NPL National Physical Laboratory

Atomic Timekeeping

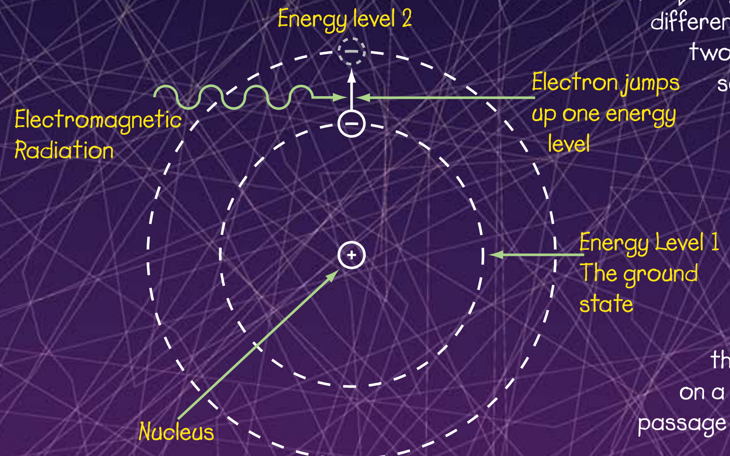
The spinning Earth gives our most basic measurement of time – the day – and for thousands of years it was our most stable timekeeper. However, the quartz and atomic clocks invented during the 1930s and 1950s are even better timekeepers which show that the Earth does not rotate steadily but wobbles! NPL built the world's first working caesium atomic clock in 1955 and paved the way for a new and better definition of the second based on the fundamental properties of atoms.

Quantum standards

Quantum standards are based on fundamental properties of matter. In the case of the atomic clock this is the energy released when electrons move between energy levels of a caesium atom. Using the movement of the Earth to define the second is a problem because this varies unpredictably with time, so the length of a second defined this way would not be constant. But quantum standards, as far as we know, will be stable forever, no matter when or where it is measured. Thousands of years in the future, or in a distant galaxy, the energy levels of the caesium atom are exactly the same, and so is the length of the second defined in this way.

How an atomic clock works – theory

The atom can be pictured as a mini solar system, with the heavy nucleus at the centre surrounded by electrons in a variety of different orbits. The orbits correspond to energy levels, and electrons can only move between levels when they absorb or release just the right amount of energy. This energy is absorbed or released in the form of electromagnetic radiation, the frequency of which depends on the difference in energy between the two levels. This transition is the source of the term "quantum jump", quantum referring to the tiny but precise amount of energy needed to allow the electron to jump to a different level. By measuring the frequency of the electromagnetic radiation, like counting the number of pendulum swings on a pendulum, we can measure the passage of time.



Why do we need the accuracy of atomic clocks?

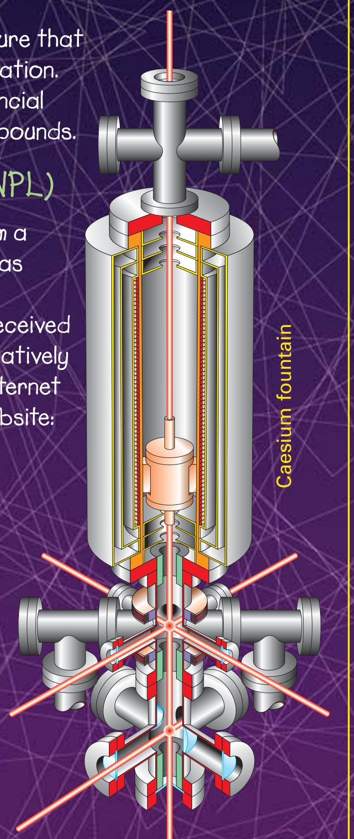
Time measurement has become a basic part of everyday life and accuracies of the nearest minute or a few seconds are usually good enough for most human activities, but highly accurate timing plays a vital role in many other aspects of the modern world.

