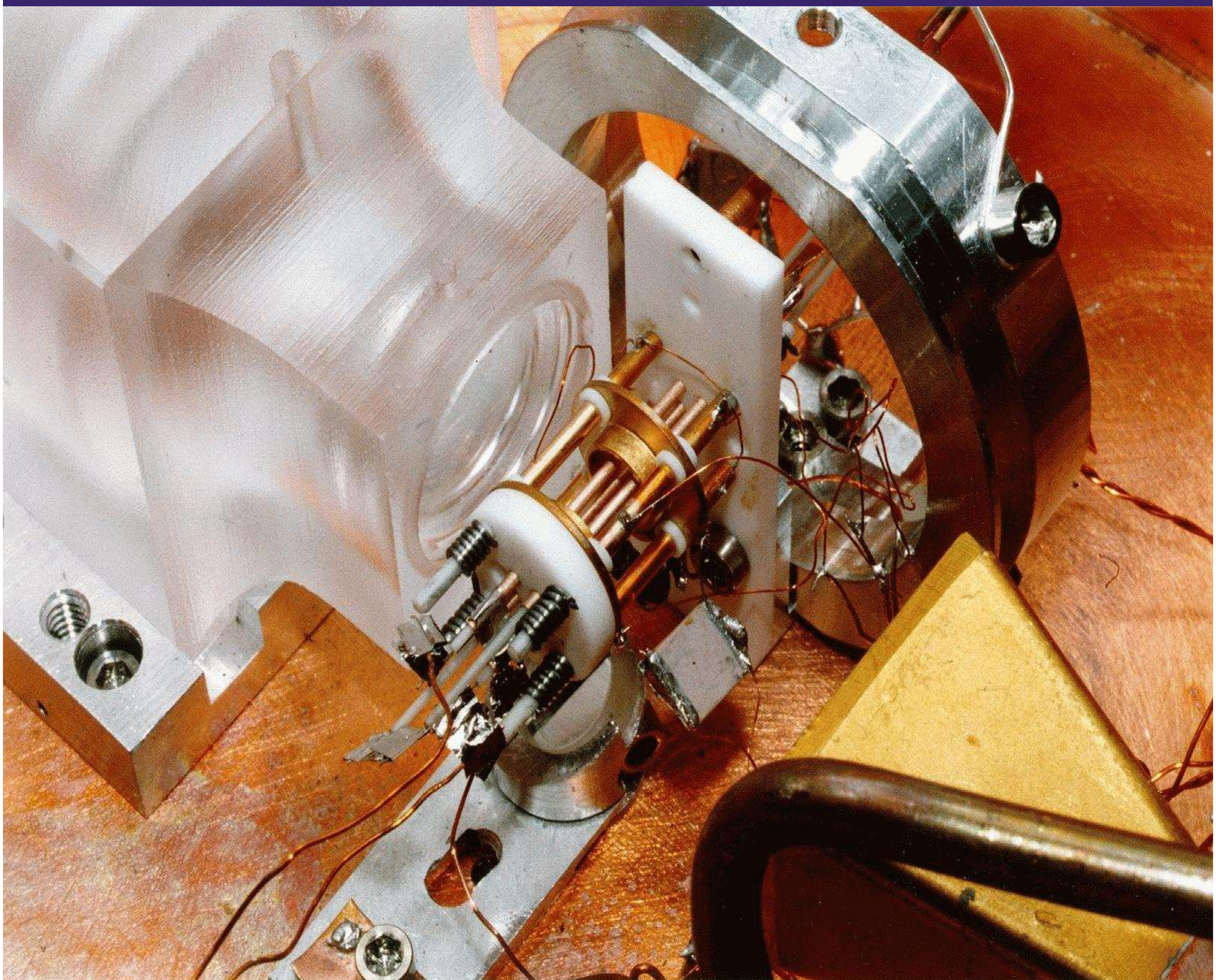
FRONTIERS OF PHYSICS LECTURE SERIES PRESENTS:

