DOI: 10.1002/anie.201409939

Chemistry: Interdisciplinary and International—and with a Sense of History

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"Only Someone who Knows the Past has a Future"

Wilhelm von Humboldt expressed this aphorism on one of his educational trips to Paris 225 years ago. Chemistry endeavors to follow this thought—both as a science and as an industry. Commemorating numerous anniversaries last year, this year, and next year gives us an opportunity to review the past and look ahead to the future. Next year, our science is celebrating 150 years of Kekulé's theory of the benzene structure, and this year the 150th anniversary of the birth of Nobel Laureate Walther Nernst. In addition, in 2013 and 2015, Bayer and BASF each celebrate 150 years of their company history. And 2013 marked the 125th anniversary of *Angewandte Chemie,* which included an international symposium in Berlin, of which our Gesellschaft Deutscher Chemiker (GDCh; German Chemical Society) is especially proud. The UNESCO International Year of Crystallography (2014) and the UNESCO International Year of Light (2015) serve as an occasion to promote interdisciplinary dialogue.

Collaboration through chemistry—chemical and molecular biology are important fields in which biologists and chemists are collaborating today. In material sciences, chemists are collaborating with physicists and engineers—on account of the advances in nanotechnology, among other things. However, this reduces the visibility of chemistry as a natural science, although many modern materials and drugs were developed by the chemical and pharmaceutical industry.

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NMR spectroscopy and X-ray structural analysis have revolutionized chemistry

Let's take a look back over a few decades: How has chemistry changed through the widespread introduction of certain physical methods? NMR spectroscopy and X-ray crystallography have revolutionized the structural analysis of complex molecules, and have thus played a key role in further developing chemistry. What newer physical methods could similarly influence chemistry in the future?

Chemistry at the Uncertainty Limit

15 years ago, in his Essay entitled "Chemistry at the Uncertainty Limit" Nobel Laureate Ahmed Zewail presented observation concepts on the atomic-scale dynamics in chemical processes. He applied ultrafast electron microscopy on the femtosecond timescale.[1] In the meantime, attosecond physics was further developed by the work of Otto Hahn Prizewinner Ferenc Krausz of the Max Planck Institute for Quantum Optics in Garching, near Munich. Ultrashort laser pulses with a time resolution of up to 50 attoseconds are used to visualize interatomic motion of electrons and thus follow molecular processes in which the borders between chemistry, physics, and biology disappear.[2]

In current work investigating photosynthesis, Petra Fromme of Arizona State University refers to the first "molecular movie". By means of time-resolved crystallography using femtosecond X-ray lasers, together with more than 50 co-authors, she studied water splitting in the photosystem II complex.[3] This is an impressive example of interdisciplinary collaboration between X-ray laser centers in the United States (SLAC Stanford) and Germany (DESY Hamburg) and biophysical chemistry institutes. This basic research is supported by the NSF, NIH, DFG, and MPG.

Chemistry, catalyst for energy research!

A better understanding of basic life processes on Earth, such as photosynthesis, is an important prerequisite for projects of applied energy research, such as the development of "artificial leaves" or innovative solar cells. Chemistry must take on a key role here! Would the topic of energy research not acquire similar international importance, against the backdrop of the global energy discussion, as the topics of particle physics, structure of the universe, genome analysis, or aerospace? And then where would be the counterpart to Geneva, Paranal, Cambridge, or Houston as the "Mecca of energy research"?

Nanoscopy

The progress made in femtochemistry and attosecond laser spectroscopy have not only advanced time resolution into new dimensions. Space resolution by means of innovative imaging techniques has also taken us into a new age of microscopy, as described by Nobel Laureate Steven Chu with "Microscopy 2.0". The resolution of fluorescence microscopy methods such as confocal laser scanning microscopy used to be limited to approximately 200 nm. The 2014 Nobel Laureate Stefan Hell of the Max Planck Institute for Biophysical Chemistry in Göttingen has lowered this limit to 20 nm by means of STED microscopy and thus achieved a breakthrough in imaging techniques as far as single-molecule fluorescence in living cells.[4]

Thus optical methods can achieve resolutions that were formerly limited to electron microscopy. Yet resolution has been improved in electron microscopy, too, by the introduction of cryoelectron microscopy into the sub-nanometer range. This makes it an important supplement to X-ray structural analysis of complex biomolecules, enabling resolutions of less than 5 Ångström.

Finally, another new technique based on nitrogen vacancy (NV) centers in diamond could revolutionize both the resolution and applications. Jörg Wrachtrup of the University of Stuttgart developed methods for detecting NV centers in diamond nanoparticles, for example, delivered into cells as sensors. These methods could improve the spatial resolution of fluorescence microscopy even further.[5]

The Outlook for Chemistry—with a Sense of History

If we use the advances of the above-mentioned methods in spatial and temporal resolution for a better understanding and elucidation of complex molecular structures—can this lead to similar advances for chemistry as those we have achieved in recent decades through the widespread use of NMR spectroscopy and X-ray structural analysis? These methods are hardly likely to experience a similarly widespread use as NMR spectroscopy and X-ray structural analysis, yet the latter also first began as exotic physical methods that a laboratory could hardly afford.

The history of chemistry is also an important discipline

Are we slowly approaching the limit of uncertainty with attosecond and picometer resolution? Are the observed physical, chemical, and biological processes still in agreement with Heisenberg's Uncertainty Principle? Or does our imagination of space and time become blurred, as already described by Thomas Aquinas in his *Summa Theologiae* 750 years ago? "An angel can be in one place at a certain moment and already in another place at the next moment, without having existed at any particular time in between".

And so the circle closes: no outlook without a solid foundation. As Kekulé stated 125 years ago in his famous "Benzolfest" speech: "We all stand on the shoulders of our predecessors. Is it then surprising that we can see further than they?"

We should not only honor the history of chemistry by commemorating anniversaries, but also acknowledge it as one of our disciplines that should be maintained at universities, although this is forgotten at many institutions, particularly in Germany. According to Wilhelm von Humboldt, it is only knowledge of the history of chemistry that gives us the best prerequisites for shaping the future of chemistry—from a stronger interdisciplinary and international perspective.

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