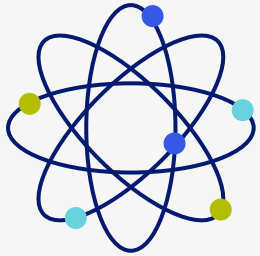
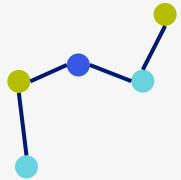
Attosecond Physics

Measuring electron movement using ultra-short light pulses



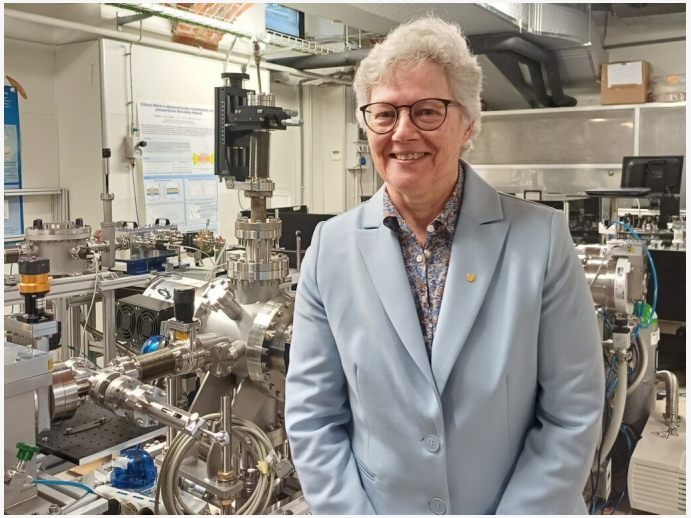


Interview with Anne L'Huillier

Who is Anne L'Huillier?

- Professor of Atomic Physics at Lund University, Sweden
- One of only five women in history to win the Nobel Prize in Physics (awarded in 2023)

➔ Atomic Physics: The science of atoms, specifically studying how electrons interact with the outside world and light



The Discovery: High-Order Harmonics

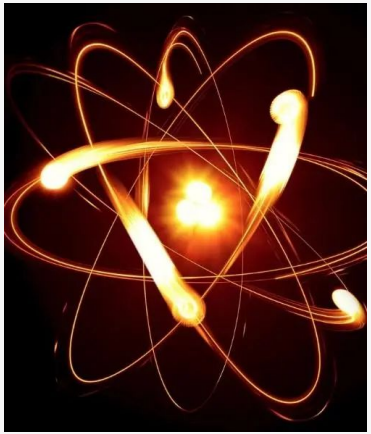
The Experiment (1987):Exposing atoms to intense laser light generates a new kind of light

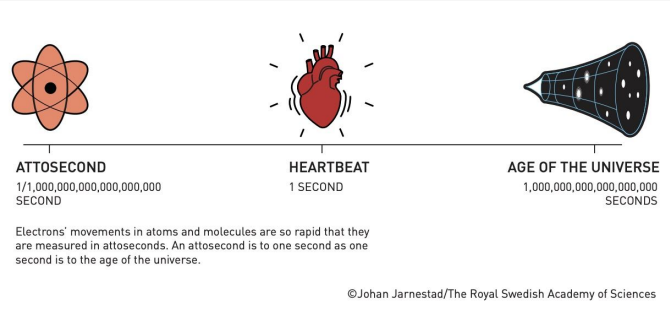
- High-Order Harmonics: This new light has frequencies equal to multiples of the original laser frequency.
- Interference Principle: By combining all these harmonics, the light waves interfere with each other to create extremely short light pulses

What is an Attosecond?

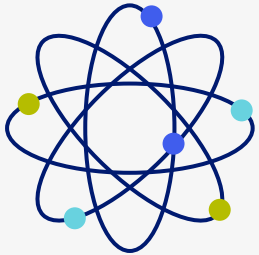
An attosecond is 10−18 seconds (one billionth of a billionth of a second) (10^{-18} s)

- To give an idea of the proportion, a single heartbeat lasts as many attoseconds as there are seconds from the beginning of the universe to the present.
- Mention that the previous limit was the *femtosecond* (10^{-15} s). While femtoseconds are fine for tracking the heavy nuclei of atoms, they are far too slow to capture the incredibly rapid motion of electrons.



