The Time Slicer

With the attosecond, physicist Ferenc Krausz has opened a new chapter in the history of time units.

Written by: **Andreas Feiertag**
Photos: **Heribert Corn**

How long does the present last? Nobody knows precisely, although the answer is getting closer every year. In theoretical physics it is believed that at some point time becomes discontinuous. As material is made of atoms, so seconds should be composed of a row of discrete pieces of time, which quantum physicists are slicing ever thinner.

Compared with the units of time the physicists are working with, the blink of an eye lasts nearly an eternity. Only after dividing a blink's duration into a million parts, and dividing one of those parts into a further 100 million pieces, has one reached the length of time that scientists are now capable of differentiating. This is the atto-world of snippets of seconds, with measurements between 16 and 18 places after the decimal point, with each attosecond in roughly the same relation to a full second as a minute is to the age of the universe.

The first researcher to reach into the atto-world with ultra-short pulses of laser light is physicist Ferenc Krausz. Nobody has come closer to the present than Krausz, who is director of the Max Planck Institute for Quantum Optics in Garching, Germany. Pulses from his laser devices serve as flash bulbs for pictures of the microscopic world. His groundbreaking work was recently published in the leading scientific magazine *Nature* (Vol. 419, p. 803).

Infineon: Your work is clearly complicated. How do you explain it to your two daughters?

Krausz: In my family there is no inherent aversion to my field, at least among my children. It is very interesting to see how, for example, my older daughter, who is now in fourth grade, relates to physics. Even before she had ever held a physics textbook in her hands and looked through one, she knew physics is not for her. I can best explain my work by saying I work with lasers. Naturally, she can imagine something that fits with that, since nowadays everyone has had some contact with lasers. And if I say that I work with very special lasers that shoot out extremely short bursts of light, she'll go that far as well.

What is the actual use of working with increasingly finer units of time?

The ultra-fast spectroscopy that we are working with can be seen as an extension of ultra-fast photography. Just as you would need a camera with a very fast shutter speed to take a sharp picture of a Formula 1 racing car speeding past, you need a femtosecond laser pulse to capture the movements of atoms within molecules.

Our goal is to trace the movements of microscopic particles, to reconstruct them and thus to gain insight into their properties and their behavior.

With the shortest laser pulses it is already possible to hold the movements of atoms within molecules still for snapshots and to reconstruct them in slow motion. With this technique we can learn, for example, just how chemical reactions take place. A chemical reaction is the breaking of a bond and the establishment of a new bond. This process takes place as a result of atomic motion within a molecule. And it's pretty darn fast.

Doesn't that reduce your work to being a sort of lab assistant to chemistry?

Only as long as one has to be content with femtosecond laser pulses are the applications for these flashes of lights limited to being a substitute ultra-fast camera for molecular processes. But our work is to extend this technology from the molecular level to the atomic level. We want to use fast flashes of light to capture and reconstruct the movement of electrons inside of atoms. We want to see and understand the inner life of atoms, to see what all is going on in there. Thanks to the recent attainment of usable attosecond pulses, this is now possible.

What can come after that? Do you think that you can keep cutting time into ever-thinner slices?

I have to say that we have just jumped over the hurdle of a femtosecond and are only in the range of several hundred attoseconds. We are still a long way from the range of just a few attoseconds. But the techniques that we are now using could also be used to generate much shorter pulses of light. It is just a matter of time.

What comes after an attosecond?

Then we would reach so-called zeptoseconds. The femtosecond scale is the natural time scale for the movements of atoms within a molecule. The attosecond level is the time scale for the movements of electrons within an atom. And the zeptosecond scale is ultimately characteristic of processes within an atomic nucleus. Looking in there is tremendously exciting. The smaller the spatial dimensions that one wants to examine, the smaller the temporal dimensions become to be able to observe processes on these extremely small scales.

You are director of the Max Planck Institute for Quantum Optics. And if the name is destiny, part of your goal must be to approach the threshold of Planck time. The smallest constant of time yet used lasts 10^{-43} seconds. Time itself is thought to have begun a Planck time after the start of the Big Bang. Countless theories are based on this constant. If you were able to reach into this dimension and then come to the conclusion that you could go even further, wouldn't this discovery call a great deal of modern physics into question? Maybe even your own work?

I hope that we will not have to call everything into question. But it would probably open the opportunity to investigate new physical models. These models would be ones that attempt to unite two currently irreconcilable theories: the theories of the very large, like Einstein's theories of space and gravitation, and the theories of the very small, quantum physics. Many scientists are working very hard on bringing these theories together. But the most promising approaches have the unfortunate shortcoming that it is presently impossible to test them.

