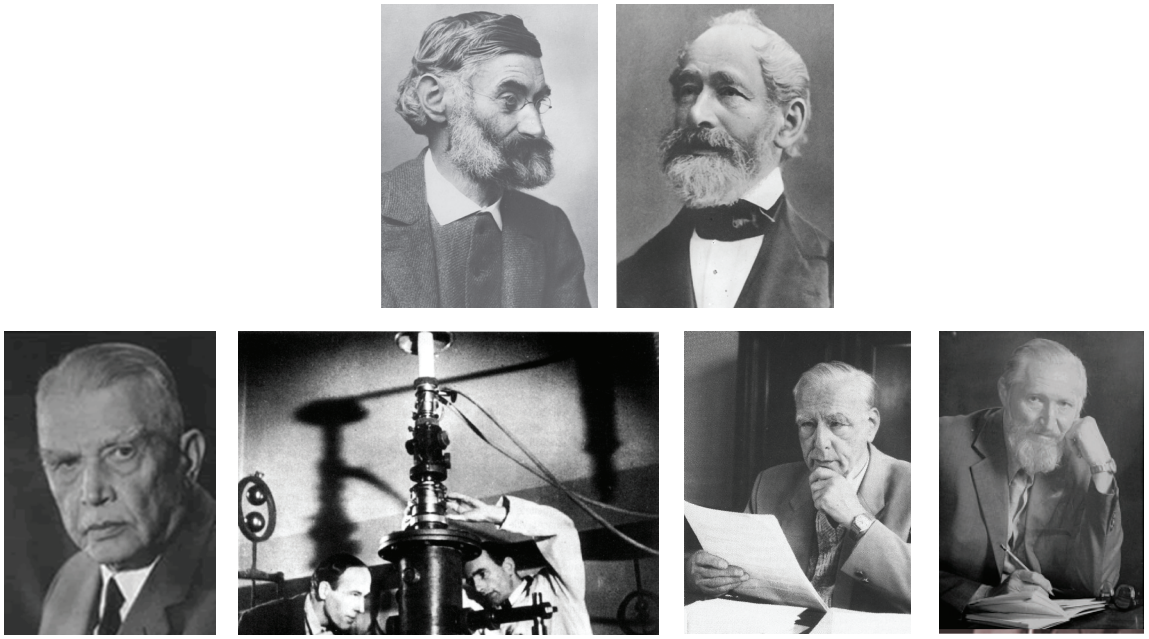

Important German contributors to electron microscopy (from left to right): Ernst Abbe and Carl Zeiss, who worked and lived in Jena and founded the Carl Zeiss factory; Hans Busch, Professor at Darmstadt University, discovered the lens property of electromagnetic coils; Ernst Ruska and Max Knoll, inventors of the electron microscope at experiment; Ernst Ruska with his Nobel lecture; Otto Scherzer, Professor at Darmstadt University, as emeritus.

History of resolution enhancement in electron microscopy driven by Ernst Abbe

A short reminiscence to the important statement of Ernst Abbe in 1876

134 years ago, in 1876, Ernst Abbe, the brilliant German mathematician, physicist, inventor of the diffraction theory of light and partner of Carl Zeiss made the visionary philosophical quote:

"...Nach Allem, was im Gesichtskreis unserer heutigen Wissenschaft liegt, ist der Tragweite unseres Sehorgans durch die Natur des Lichtes selbst eine Grenze gesetzt, die mit dem Rüstzeug unserer dermaligen Naturkenntnis nicht zu überschreiten ist. ... Es bleibt natürlich der Trost, dass zwischen Himmel und Erde noch so Manches ist, von dem sich unser Unverstand nichts träumen lässt. Vielleicht, dass es in der Zukunft dem menschlichen Geist gelingt, sich noch Prozesse und Kräfte dienstbar zu machen, welche auf ganz anderen Wegen die Schranken überschreiten lassen, welche uns jetzt als unübersteigbar erscheinen müssen. .. Nur glaube ich, dass diejenigen Werkzeuge, welche dereinst vielleicht unsere Sinne in der Erforschung der letzten Elemente der Körperwelt wirksamer als die heutigen Mikroskope unterstützen, mit diesem kaum etwas anderes als den Namen gemeinsam haben werden. ... ".

Here we will shortly sketch the main ideas of Ernst Abbe's important vision: (1) According to our present (19th-century's) knowledge, our understanding of the microscopic world is limited by the nature of light, which we cannot surpass with known tools. (2) However, there is hope that there exist other means between earth and heaven, which are yet unknown. (3) To attain sub-light resolution, a new type of instrument might be developed, which may not have much in common with present microscopes apart from the name.

The Apochromates introduced by Abbe in 1879 [B] represent a significant advancement that compensate besides spherical aberration also for the chromatic aberrations over the entire wavelength range of visible light very. With the help of an Apochromat Abbe succeeded already more than a hundred years ago, to reach the theoretical resolution limit of the light microscope by slightly less than the wavelength of light also for polychromatic light (eg sunlight).

In 1928, Professor Hans Busch (Darmstadt University) showed that electron rays can be focused by magnetic solenoids. Soon after this discovery, Ernst Ruska and Max Knoll (TU Berlin) perceived that the vision of Ernst Abbe could be realized by substituting electrons for light. Already their first electron microscope surpassed the resolution of the best light microscopes. Their microscope operated at an accelerating voltage of about 70kV (!) and was predominately used for the analysis of small bacteria and viruses. Owing to the poor performance of the electron microscope at that early state, they could not aim for atomic resolution of these objects.

[1] *Kahl, F.: Design eines Monochromators für Elektronenquellen. Dissertation, Referent Prof. Dr. rer. Nat H. Rose., TU-Darmstadt (1999).*

In 1936, Scherzer proved that aberrations of round lenses are unavoidable by showing that the coefficients of chromatic and spherical aberrations are always positive. In order to obtain atomic resolution, this limitation had to be overcome. After great efforts of Otto Scherzer himself, the final successful design of an aberration corrector was achieved by Professor Harald Rose (Darmstadt University, a former PhD student of Otto Scherzer, now Carl Zeiss senior professor at Ulm University). The practical realization of this aberration corrector was performed by Max Haider (director of CEOS GmbH, a former PhD student of Harald Rose). Of course, we are not able to judge whether the spirit of Ernst Abbe affected the development of electron microscopy, or the other exciting developments in mi-croscopy such as X-ray microscopy, scanning tunnel microscopy or near field microscopy. However, in accordance with Einstein (born in Ulm and the son of our city) we know: "Imagination is more import than knowledge. Knowledge is limited, imagination encircles the world."

The aims of the SALVE (Sub-Angström Low-Voltage Electron microscopy) I-II project (Ulm University partners are Carl Zeiss NTS and CEOS GmbH) continue the vision of Ernst Abbe and the first electron microscopists, as low voltages and beam-sensitive (also carbon-rich) objects are targeted again, a human lifetime later, yet with 10^4 times higher resolution. The realization of this ambitious goal is not an easy task. The outcome is open because we know in analogy to the quote of Carl Friedrich von Weizsäcker (German physicist and philosopher) that we can learn about nature only through the experiment, the experiment however influences the nature.[2]

[2] *Carl Friedrich von Weizsäcker: „Wir können vom Atom nicht anders etwas erfahren als durch das Experiment; das Experiment ist aber eben eine Vergewaltigung der Natur. "*