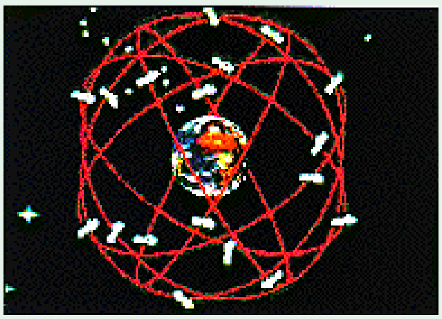
Atomic, Molecular, and Optical Science

Addressing Fundamental Questions and National Needs

3. Atomic Clocks

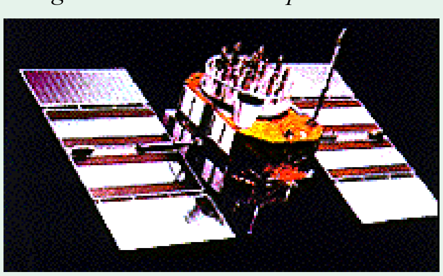
- Clocks depend on regular periodic motion—swinging pendula, vibrating quartz crystals, or quantum oscillations of ultracold atoms.
- Recent advances in laser cooling and trapping promise to enhance clock precision by a factor of 100.
- Improved clocks will find numerous applications, including the Global Positioning System that is so essential to accurate navigation.

Atomic Clocks and the Global Positioning System



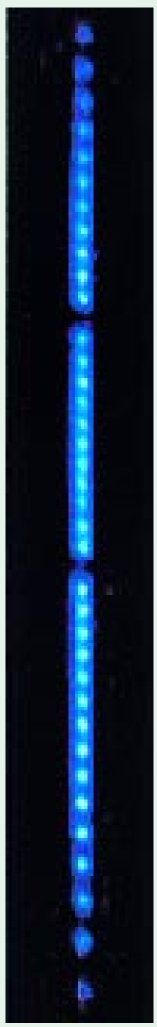
24 GPS satellites orbit Earth

The Global Positioning System (GPS) is an array of 24 satellites that provides accurate data on timing, position, and velocity. Atomic clocks on board the orbiting satellites are the heart of the system. With an appropriate receiver unit, one can use radio signals from the satellites to determine location to within about 10 meters and time synchronization to within a few nanoseconds. Applications range from commercial and military navigation to research on plate tectonics.

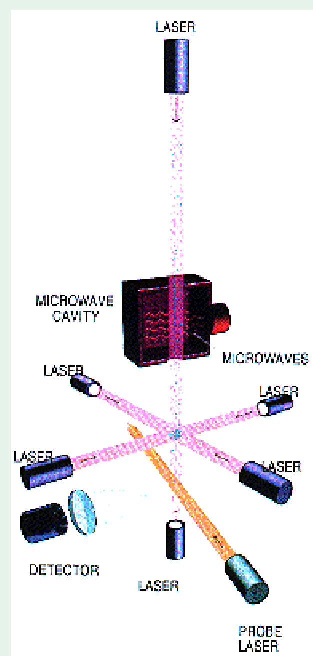


a GPS satellite

The Most Accurate Clocks in the World



The world's primary time standard, known as NIST-7, is based on the quantum mechanical oscillation of cesium atoms. This time standard is about 10 million times more accurate than the quartz oscillator in a wristwatch. A fundamental limitation on its accuracy is the motion of the atoms: because they are moving at about 200 meters per second, their oscillations cannot be measured for very long before they are lost. Using lasers to create an "atomic fountain" of ultracold atoms (below right) can help to overcome this limit. In this technique, cesium atoms are launched upward so that they pass through the microwave cavity that measures their oscillations twice, once on the way up and once on the way down as they fall under the pull of gravity. This scheme can increase the measurement time hundredfold. Another approach uses the oscillations of a sample of trapped ions, which can be measured for very long times indeed. Experiments using trapped mercury ions (such as those in the photograph at left) have already surpassed the precision of NIST-7 by about 40 percent—achieving a reproducibility of about 3 parts in 10^{15}!



This is one in a series of one-page handouts based on the National Research Council report *Atomic, Molecular, and Optical Science: An Investment in the Future* (National Academy Press, Washington, D.C., 1994). For more information on this report, look on the World Wide Web at http://www.nap.edu/readingroom/books/amo or contact the NRC Board on Physics and Astronomy on the World Wide Web at http://www.nas.edu/bpa, by email at bpa@nas.edu, or by telephone at 202-334-3520.