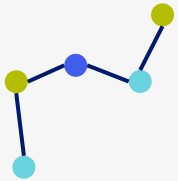


Future Applications and Breakthrough

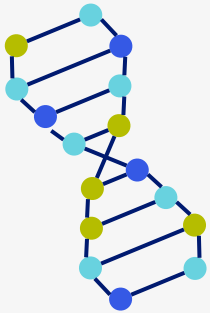


Measurement Breakthrough: Since no detector is fast enough, her Nobel co-laureates found a way to measure the pulses using the very laser field that produces them.

- Practical Applications: Understanding and controlling fundamental chemical reactions initiated by electron motion.
- Examples: Better understanding of photosynthesis and improving solar cell efficiency.

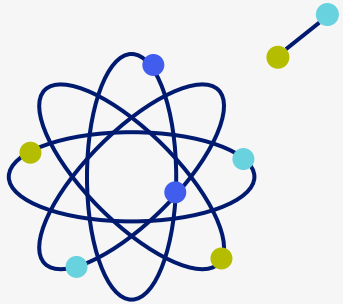


Scientific and Personal Message



Inspiration: Anne L'Huillier was deeply inspired by **Marie Curie** (the first woman to win a Nobel, pioneer in radioactivity).

- Resilience in Science: Careers in science have ups and downs; researchers must be obstinate and resilient against failures.
- Inclusivity & Teaching: Teaching is vital to inspire the next generation. Diverse research teams (including more women and different backgrounds) work best.



The Technical Differences Between Their Experiments

Pierre Agostini

He managed to make these overtones interfere with one another to produce a continuous series—called a **"pulse train"**—where each individual pulse lasted just **250 attoseconds**.

Ferenc Krausz

He developed a different approach that allowed him to isolate a **single, distinct pulse of light** lasting **650 attoseconds**.

Anne L'Huillier

She discovered that shining a laser through a noble gas created "overtones" (light waves with much shorter wavelengths in the ultraviolet spectrum). This happens because the laser pushes electrons away from the atoms, and when they snap back into place, they release energy as short bursts of light.

Heisenberg’s Uncertainty Principle & Attoseconds

- attosecond science **does not violate Heisenberg's uncertainty principle**

In quantum mechanics, it is fundamentally impossible to measure **both** the exact **position** and the exact **velocity (momentum)** of a particle (like an electron) at the same time.

How Attosecond Physics Works Within the Rules:

- It does **not** track a single electron's exact point and speed simultaneously.
- Instead, it measures the **time** it takes for an electron to shift or migrate across a molecule.
- It allows us to map the general **region** the electron occupies at a specific, ultra-short instant.

LASER and ATTOSECONDS
The dynamics of matter on the nanoscale

10^{17}s

age of the universe

1s

Heartbeat

10^{-18} s

Attosecond (Electrons)

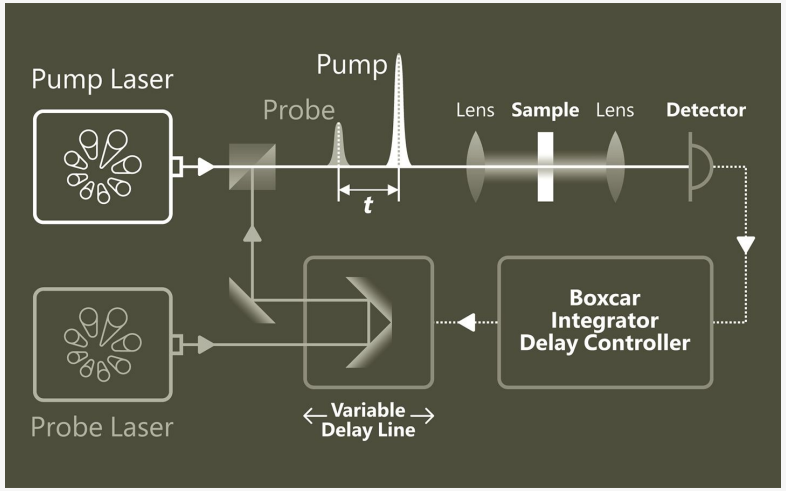
The timescale of modern physics covers over 35 orders of magnitude.
An attosecond is to a second as a second is to the age of the universe.