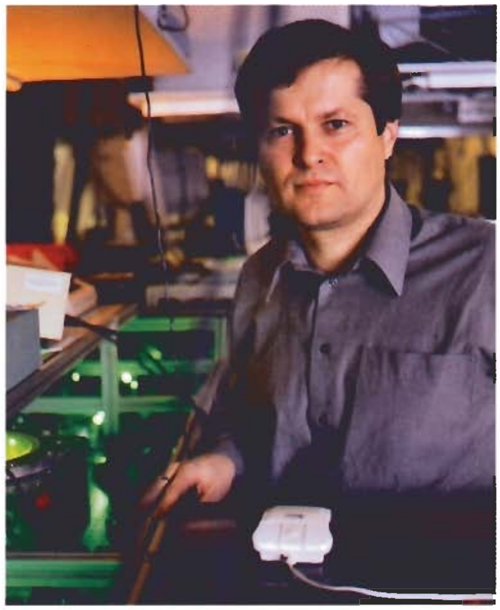
Returning to a relative eternity: You were the first to reach the attosecond scale. Do you really understand how fast things happen there, do you have an image of an attosecond?

It's difficult. The closest that I can really come to communicating the speed is maybe the following example. Light has such a high speed, known to be roughly 190,000 miles per second, that it could circle the earth ten times in less than one second. In a femtosecond, light only moves a micrometer, one thousandth of a millimeter. And in an attosecond, of course, it is much less.

Speaking of lasers, some people hope that your work will sooner or later enable the development of an X-ray laser. Do you share this hope, and if so, what would an X-ray laser be useful for?

I do share the hope, even if at the same time I have to say that there are no guarantees. If it should work, then there would be a great many applications. For example, there could be X-ray microscopes that would have a far higher resolution than an electron microscope, which would allow people to study molecules without destroying them in the process. In medicine, there >

At home with Krausz: His daughters have only a fleeting interest in Dad's doings in the lab.



Researcher Krausz: Is everything just a question of time?

would be an alternative to regular X-ray machines. Using an X-ray laser to look into the body would be much more precise and require a much lower dosage of radiation. However, it is not impossible that there are fundamental reasons why building a compact X-ray laser would fail, even though there have already been demonstrations at large research facilities.

Has any aspect of your research already been used for the common good?

Of course. One example is our cooperation with partners at the University of Vienna's Institute for Medicinal Physics. They are using our short-pulse laser for tomographic imaging of the human eye. They are able to make examinations in which a previously unattainable resolution makes it possible to see the structure of the eye all the way back to the connection with the brain. That helps the doctors diagnose diseases like green star and its causes in their very earliest stages. Another example is machining materials with maximal precision, now down to a scale of just a few nanometers. Working with materials at this length is currently only possible with femtosecond lasers. An equally fascinating area of application is dentistry. Because these short pulses operate with lightning speed for such a short time span, they can be used to remove material in a very different fashion from everyday lasers. The fundamental difference is that the exchange in the material happens so quickly that no time remains to transport the energy from the spot of illumination to another area. Before any heat can be radiated, the dental material is already removed, flying off and taking all of the energy with it. The surroundings stay cool. And if no heat reaches the oral nerves, it doesn't cause any pain. □

FERENC KRAUSZ' favorite free time activities are named *Anita* and *Martina*. The 41-year-old physicist travels to the countryside with his two daughters, one 14 the other 10, or takes them to the movies, theater and concerts. If he has any time left for himself, he is mainly interested in music and literature.

Until his appointment as director of the Max Planck Institute for Quantum Optics in Garching, Germany, Krausz was a scientist in Budapest and Vienna. He earned a degree in electrical engineering in Budapest in 1985, and a doctorate in quantum electronics at the Technical University of Vienna. Following a research position in the United States, he was a professor at the Technical University of Vienna's Institute for Phontonics.

Among his peers, Krausz is seen as very communicative and team-spirited, in contrast to the cliche of a theoretical physicist.

What inspires him to come to the lab every day? «Since childhood I have always been frightfully curious,» he says. Thus it seems only logical that he is more interested in advancing knowledge through basic research than in the possible applications of his results.

A LAB WITH A VIEW: Krausz, shown here in his laboratory, uses extremely brief flashes of light to capture movements on the atomic scale.

The Time Slicer

With the attosecond, physicist Ferenc Krausz has opened a new chapter in the history of time units.

Written by: **Andreas Feiertag**
Photos: **Heribert Corn**

How long does the present last? Nobody knows precisely, although the answer is getting closer every year. In theoretical physics it is believed that at some point time becomes discontinuous. As material is made of atoms, so seconds should be composed of a row of discrete pieces of time, which quantum physicists are slicing ever thinner.

Compared with the units of time the physicists are working with, the blink of an eye lasts nearly an eternity. Only after dividing a blink's duration into a million parts, and dividing one of those parts into a further 100 million pieces, has one reached the length of time that scientists are now capable of differentiating. This is the atto-world of snippets of seconds, with measurements between 16 and 18 places after the decimal point, with each attosecond in roughly the same relation to a full second as a minute is to the age of the universe.

The first researcher to reach into the atto-world with ultra-short pulses of laser light is physicist Ferenc Krausz. Nobody has come closer to the present than Krausz, who is director of the Max Planck Institute for Quantum Optics in Garching, Germany. Pulses from his laser devices serve as flash bulbs for pictures of the microscopic world. His groundbreaking work was recently published in the leading scientific magazine *Nature* (Vol. 419, p. 803).