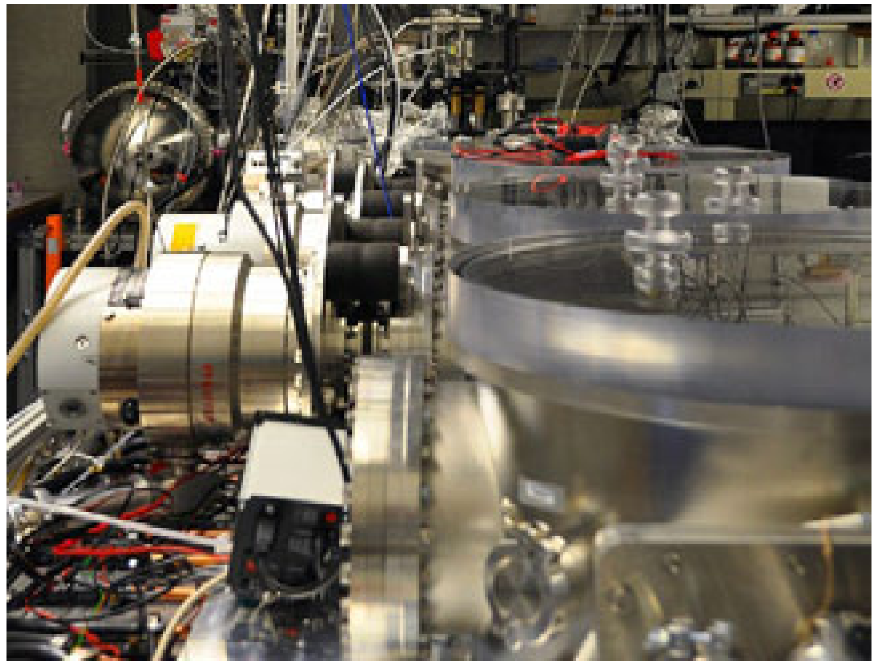

The attoline (centre) enables ultrafast processes such as electron transfer in molecules to be studied at a higher temporal resolution.

At the boundaries of the measurable

Felix Würsten

With her ultrafast lasers, Ursula Keller studies inconceivably short processes that can only be explained with the ideas of quantum mechanics. These elusive phenomena have a big impact on our everyday lives. For without them there would be no photosynthesis, no breathing and no eyesight.

Whether at her coffee machine in the morning, on her way to work in the car or at her computer in the office – Ursula Keller keeps seeing items in her daily life that were produced with the aid of laser processing. Nowadays, these powerful light sources are used in many places to shape surfaces or cut materials to the right size, and Keller has had a major hand in this. As a professor of experimental physics over 20 years ago, she developed SESAM technology that enables laser light to be focused into ultra-short pulses. And it is these same, short, high-energy pulses that make it possible to process materials in a gentle, precise way.

In recent years, Keller's group has managed to generate such laser pulses in ever new colours and with increasing efficiency.

Despite the enormous progress, however, there is no end to the work in sight: "Whatever improvements we make, the users keep wanting new things" says Keller, laughing, indicating that she accepts this challenge gladly.

Rapid electron transfer

The further development of the lasers, however, is only part of Ursula Keller's work. For her group also uses these ingenious devices to study ultrafast processes. With the futuristic-looking attoclock and the equally impressive attoline, the physicist and her team can now study fundamental physical processes that take place in the space of a few attoseconds, thus lasting no more than a few billionths of a billionth of a second. "With our devices, we are moving into a completely new area of metrology", explains the scientist with visible pride.

For example, she also uses this complex equipment to study the tunnel effect, a quantum-mechanical phenomenon that is virtually impossible to investigate experimentally because it takes place at an inconceivable speed. In concrete terms, it concerns how quickly an electron excited with light can be transported away from an atom. According to the laws of classical physics, an electron only breaks away from its atomic nucleus if it exceeds a certain energy potential. Not in the world of quantum mechanics, where the electron can simply cross the "potential mountain", which prevents it from drifting away, through a "tunnel".

The question now is: how quickly does the electron cut through this tunnel? Theorists are at odds with each other on this, and their predictions lie somewhere between zero and 500 attoseconds. Ursula Keller has now succeeded in demonstrating that it takes the electron 50 to 100 attoseconds to pass through the tunnel. "Our data provides key evidence as to which models might be right", she explains. "That our measurements are important is also apparent in the fact that we have frequently disproved predictions that theorists have made".

Important for everyday life

It is by no means only theorists who have an interest in clarifying these questions. After all, the tunnel effect plays a key role in many everyday chemical reactions. During photosynthesis, for instance, sunlight is captured when an electron is excited by light in a specialised molecule. If the electron were then to remain in the same spot, this energy would immediately be lost again. Consequently, the electron has to be transported to another place as quickly as possible so that it can trigger a chemical reaction there. "To this day, artificial photosynthesis remains an ideal that's beyond our grasp", says Keller. "One major reason for this is that we don't yet understand this electron transfer sufficiently".

Physics is not enough by itself

There are also similar rapid phenomena in other biological processes, such as when oxygen binds to red blood cells or the incident light in the retina is converted into an electrical impulse.

"We have come on in leaps and bounds in optoelectronics in recent years", says Keller, summing up the current situation. "Nowadays, we construct semiconductors on the drawing board on an atomic scale and can describe the electron transfer in the crystal lattice with a simple model, which enables us to build slender, efficient mobile phones. Comparatively speaking, we are still in the early stages in biology".

So the crucial question is this: how can the behaviour of biologically active molecules be displayed in a model as easily as possible? "If we manage to do that, we can get creative and synthesise molecules selectively", says Keller optimistically.

This goal cannot be achieved with physics alone, for her that much is clear. "We need physicists, chemists, engineers and biologists, all working closely with one another", she explains. She finds precisely this interdisciplinary collaboration in the National Centre of Competence in Research, "Molecular Ultrafast Science and Technology", which she co-runs as director.

"We are setting up a versatile community in Switzerland that focuses on ultrafast processes on an atomic and molecular level".

Ursula Keller would also like to facilitate the collaboration between the departments within ETH Zurich. With the Fast Initiative – abbreviated from Femtosecond and Attosecond Science and Technology – she wants to bring together as many scientists as possible who study rapid processes with powerful lasers. "If we could unite these people under one roof, it would give our research an enormous boost". ■

Ultrafast Laser Physics:
www.ulp.ethz.ch →

National Center of Competence in Research MUST:
www.nccr-must.ch →

12,42 m/s

Usain Bolt's top speed when he broke the 100-metre world record.