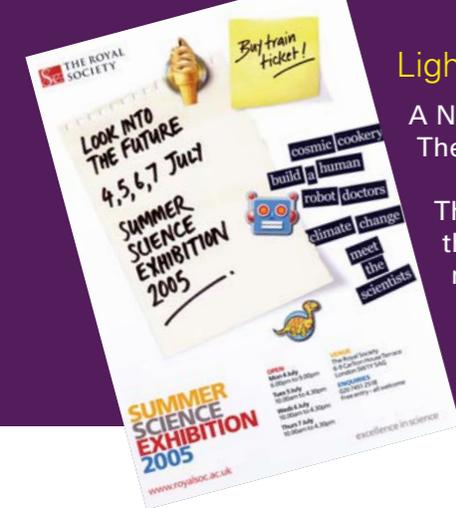


Light years ahead – Summer Science Exhibition 2005

A National Physical Laboratory Exhibit
The Royal Society, London: 4 – 7 July 2005 Free entry – all welcome

The Summer Science Exhibition offers a fantastic opportunity to discover the best of the UK's science and technology research and the chance to meet and talk to the researchers who are behind the work on show.

For further details please contact the Royal Society on 020 7451 2518 or see www.royalsoc.ac.uk



NPL
National Physical Laboratory

METROMNIA

Celebrating the 50th anniversary of the atomic clock

News from the National Physical Laboratory
Summer 2005 | Issue 19

The importance of time

We all use the time – all the time – often without really thinking about it. It gets us to work punctually, lets us know when our favourite TV programme is being shown, and keeps society and the economy functioning more or less smoothly.

Most of us don't need accuracy to much more than a couple of seconds, though we do enjoy watching a sportsman winning or losing a race by fractions of that amount. Is it necessary to have accuracy beyond that?

It most certainly is. It is very precise time that keeps the Internet and e-mail functioning, enables us to send text messages, and synchronises the distribution of electricity. Accurate timekeeping is integral to a network of global navigation satellites that are being used for everything from precision mapping and surveying to environmental monitoring of earthquakes and personal location-based services. Time is critical in calculating the interest on billion pound financial transactions and ensures television broadcasts arrive at our TVs. There is even a radio-controlled clock next to Big Ben - to keep the world's most famous clock right on time.

Where does time come from?

Time can only be useful if it is the same for everyone, and that requires a single source of time against which we can all check our clocks.

Time was measured by early civilizations according to the movement of the sun

through the sky, with daylight eventually divided into smaller units of time by using easily divisible numbers like 12 and 60.

As long ago as 1879, Lord Kelvin proposed that a clock based on atomic structure could keep time more accurately than any method based on the movement of celestial bodies.

UK-led international research in the 1940s began to demonstrate that the transition of electrons between states in atoms was a natural occurrence that could be far more accurately quantified than the movement of planets.

Today that source of time - known as Coordinated Universal Time (UTC) - is maintained by a network of more than 230 atomic clocks in 65 laboratories around the world. This diversity of sources provides ample back-up in the event that any of the atomic clocks were to develop a fault, and enables regular maintenance and upgrades on individual devices. All of the time data from atomic clocks across the world is collated at the International Bureau of Weights and Measures (BIPM) ensuring the accuracy and consistency of the global time standard.

FORTHCOMING EVENTS

15 Jun 2005 Mech Clubs - Pressmet Annual Meeting: Data Acquisition & Analysis NPL, Teddington

Contact: Roger Hughes
Tel: 020 8943 6164
E-mail: roger.hughes@npl.co.uk

28 - 29 Jun 2005 Optical Radiation Measurement Club Annual Meeting NPL, Teddington

Contact: Fiona Jones
Tel: 020 8943 6743
E-mail: fiona.jones@npl.co.uk

06 Jul 2005 Freespace Optical Communication Systems Workshop NPL, Teddington

Contact: Clare Melton
Tel: 020 8943 6327
E-mail: clare.melton@serco.npl.co.uk

05 - 09 Sep 2005 ICRM 2005 15th International Conference on Radionuclide Metrology Oxford, UK

