Translated from the german text by Josef Zens

„From now on you are sour"
Looking at reacting acids

Scientists of the Max Born Institut für Nichtlineare Optik und Kurzzeitspektroskopie (Max Born Institute for Nonlinear Optics and Short Pulse Spectroscopy; MBI) succeeded – in a cooperation with a research group of the Ben Gurion University of the Negev in Israel –, to shed light on the ultrafast exchange of protons in chemical reactions. Protons are elementary particles, with which atomic nuclei are built. For their study the MBI-researchers used a so-called photoacid-derivative of pyrene, to react with acetate. The study provides fundamental insight in processes, that occur e.g. in biological cells. In addition, the study refines the standard model of proton transfer in an important fashion. The researchers report on this the distinguished US-scientific journal Science (volume 301, pages 349-352).

Photoacids have the special property that they can exist in two states. Under normal circumstances they are only weakly acidic, and because of that not very reactive. Only after exposure by light pulses, the acidity is changed instantly – and the acid wants to react vehemently. "One shoots with an ultraviolet laser beam in the liquid", explains group leader Dr. Erik T. J. Nibbering, "and gives the signal: From now on you are acidic!" This effect is important, because with this trick one can define accurately the start of the reaction in time.

After excitation with the UV-light the experts at the MBI probe the liquid with another laser pulse. This laser pulse is tuned in the infrared spectral region. "We use the sensitivity of molecular vibrations towards exposure to infrared light", says Nibbering. From this new information could be gathered. In particular with this pump-probe experiment the research group was able to determine when a proton leaves the acid, and when it arrives at the base.

„That does not have to be the same proton", reports Nibbering. One could envisage a situation of protons transmitted between the solvent water molecules, similar to that of the ball game, that often can be found on office desks. Here five or six balls hang side-by-side, in close contact to each other. If one now pulls a ball on one end, letting it fall back on the others, the momentum is transmitted through the line of balls, and on the other end the last ball jumps away. The researchers measured proton transfer in 100 femtosecond tact. "This is extremely fast" says Ph.D. student Matteo Rini. "For comparison: if one turns a laser beam on for the duration of a second, the laser beam has already reached the moon. After 100 femtoseconds a laser beam has travelled for a distance that corresponds with the thickness of a human hair."

The chemical reactions and the measurements take place on a small space and in extremely short time. In their study the researchers pumped the acid-base-water mixture through a small slit. A miniature waterfall with a width of 5 millimeter resulted. The "liquid curtain" is only 100 micrometers thick, about two times the width of a human hair. Through this "curtain" the researchers directed the UV-light beam: the acids were switched on and started to react. The measurements with the infrared laser source took place at the same time, to determine how the protons wander from acid to base. This process has been explained theoretically by the german Nobel prize laureate Manfred Eigen many decades ago. Eigens work resulted in the so-called Eigen-Weller model for proton transfer.

This model has to be refined. When acid and base are already in direct contact, the proton transfer occurs rapidly. When however photoacid and base first have to move to each other, the proton flow is delayed, the contact between acid and base appears to occur at later times than explained by Eigen and Weller. Why is that? “We don’t know yet”, says Nibbering. He speculates that perhaps first water molecules between acid and base have to move away. “Or the protons hop between water molecules to the base”. In any case an additional intermediate stage has to be integrated in the Eigen-Weller model.

That model, that predicted reaction rates in picosecond time range, could not be proven experimentally at the time the model was postulated. Manfred Eigen talked about “immeasurably fast reactions”. In those days (1960s) lasers already existed, even ones operating in nanosecond time range. A nanosecond is a billionth times smaller than a second. One could not imagine to reach the time range of picoseconds (thousand times smaller than nano) or even femtoseconds (another thousand times smaller). Nowadays scientists speak of attoseconds – also at the MBI in Berlin. An attosecond is a billion times smaller than a billionth part of a second (10^{-18}, or 0, 000 000 000 000 000 001 seconds).

And what has now been achieved, when one can watch at protons wandering around? “This is fundamental research”, says Nibbering. “But it enables us to achieve a better understanding of proton conductivity in water, so also a better understanding of processes, that occur in biomembranes”. Perhaps one could construct a molecular switch, on the basis of a photoacid, speculates the physicist. In any case these efforts show: What once was thought to be impossible in physics, may not remain impossible for all times.

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The Max Born Institute (MBI) for Nonlinear Optics and Short Pulse Spectroscopy was founded in 1992. It belongs to the "Forschungsverbund Berlin e.V." and is a member of the "Wissenschaftsgemeinschaft Gottfried Wilhelm Leibniz (WGL)" - short: "Leibniz assoziation". The MBI has about 180 members of staff of which 90 are scientists (including PhD students).

The MBI conducts basic research in the field of nonlinear optics and ultra fast dynamics of the interaction of light with matter and pursues applications wich emerge from this research. For these investigations it uses laser based short pulse light sources in a broad spectral range from the mid-infrared through the visible down to the x-ray wavelength region.

With its research the MBI fullfills a nationwide mission and is an integral part of the the international science community. It offers its facilities and its scientific know-how also to external researchers within the framework of an active guest programme through the European Union funded Large Scale Laser Facility. The MBI is involved in a large number and variety of cooperative reserach projects with universities, other research institutions and industrial partners.

The Forschungsverbund Berlin e.V (FVB) represents eight Berlin research institutes active in the fields of the natural sciences, the life sciences and the environmental sciences. The institutes pursue common interests within the framework of a single legal identity while preserving their scientific autonomy. As research institutes of national scientific importance, they are jointly funded by the German federal and state governments in accordance with Article 91b of the German Constitution.