K-State's fast laser research and theory building on Einsten's work by timing electrons emissions

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Ultrafast laser research at Kansas State University has allowed physicists to build on Nobel Prize-winning work in photo-electronics by none other than Albert Einstein.

Einstein received the Nobel Prize in 1921 for his theoretical explanation in 1905 of the so-called photo-effect -- that is, the emission of electrons from a metal surface by incident light.

In Einstein's time, laboratory light sources provided light of very low intensity in comparison with modern lasers like those at K-State. Back then, experiments could measure the energy -- or speed -- of light-emitted electrons but could not resolve their motion in time. In modern laboratories, lasers are used as light sources that provide very short and intensive flashes of light.

Uwe Thumm, K-State professor of physics, and Chang-hua Zhang, a postdoctoral research associate in physics, are theorists who have developed a model that allows them to compute not just the energy of photo-emitted electrons, but also the times after their release at which they can be detected. Within their quantum mechanical model, Thumm and Zhang found that electrons that are emitted by ultra-short laser pulses from different parts of a metal surface will arrive at an electron detector at slightly different times.

"It's a feat that would be impossible without high-intensity lasers like those at K-State's J. R. Macdonald Laboratory," Thumm said. "With the help of ultrashort laser pulses, the motion of electrons can now be followed in time. This has started an entire new area of research, called attosecond physics."

An attosecond is a billionth of a billionth of a second. It's an incredibly short time to humans -- but not to electrons, Thumm said.

"Fifty attoseconds is about the time resolution needed to resolve the motion of electrons in matter," he said.

In agreement with a recent experiment, their calculation shows that electrons of a metal surface that are near atomic nuclei are photo-emitted with a delay of about 110 attoseconds relative to another type of electron. These conduction electrons are not attached to individual atoms and enable metals to conduct electricity.

Thumm and Zhang published their work in *Physical Review Letters* in March. Their research was supported by the National Science Foundation and the U.S. Department of Energy.

Thumm said that Einstein's research, which laid the groundwork for their own research, is often understood as a proof for light behaving as a particle called a photon rather than as a wave. Einstein showed that only light above a certain minimal frequency -- in the blue end of the visible spectrum -- could make metals emit electrons.

"It was a celebrated model, and it's still in textbooks as an explanation that light is made up of photons," Thumm said. "You can talk to a lot of physics students who get it wrong."

While Einstein's model is not wrong, it is not a proof for the particlecharacter of light, Thumm said. Einstein published his model about two decades before modern quantum theory was developed. Modern quantum theory of matter predicts the emission of an electron even when light is regarded as a classical electro-magnetic wave.

Today, physicists have lasers that provide light at such high intensities that electrons can be emitted at lower frequencies, toward the red end of the visible spectrum. And today, scientists look at light as behaving both like a particle and a wave.

"There is a bit of a philosophical debate," Thumm said.

Thumm said that the new and exciting part of this research is that short pulses from ultrafast lasers like the Kansas Light Source at K-State's J.R. Macdonald Lab allow physicists to measure the timing of electrons emitting from metals, thus building on models like the one he and Zhang developed.

Researchers can use short, intense pulses of extreme ultraviolet light to get a tungsten surface to emit electrons. They can synchronize these extreme ultraviolet pulses with a delayed infrared pulse, into which the electron is emitted. Thumm said that this infrared pulse changes the energy of the emitted electrons over time and serves as a measuring stick to judge the timing of the electron emissions.

He said that it is a bit like how high-speed photography in the 19th century proved that all four of a horse's hooves leave the ground while running.

"In this case it's not the horse's hooves but the electrons that we're seeing," Thumm said. "The bigger picture is that if we resolve in time how electrons move, we can understand the timing of chemical reactions taking place. We can understand the basics of chemistry, biology and life."

While Thumm and other K-State physicists continue to delve further into attosecond research, the university will be host to the Second International Conference on Attosecond Physics from July 28 to Aug. 1, bringing physicists from around the world to the K-State campus in Manhattan.

More information: More information on recent attosecond research at K-State is available online at jrm.phys.ksu.edu .

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