Contact: Clare Melton
Tel: 020 8943 6327
E-mail: icrm2005@serco.npl.co.uk

21 - 23 Sep 2005 OMFC 2005 NPL, Teddington

Contact: Clare Melton
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24 - 26 Oct 2005 Single-Photon Workshop (SWP) 2005 NPL, Teddington

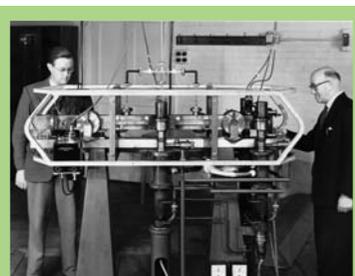
Contact: Jessica Cheung
Tel: 020 8943 6304
E-mail: jessica.cheung@npl.co.uk

09 Nov 2005 Medical Thermomography & Thermometry NPL, Teddington

Contact: John Pickett
Tel: 020 7377 7000
E-mail: j.a.pickett@qmul.ac.uk

14 - 17 Nov 2005 BEMC 2005 NPL, Teddington

Contact: Clare Melton
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Dr Louis Essen (above right) was born in Nottingham in 1908, he graduated from that city's university before joining the National Physical Laboratory. During the Second World War his work on high-frequency radar led him to develop the cavity resonance wavemeter, which was used to measure the speed of light. His pioneering work on the atomic clock led to a medal from the Worshipful Company of Clockmakers and he is the only British physicist ever to have been honoured for his contribution to science by both the USA and USSR during the Cold War. He was awarded an OBE in 1959 and elected a Fellow of the Royal Society in 1960.

For further NPL events please go to www.npl.co.uk/news-and-events

FURTHER INFORMATION

For additional copies of this newsletter, or for more information on any aspect of NPL's work and the range of services available from the Laboratory, call the NPL Helpline:

Tel: 020 8943 6880 | Fax: 020 8943 6458 | Switchboard: 020 8977 3222

E-mail: enquiry@npl.co.uk | Website: www.npl.co.uk

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Essen (right) with original atomic clock

Essen, NPL and the invention of the atomic clock

The high point in the pursuit of the first working atomic clock was reached on 3 June 1955 at the National Physical Laboratory in Teddington, London. On that date, NPL research scientist Dr Louis Essen pencilled a few columns of numbers and graphs into his notebook. Almost 80 years after Kelvin proposed the idea, Dr Essen perfected the atomic clock, the first version of which was accurate to one part in 10^{10} (one part in ten billion). It was based on the absorption of microwaves by caesium atoms. By detecting and measuring this absorption, scientists could measure time to an unprecedented level of accuracy.

The astronomical community resisted the move to atomic time, but finally in 1967 the General Conference on Weights and Measures adopted the caesium atomic clock as the basis for the international definition of time.

The second as we know it became defined as 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.

Time in the UK

The UK's home of accurate time is the National Physical Laboratory, where a team of scientists maintains five atomic clocks which are kept in step with UTC. The MSF time radio broadcast from Rugby is synchronized to NPL's clocks. NPL also provides time signals to organisations like

the BBC – the "pips" on the radio – and BT's speaking clock. When the speaking clock beeps, it is because NPL's atomic clocks have told it to.

NPL is in the premiership of international timekeepers – one of just five laboratories in the world using a caesium fountain to contribute to UTC. Caesium atomic clocks use a beam of fast atoms emitted from an oven, with accuracies equivalent to one second in 3 million years. The caesium fountain uses laser light to slow these atoms down, cooling them to a few millionths of a degree. Their slow movement means they can be observed for longer, enabling more accurate time measurements.

How accurate do we need to be?

Anything within a couple of seconds, or even minutes, is usually good enough for individuals managing their day-to-day lives, but industry and the economy depend on a much higher degree of accuracy. The accurate definition of time – defined by the length of a second – has a critical impact on a number of applications.

