OPTICAL ATOMIC CLOCK: SCIENCE & TECHNOLOGY
NEWS: Intercontinental optical clock comparison sets stage to redefine the second
WHAT'S IN THE NEWS?
Optical atomic clocks, which use visible light frequencies for time measurement, are far more precise than caesium-based clocks and are likely to redefine the SI second by 2030. This advancement supports critical fields like satellite navigation, climate monitoring, and quantum technologies.

Context

- Researchers from **six countries** have conducted the **world's most accurate comparison of optical atomic clocks** across three continents.
- This is a significant breakthrough that could **redefine the SI unit of time — the second**, replacing the existing caesium-based atomic standard.

Current Definition of a Second (since 1967)

- **Present Standard**:
- **Why Caesium?**
    - Chosen One second is defined as **9,192,631,770 oscillations (or cycles) of microwave radiation** corresponding to the transition between two hyperfine energy levels of the **caesium-133 atom**.
    - due to its **high stability**, **long-term reliability**, and **global consensus** in the metrology community.
- **Timekeeping in India**:
    - The **National Physical Laboratory (NPL)** in Delhi maintains the official **Indian time standard** using **five caesium clocks**.
    - These time signals are disseminated nationwide via:
        - **INSAT satellite network**
        - **Telecom and internet systems**
        - **Optical fibre links**

What are Optical Atomic Clocks?

1. Basic Principle

- Like traditional atomic clocks, optical clocks work on the **atomic transition principle** — measuring time based on how atoms **switch between two fixed energy levels**.
- But while caesium uses **microwave radiation**, optical clocks use **visible light (optical frequencies)** through **high-precision lasers**.

2. Common Atoms Used

- **Strontium-87 (Sr)**
- **Ytterbium-171 (Yb)** and **Ytterbium ions (Yb^+)**
- **Indium-115 ions (In^+)**
- **Strontium-88 ions (Sr^+)**
- These atoms are chosen because of their **extremely narrow linewidth transitions** and **minimal sensitivity to environmental disturbances**.

Why Replace Caesium with Optical Clocks?

1. Higher Frequency, Better Precision

- Optical clocks operate at frequencies **thousands of times higher** than microwave clocks.
- More oscillations per second → **better resolution of time intervals**.
- Comparison of frequencies:
    - **Caesium**: ~9.19 billion Hz (microwave)
    - **Strontium**: ~429 trillion Hz (optical)
    - **Ytterbium**: ~642 trillion Hz (optical)

2. Extreme Stability and Accuracy

- Some optical clocks have a **stability level of one second drift over 15 billion years**.
- That's up to **10,000 times more stable** than traditional caesium clocks.
- Enhanced stability enables better synchronization in scientific, navigation, and financial systems.

3. Enhanced Measurement Tools

- Optical clocks enable detection of even **minuscule gravitational changes** due to their extreme sensitivity.
- Useful in **geodesy, climate monitoring**, and **fundamental physics tests** (e.g., Einstein's General Relativity).

How Optical Atomic Clocks Work

- A **laser** is used to stimulate electrons in atoms (e.g., Sr, Yb) to **jump between energy states**.
- The **frequency of this transition** becomes the clock's "tick".
- Since optical frequencies are so high, they allow **greater precision and time resolution**.

Significance of the Development

1. Redefining the SI Second (Target: ~2030)

- This global optical clock comparison lays the technical foundation to **revise the definition of the second** in the SI system.
- The redefinition will be **based on optical frequencies**, aligning with advances in timekeeping.

2. High-Precision Scientific Applications

- **Satellite Navigation**:
  - Systems like **GPS**, **NavIC**, **Galileo** will benefit from better time synchronization.
- **Radio Astronomy**:
  - Black hole imaging and deep-space observations require atomic time stability.
- **Climate Science & Earth Observation**:
  - Optical clocks help track **gravity-induced sea level and ice sheet changes**.
- **Quantum Technologies**:
  - Accurate time signals are critical for emerging **quantum communication and computing** systems.

Conclusion

Optical atomic clocks represent a transformative leap in timekeeping science, offering **unparalleled stability and accuracy**. Their global adoption is poised to **redefine the second** and enable breakthroughs in navigation, geophysics, and fundamental science, with India's NPL expected to integrate these standards in the future.

Source: https://www.thehindu.com/sci-tech/science/intercontinental-optical-clock-comparison-sets-stage-to-redefine-the-second/article69787042.ece