Attosecond Science

Why in news?

2023 Nobel Prize for Physics was awarded to Anne L'Huillier, Pierre Agostini, and Ferenc Krausz for experimental methods that generate attosecond pulses of light for the study of electron dynamics in matter.

What is Attosecond Science?

- **Attosecond-** It is *one quintillionth of a second or 10^{-18} seconds*, the timescale at which the properties of an electron change.
- These pulses are used to unravel dynamical processes in matter with unprecedented time resolution.
- **Attosecond science-** It is a branch of physics that deals with *light-matter interaction* phenomena, production of extremely short light pulses and using them to study superfast processes.

What is the physics of producing an attosecond pulse?

- **Wave mechanics**- The concepts underlying the production of attosecond pulses come from *wave mechanics.*
- In 1988, Anne L'Huillier and her colleagues passed a beam of *infrared light through a noble gas* which emitted light in a high multiple frequency of the beam's frequency.
- The emitted waves are said to be overtones of the original.
- The researchers also found that as the frequency of the original beam increased, the intensity of the emitted light dropped sharply, then stayed constant for a range, and then dropped again.
- **Studying the light** - A beam of light consists of oscillating electric and magnetic fields.
- 'Oscillating' means that at a given point, the field's strength alternately increases and decreases. So an electron at this point would be imparted some energy and then have it taken away.
    - **When energy is imparted**- The electron would come loose from an atom.
    - **When the energy is taken away**- The electron and the atom would recombine, releasing some excess energy.
- This energy is the light re-emitted by the gas.
- **Quantum mechanics-** The researchers also found a way to describe this process using the equations of quantum mechanics.

How is an attosecond pulse produced?

- **Multiple overtones**- When the infrared beam strikes the noble gas atoms, it produces multiple overtones.
    - **Constructive inference**- If the peak of one overtone merges with the peak of another, they undergo constructive interference (like in the double-slit experiment) and produce a larger peak.
    - **Destructive Inference**-When the peak of one overtone merges with the trough of another they cancel themselves out.
- **Light pulses**- By combining a large number of overtones in this way, physicists could fine-tune a setup to produce light pulses for a few hundred attoseconds due to constructive interference and then stop, due to destructive interference.
- These pulses are produced only when the beam's frequency is within the plateau range.



What the scientists have exactly done?

- **RABBIT**- It is developed in 1994 by Pierre Agostini and his colleagues which is a major technique to measure the duration of a short light pulse.
- The attosecond pulse and another pulse of a longer duration are shined on atoms of a noble gas.
- The photons in the two pulses kick out electrons from the atoms.
- Physicists harvest data about these electrons and the atoms which also gives information about the pulse's properties including its duration.
- **Attosecond pulses in train**- It was only in 2001 that Agostini et al. and Ferenc Krausz et al. were able to produce verified attosecond pulses in a train.
- Pulses in a train refers to a pulse followed by a gap, followed by a pulse, and so forth.
- **Short attoseconds-** After these achievements, all three groups, and other physicists, kept refining these techniques so that, by 2017, experts were able to produce a pulse as short as 43 attoseconds.

What are the applications of attophysics?

- **Atomic and molecular physics** - With these attosecond pulses, scientists can "freeze" the motion of electrons within atoms and molecules, providing a real-time view of electron movement during chemical reactions.
- **Create and manipulate extreme ultraviolet (XUV) and X-ray pulses** - These are vital for imaging ultrafast processes at the atomic and molecular scale. These pulses are produced using high-intensity laser systems that generate attosecond bursts of light.
- **Electronic gadgets**- A better understanding of how electrons move and transmit energy can also help in creating more efficient electronic gadgets.
- **Development of new tech** - They allow scientists to observe the quantum mechanical nature of electrons and the intricate dance they perform when interacting with one another and with atomic nuclei.
- This knowledge has profound implications for fields such as chemistry, materials

science, and even the development of new technologies.

- **Solar power**- Photoelectric effect is the core of solar power and by refining the theoretical understanding it will make big strides in renewable energy production.

References

1. The Hindu- Attophysics new tools to fathom the world of electrons
2. The Hindu- Let there be light 2023 Nobel Prize for Physics

