelson-Morley experiment of 1887. Unfortunately, some influential people who did not understand physics, published claims that Einstein's work was just a repetition of the results of others (Slide 194 and197). It is easy to show that this is nonsense.

Lorentz and Fitzgerald independently of each other postulated that in motion through the elastic immobile ether the dimension of a body in the direction of motion is contracted. Contraction was regarded as real and resulting from the properties of molecular forces (Slide 195). Similar approach was due to Joseph Larmor, while Voigt attempted another transformation (Slides 196 and 198). Einstein's papers appeared in the period during which so-called electromagnetic theory of matter enjoyed popularity (Slides 200-201). It predicted, among other things, that the mass of the electron, being wholly of electromagnetic nature, depends on the velocity of its motion. The first measurements performed by Kaufmann seem to confirm that prediction (Slides 202-203). The propagators of the electromagnetic theory of matter considered various models of the electron (Slide 204) which gave slightly different predictions for the change of the electron's mass with its velocity (Slides 205 and 206). Einstein's special relativity theory also predicted changes of the electron's mass with its velocity. His formula was formally identical to that derived by Lorentz although his derivation followed from completely different assumptions: the two postulates of the theory of relativity, and not the arbitrary considerations of the shape of the electron (Slide 205). The German mathematician Hermann Minkowski was one of the first who understood Einstein's novel approach and he commented with irony on the efforts of Abraham, Lorentz and others (Slide 207). Nevertheless, for several years the physicists were nor able to decide between rival theories, and only the precise measurements performed by Guye and Lavanchy in 1915 decided in favour of Einstein (Slides 208-213).

Hendrik Lorentz built his theory of the deformable electron by using eleven arbitrary assumptions (Slide 215) some of which were quite uncertain. In contrast. Einstein used only the two postulates of special relativity and was able to derive transformation equations for the coordinates, time and fields. These transformations are now known as Lorentz transformations, because he derived them first, albeit under completely arbitrary assumptions (Slide 217). Lorentz himself admitted that the theory of relativity was really solely Einstein's work (Slide 218).

The French mathematician and theorist Henri Poincaré had always assumed the existence of the ether and he believed in the deformable and compressible electron. He could not understand that time dilation and length contraction follow from the two postulates of Einstein, and not from hypothetical behaviour of the electron moving through the ether (Slides 220-224).