Physics update
DECEMBER 2023
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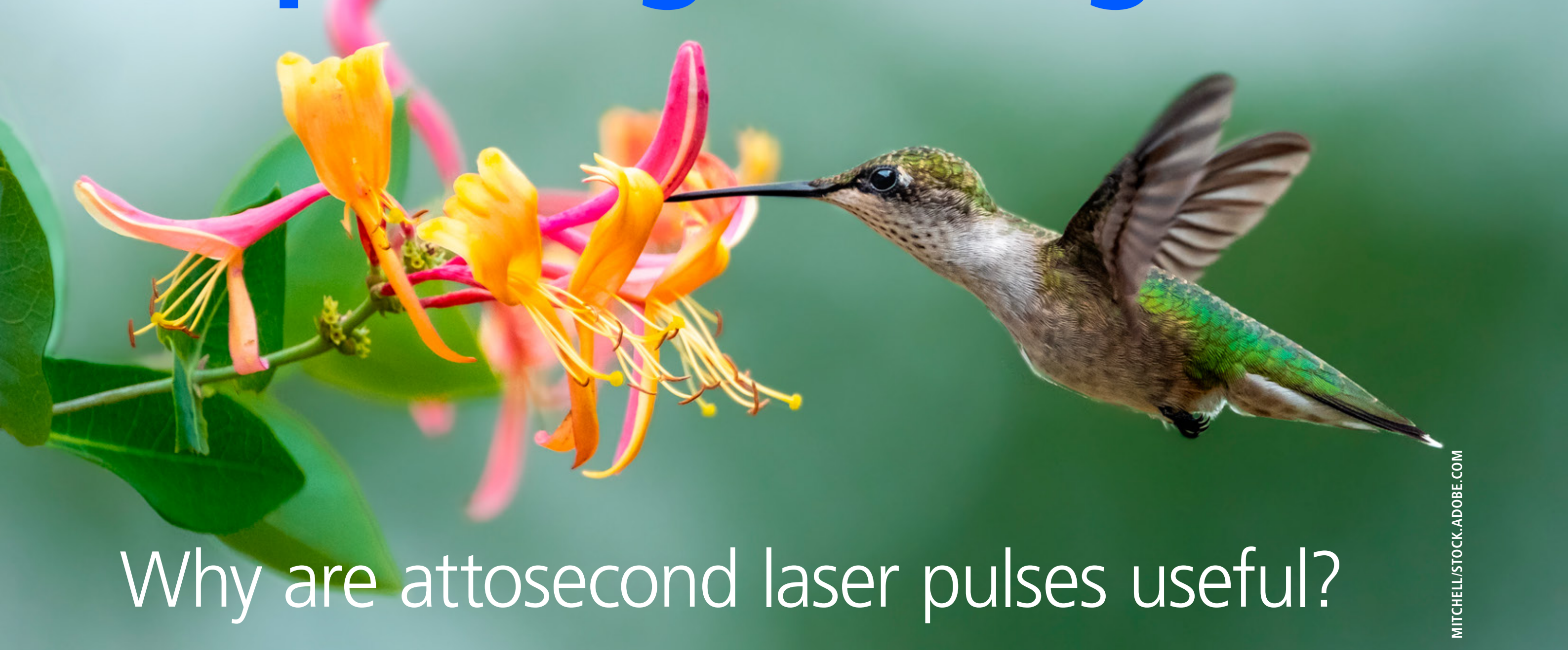
Capturing a wingbeat



Why are attosecond laser pulses useful?

This year the Nobel Prize for Physics was awarded to three physicists for their work generating attosecond pulses of light to study the behaviour of electrons. **Carol Tear** investigates.

Electrons move very quickly. In 2005 it was reported that an electron takes only 320 attoseconds to jump from a sulphur atom on the surface of a metal to the metal underneath. An attosecond is 10^{-18} s, one million times smaller than a picosecond (see Table 1). It is extremely difficult to imagine such a small amount of time; there are about the same number of attoseconds in a second as there have been seconds since the Big Bang, 14 billion (13.8×10^9) years ago.

