This is the 'world's most accurate clock' that took 20 years to build

NIST scientists have built the world's most accurate aluminum ion atomic clock, a 20-year effort. The deviation only occurs after a period longer than the age of the universe, opening up the possibility of redefining the second and applying it to both Earth science and fundamental physics.

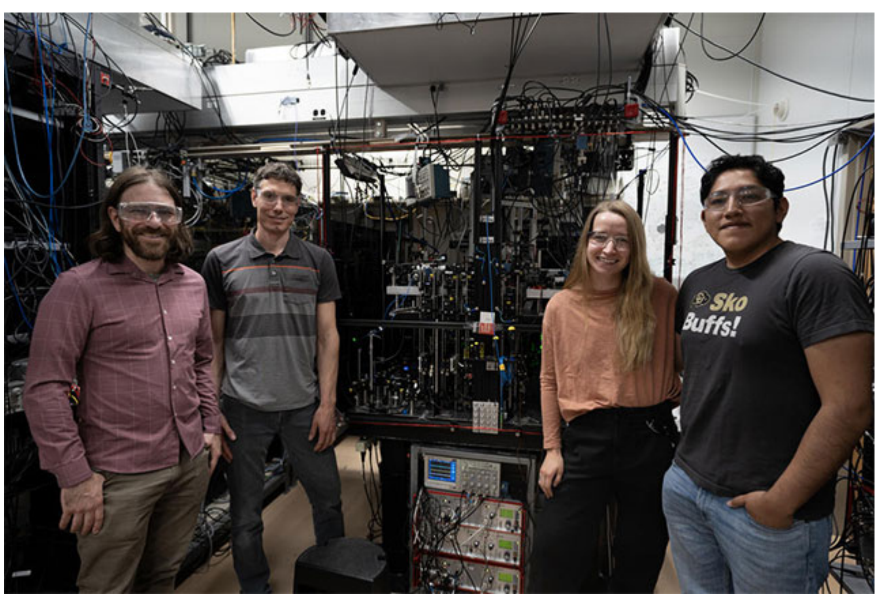
Researchers at the US National Institute of Standards and Technology (NIST) have just announced the world's most accurate optical atomic clock, built based on a single aluminum ion.

The clock has a fractional frequency uncertainty of just $5.5 \times 10?^{1}?$, meaning it would have to run longer than the age of the universe to lose a second. It also has a fractional frequency stability of $3.5 \times 10?^{1}? / ??$ second, which is 2.6 times more stable than any previous ion clock.

The result of 20 years of research

Optical clocks are judged on two factors: accuracy (how close to 'real time' they are) and stability (how consistently accurate they remain). The team spent 20 years continuously improving the laser system, ion traps and vacuum chambers of the aluminium clock to achieve this record.

'It's really exciting to be working on the most accurate clock ever,' said Mason Marshall, a NIST researcher and lead author of the paper.



How a watch works

The meter is based on quantum logic spectroscopy of an aluminum ion ^{2}?Al?. A magnesium ion ^{2}?Mg? is trapped to assist in cooling and reading the state of the aluminum ion. Aluminum ions are essentially extremely stable in their oscillation frequency, less affected by temperature and magnetic fields, but are difficult to control with lasers. Meanwhile, magnesium ions are easier to control, acting as a 'helper' to cool and indirectly measure aluminum ions.

Key improvements applied to the watch include:

1. Rabi detection time extended to 1 second, thanks to laser stabilization transmitted from JILA lab via 3.6 km fiber optic cable. This reduces instability by three times compared to before.
2. Redesigned ion trap with thicker diamond wafer and adjusted gold coating, minimizing unwanted micro-oscillations.
3. Titanium vacuum chamber, which reduces background hydrogen gas by up to 150 times, limits collisions that cause errors, allowing the watch to run for many consecutive days without needing to recharge new ions.
4. Measures the alternating magnetic field from the radio frequency trap in the sensitive direction, eliminating uncertainties due to magnetic field direction.

Thanks to these changes, the watch can achieve accuracy to 19 decimal places in just 36 hours, instead of the three weeks it took before.

Willa Arthur-Dworschack – a PhD student participating in the project – commented:

> *With this platform, we can explore new clock architectures, even expanding the ion count or creating quantum entanglement to further improve accuracy.*

This achievement not only opens up the possibility of redefining the second with greater precision, but also promises applications in Earth science and fundamental physics, such as testing whether constants of nature are truly 'invariant' over time.

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