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2023 NOBEL PRIZE IN PHYSICS: SEEING ELECTRONS THROUGH BRIEF PULSES OF LIGHT

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(L-R) Pierre Agostini posing in his apartment in Paris; Ferenc Krausz speaking during a presentation at the Max-Plank-Institute of Quantum Optics in Munich; and Anne L'Huillier talking to journalists at Lund University, Sweden. The trio has been awarded the 2023 physics Nobel Prize. | Photo Credit: AP

The 2023 Nobel Prize for Physics was shared by three scientists—Pierre Agostini, Ferenc Krausz and Anne L'Huillier—for their "experimental methods that generate attosecond pulses for the study of electron dynamics in matter."

The laureates have been awarded the Prize for experiments that have allowed scientists to produce ultra-short pulses of light, with which they can finally 'see' directly into the super-fast world of electrons.

"Attosecond physics gives us the opportunity to understand mechanisms that are governed by electrons," Eva Olsson, chair of the Nobel Committee for Physics, said in a statement.

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Electrons are the negatively charged particles of an atom. They zoom around the denser nucleus. Before being able to study them directly, scientists understood their properties through averages.

It's like taking a picture of a race car. The longer the aperture of the camera is open, the blurrier the picture gets. But if the exposure time is small, only a small amount of light reaches the camera's sensors, yielding a sharper image. The shorter the exposure time, the sharper the image.

Similarly, the rapid movement of electrons would seem to blur together in the eyes of a camera that couldn't lower its exposure time to the order of attoseconds.

The movement of an atom in a molecule can be studied with the very shortest pulses produced by a laser. These movements and changes in the atoms occur on the order of femtoseconds—a millionth of a billionth of a second. But electrons are lighter and interact faster, in the attosecond realm. An attosecond if a billionth of a billionth of a second.

All light consists of waves of electric and magnetic energy. Each wave has a sinusoidal shape—starting from a point, going up to a peak, dipping into a trough, and finally getting back to the same level as the starting point.

By the 1980s, physicists had found ways to produce light pulses whose duration was a few femtoseconds. The technology used to produce these pulses couldn't be refined any further, so physicists believed the femtosecond to be the hard lower limit Yet 'seeing' electrons required an even shorter flash of light.

In 1987, Anne L'Huillier and her colleagues at a French laboratory passed an infrared laser beam through a noble gas. The beam's interactions with atoms in the gas produced overtones: waves of light whose wavelength was an integer fraction of the beam. For example, if the beam had a wavelength of 100, the overtones would have wavelengths of 10, 25, 50, etc.

The team also noticed that many of the overtones were just as intense as the beam. Through the 1990s, she and her colleagues continued to explore this phenomenon, in the process laying an important theoretical foundation.

Physicists found that the overtones emitted were in the form of ultraviolet light. As multiple overtones were created in the gas, they began to interact with each other. When the peak of one overtone merges with the peak of another, they produce an overtone of greater intensity, through constructive interference. But when the peak of an overtone merges with the trough of another, they cancel each other out, in destructive interference.

By fine-tuning the setup used to produce the overtones, scientists realised that it should be possible to create intense pulses of light each a few attoseconds long (due to constructive interference), with destructive interference ensuring that they didn't last for longer.

In 2001, Pierre Agostini and his research group in France successfully produced and investigated a series of 250-attosecond light pulses, or a pulse train. By combining the pulse train with the original beam, the group was able to conduct some rapid experiments.

At the same time, Ferenc Krausz and his team in Austria developed a technique to separate an individual 650-attosecond pulse from a pulse train. Using that, the researchers were able to measure the energy of some electrons released by some krypton atoms.

Attosecond pulses allow scientists to capture 'images' of activities that happen in incredibly short time spans. As a result, scientists can use such pulses to explore short-lived atomic and molecular processes implicated in fields like materials science, electronics, and catalysis.

For medical diagnostics, attosecond pulses can be used to check for the presence of certain molecules based on their fleeting signatures. These pulses could also be used to develop faster electronic devices, and better telecommunications, imaging, and spectroscopy.

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