Name	Symbol	Factor
milli	m	10^{-3}
micro	μ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}
femto	f	10^{-15}
atto	a	10^{-18}

Table 1: Metric prefixes

When something happens so fast that we cannot see it, we need a camera with a very fast shutter speed to get a clear picture. A hummingbird's wings are just a blur to our naked eyes. To freeze the motion, we need a shutter speed that is less than the time for one wingbeat. We can then get better measurements and understanding of the process. If our camera can take a lot of pictures in a very short time, the sequence can give us a lot more information. Attosecond pulses will enable us to study how the distribution of electrons oscillates in atoms, and how they move from place to place in molecules. Currently, only their mean position can be measured.

Why were such short pulses thought to be impossible?

Physicists thought that it was impossible to get pulses shorter than a few femtoseconds (10^{-15} s) because the shortest possible pulse is one period of the wavelength of the laser. The period depends on the frequency, so a very high frequency is needed. This requires a very short wavelength, equivalent to the

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ultraviolet or x-ray regions of the electromagnetic spectrum.

Period $T = \frac{1}{f}$ where f = frequency

Wavelength $\lambda = \frac{v}{f}$ where v = speed of light

There are technical difficulties in constructing lasers that work in these regions of the spectrum, and this limits the pulse to a minimum of a few femtoseconds.

How are they generated?

When laser light passes through a gas the photons interact with electrons in the atoms to produce harmonics, or overtones. These are waves with frequencies that are multiples of the original frequency. You may be familiar with these from studying the standing waves on a guitar string.

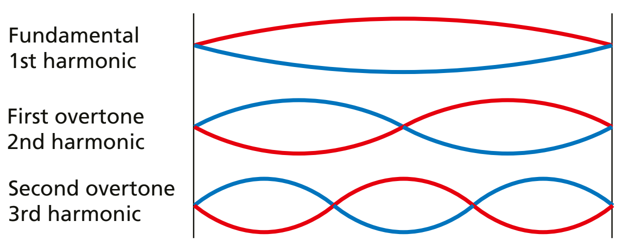

Figure 1: Standing wave harmonics

Anne L'Huillier and her colleagues explored this effect, irradiating argon gas and producing ultraviolet overtones with an infrared laser. When ultraviolet overtones that are in phase superpose in the gas, constructive interference occurs and results in attosecond pulses.

Piere Agostini and his colleagues produced a series of consecutive pulses, which they combined with a delayed part of the original laser pulse. They could see how the overtones were in phase with each other and measured the duration of each pulse. It was 250 attoseconds.

At the same time, Ferenc Krausz and his colleagues worked on a method of selecting a single pulse. This pulse was 650 attoseconds long.

These pulses have potential applications in many fields, from electronics to medicine. For example, a pulse can be used to push a molecule, which makes it emit a signal from which the molecule can be identified. This has potential to be used for medical diagnosis.

In conventional electronics, a transistor regulates the charge flowing between two charged plates by changing the charge on a third charged plate. In a similar way, using the photoelectric effect, an attosecond pulse of light can be absorbed and cause emission of an electron from one metal plate. This then travels to another plate with opposite charge. Controlling the flow of charge with light is much faster than using electrons and may lead to much faster electronic devices. Ferenc Krausz thinks it may be possible to increase the power of computers by a factor of 100,000 using this method.

Questions

1. How many seconds are there in 13.8 x 10^9 years? Check that it is about 10^{18}.
2. How many attoseconds does it take for light to travel 1 mm? (Speed of light = 3 x 10^8 m/s^{-1}).

Answers

1. Multiply by the number of seconds in a year: 13.8 x 10^9 x 365 x 24 x 60 x 60 = 4.35 x 10^{17} s.
2. Time = distance ÷ speed: Time = (1 mm) ÷ (3 x 10^8 m/s^{-1}) = 0.001 ÷ 3x 10^8 = 3.33 x 10^{-12} s. Change from seconds to attoseconds: x 10^{18} = 3.33 x 10^6 as. So, it takes 3 million attoseconds for light to travel 1 mm.

Resources

Nobel prize in Physics 2023: **https://tinyurl.com/artc6ucs**