straboscopic photography

To observe fast processes, the duration of the "flash" must be less than the time scale of the movement.

- Ultra-Small: Atomic spatial resolution (nanometers).
- Ultra-Fast: Temporal resolution (femto/attoseconds).
- Intersection: Many fundamental processes happen right here.

Ultrafast Methods
The Pump-Probe Method



1. The Pump Pulse (Pump)

The Pump pulse hits the sample and "turns on" the dynamics, acting as time zero.

2. The Probe Pulse (Probe)

The Probe pulse arrives after a controlled delay and captures a snapshot of the system.

System Dynamics

PUMP

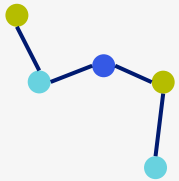
The physical or chemical dynamics begins. Time reference point.

PROBE

Shows structural or electronic changes as they occur

Footage

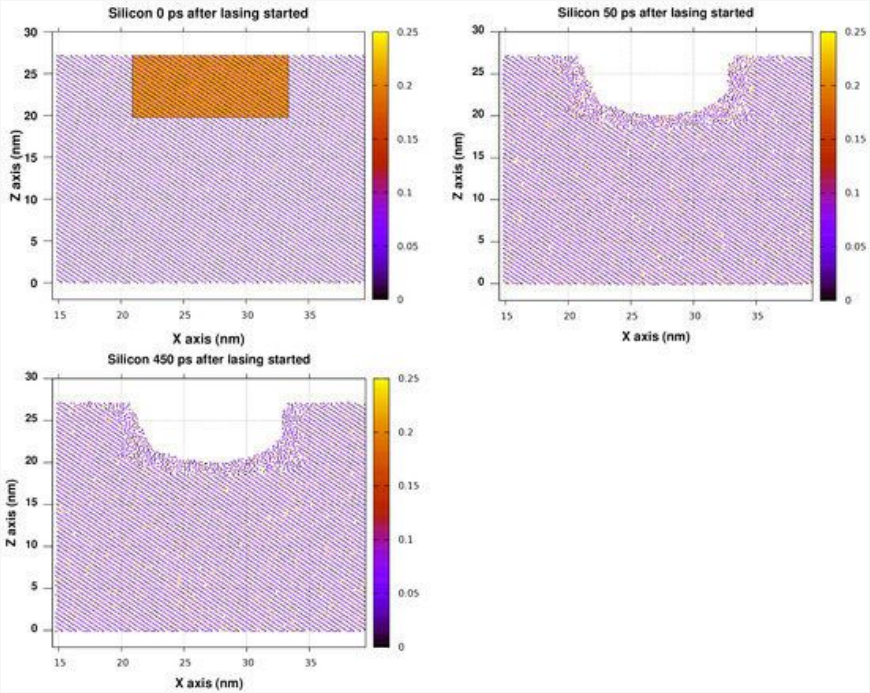
By varying the delay you get a movie frame by frame



Nanoscale Movies

Using ultrashort laser pulses, we can visualize how a nanomaterial changes shape and structure in a few femtoseconds.

This technique allows us to see processes that were previously only theoretical "in real time."



Ahmed H. Zewail
Femtochemistry

The Birth of a Camp

Zewail pioneered the use of femtosecond lasers to study chemical reactions.

- **Transition State:** It allowed us to observe the exact moment when chemical bonds break and form.
- **1999: The Nobel Prize** honors the ability to "film" moving atoms.

THANKS FOR THE ATTENTION!

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5BL