Satellite navigation systems

Satellite navigation is at the leading edge of technologies requiring accurate time. There are nearly 100 atomic clocks on Global Positioning Satellites (GPS) orbiting the earth, positioned so that at any time any point on the globe is within range of at least four transmitters. A receiver only slightly larger than a mobile phone can pick up signals from the satellites and pinpoint its location in 3D with metre accuracy. The signal from a GPS navigation satellite travels at light speed – 30 cm in a nanosecond (or 300 million metres in a second), so a tiny error in a time signal can throw navigation a long way off course.

Telecommunications and the Internet

Without accurate time there would be no Internet, mobile phone calls or e-mail the way we appreciate them today. Atomic clocks are at the heart of telecommunication networks which keeps them functioning. Voice and data are distributed around the world in tiny packets of information which are split up when they leave their origin and then reassembled at their destination. Each packet

is time stamped to enable the transmission to be reconstituted in the correct order – letting us hear people's voices on the phone and to receive words and pictures in an intelligible form. As data rates increase, and with new applications - such as the transmission of video by mobile phones - so telecommunication networks require more and more robust and accurate time.

How accurate do we need to be in the future?

Atomic clocks enjoyed steady improvements for forty years. By 2000 the best caesium clocks were accurate to one part in 10^{15} . In other words, they would lose just one ten billionth of a second a day, or one second during the known age of the universe.

Technology does not stand still, so standards must continuously evolve. Time and position data from global navigation satellites does not yet have the accuracy or speed to be used to land a passenger aircraft or steer a car – but it could in the future. They will also be crucial to deep space exploration. If we are sending a spacecraft millions of kilometres to an unexplored part of the universe – and asking it to land gently in a particular place – then we need an extremely accurate clock to synchronise its navigation equipment.

Physicists believe they are close to the accuracy limit of caesium-based atomic clocks. They have long speculated that the much higher frequencies of optical transitions (as opposed to the microwave transitions in caesium) would better define the second, and therefore time itself. The frequencies of atomic transitions are counted like the ticking of a clock, so the more ticks counted in a given period, the more accurately time can be measured.

Defining an optical future

By the turn of the century an elite group of international physicists at German, French, American, Canadian and British standards laboratories were racing to build the first atomic clock based on an optical transition. The opportunity existed to develop a device which went beyond the accuracy limits of caesium – and perhaps to redefine the second for the first time in 37 years.

In November 2004, an NPL research team led by Prof Patrick Gill measured an optical frequency transition of a single strontium ion (an atom with one electron stripped away). It was three times more accurate than any previous attempt – to within 3.4 parts in 10^{15} paving the way for an optical atomic clock.

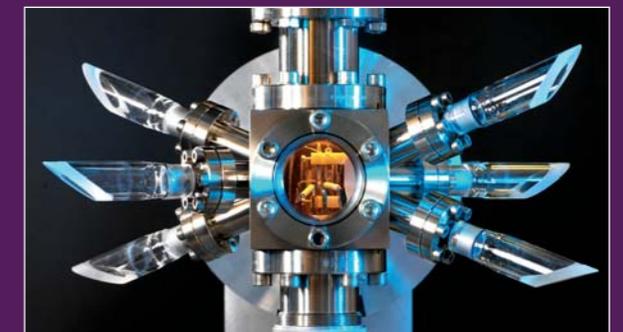
How it works

Prof Gill and his team are changing the course of time measurement with their strontium ion trap, one of only two in the world. The frequency standard is created by trapping and isolating a single ion of strontium in a vacuum before cooling it to near absolute zero (-273 °C) with a blue laser beam (wavelength of 422 nm). This laser bombards the lone ion with millions of tiny packages of light (photons), like an atomic machine gun firing light bullets repeatedly at the same tiny target.

The impact, absorption and re-emission of each photon causes the ion to recoil very slightly, thereby losing a small amount of energy. Eventually, after many photons are scattered in this way the ion is cooled down.

A second highly-monochromatic red laser (674 nm) is aimed at the cold ion, and tuned to two very precisely defined energy states in the cold ion. Once the laser is locked on to this precise energy or frequency interval it becomes very stable.

This laser now provides the optical frequency, which NPL believes, will lead towards the world's most accurate clock, possibly able to measure the second down to one part in 10^{18} . That is nearly one thousand times more accurate than the best clocks of today.



NPL Ion trap