The Global Positioning System (GPS) satellites broadcast timing signals from onboard atomic clocks, which enable land vehicles, shipping and aircraft to know their location within a few metres. Other people making use of GPS include ecologists tracking the movements of rare animals, prospectors, surveyors, mountaineers, and the search and rescue teams if any of these pursuits go wrong. Research is underway to make specialist location systems accurate to within millimetres.

Whether surfing the Internet or making a telephone call, telecommunications rely upon accurate timing to ensure that digital messages are safely delivered to their destination. The recording of the timing and the order of a financial transaction is critical when transferring millions of pounds.

Access to the national time scale, UTC(NPL)

NPL has been disseminating the UK national time scale from a transmitter at Rugby since 1950. This transmitter, which has the call sign MSF, operates 24 hours a day at a frequency of 60 kHz; transmissions can be received as far away as Iceland and Gibraltar. Alternatively you can connect to the NPL timescale over the internet from anywhere in the world, and set your PC or Mac to UTC(NPL). Visit our website:
www.npl.co.uk/time/truetime.html



Caesium fountain

How long is a second?

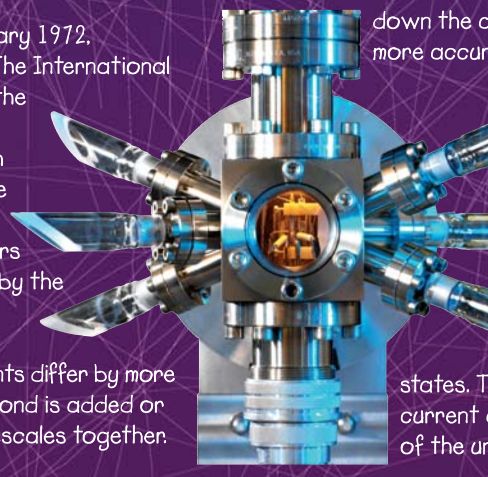
The second is the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the caesium 133 atom.

How do you keep time around the world?

Everyone around the world needs to keep to an agreed timescale. On the 1st January 1972, Coordinated Universal Time (UTC) was adopted as the official time for the world. The International Bureau of Weights and Measures (BIPM) acts as the official time keeper of atomic time for the world. There are 65 laboratories with over 230 clocks contributing to the international timescale. As BIPM counts the seconds astronomers still continue to measure time by the rotation of the Earth about its axis. This is compared to UTC, and if these measurements differ by more than 0.9 seconds a leap second is added or subtracted to keep the timescales together.

How an atomic clock works – practice

In 1955 Louis Essen built the world's first caesium atomic clock at NPL. Today a new form of atomic clock, the caesium fountain, is being used. In this clock, a cloud of atoms is projected up into a microwave chamber and allowed to fall down under gravity. The fountain uses laser beams to slow down the atoms. The slow movement of the atoms allows a more accurate measurement of the transition between energy levels and hence the frequency of radiation.



Ion Trap

The next generation

Clocks for the 21st century are being developed in the form of ion traps. Ions are charged atoms which can be trapped by electromagnetic fields almost indefinitely. Once trapped a laser beam can then be used to cool the ion down close to absolute zero, keeping it stationary. At NPL the element strontium has been chosen to develop ion trap clocks as its ions can have very stable states. These clocks may have accuracies of around 1000 times higher than the best current atomic clocks. That is equivalent to losing no more than one second in the lifetime of the universe.

Time Line

3500BC

Sundials

± 10 seconds per day

Pendulum clocks

1762
± 1 second in 3 days

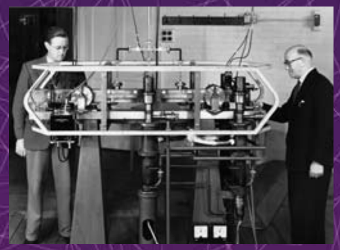
Harrison's chronometer

Earth's rotation

1930s
± 1 second in 3 yrs

1930s
± 1 second in 30 yrs

Quartz



Essen (right) with original atomic clock

1955
± 1 second in 300 yrs

1980s
± 1 second in 300 000 yrs

2004
± 1 second in 60 million yrs

Caesium fountain