DR. DAVID WINELAND
OPTICAL ATOMIC CLOCKS



DEPARTMENT OF PHYSICS | UNIVERSITY of WASHINGTON

A SHORT HISTORY OF TIME KEEPING

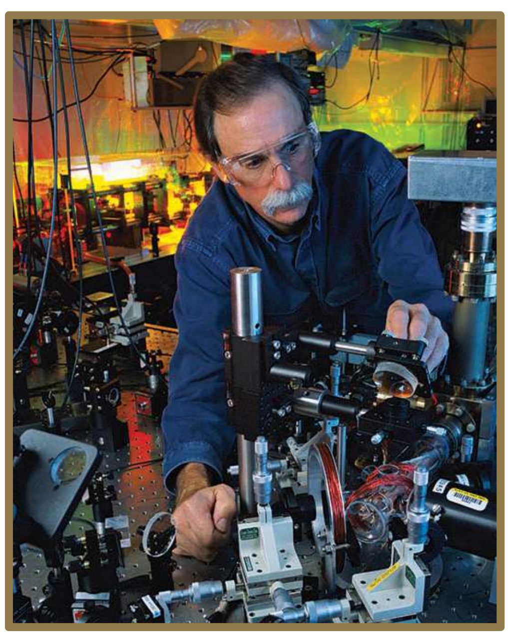
Written by: Phil Ekstrom, Ph.D. '62

Time has been kept in some way or other for millennia. However, precision timekeeping began in 1656 when an invention of Galileo's, the pendulum, was married to an earlier invention, the escapement. The toothed wheel of the escapement would turn by one tooth at each swing of a pendulum. In so doing it would both nudge the pendulum to keep it swinging and drive the gears that would count those swings. With each pendulum swing, the escapement made a sound that gave us our word "tick", used here to indicate any event that repeats at uniform intervals. This beginning was refined by many improvements, but for centuries, the best clock in the world was always a pendulum clock.

A true clock has two crucial parts: an oscillator to make ticks and a counter to tally them up. The counter of early clocks was always mechanical, usually consisting of gears for counting and hands on a clock face to display the count. With today's precision clocks, the ticks come at a much higher rate, and the counter is always electronic rather than mechanical. In either case, it is possible to count perfectly. No ticks need ever be lost. But it is not possible to make a perfect oscillator, so it will never be possible to keep perfect time. The history of precision clocks is a story of better and better oscillators, devices that tick more and more uniformly.

Electronic oscillators controlled by a slice of crystalline quartz were introduced in the 1930's. They would tick at a rate determined by the very stable dimensions of the slice and quickly displaced the pendulum as the heart of the world's best precision clocks. Thus, the word "Quartz" appears on most wristwatch faces.

The next major advance was the atomic beam clock. In such a clock, a stream of individual atoms, usually cesium, is exposed to a microwave radio field that is derived from the tick rate of the clock's oscillator. The oscillator is adjusted until the microwave frequency matches a natural resonance of the atoms and produces an observable change in the beam. Note that an atomic clock is not radioactive and has no connection with atomic, more properly called nuclear, energy. Rather, it is named for its dependence on the properties of individual atoms that are not part of any molecule or crystal. The first reliable cesium beam clock was introduced in 1955, and quickly became the world's best clock.

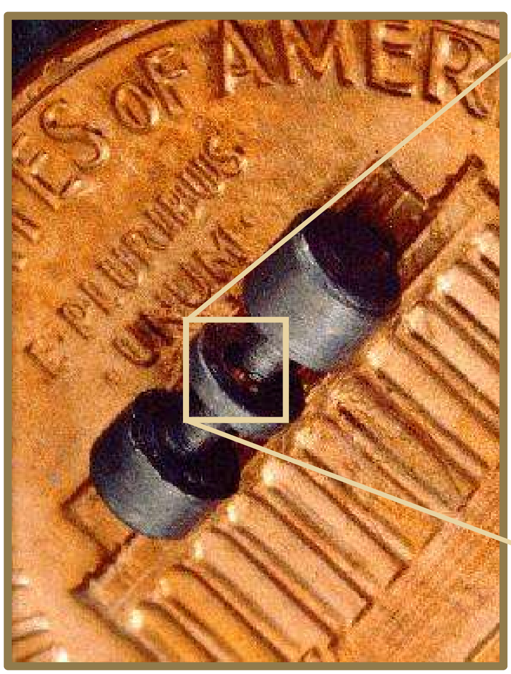


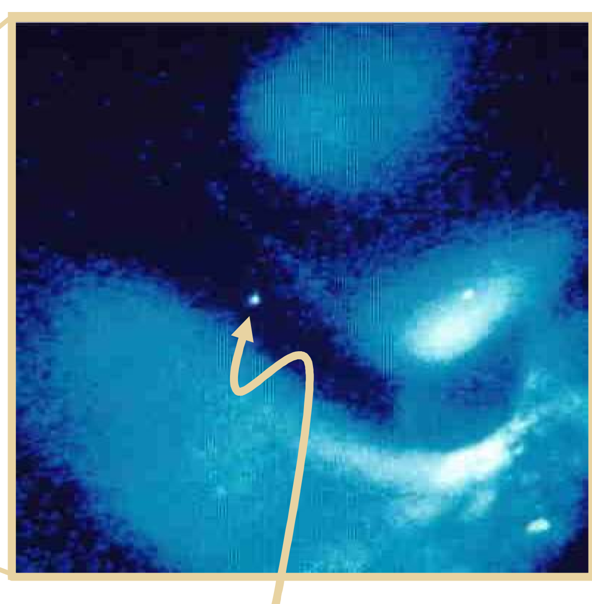
Dr. David Wineland

Today the atomic fountain clock is replacing the atomic beam clock. The atoms forming the fountain are caught in a net woven of laser beams and tossed up through the microwave radio field. They rise up a foot or two and then fall back through the field to be examined for effects of the experience. Again, the clock matches the microwave frequency to the atomic resonance. When compared with the quick flight of an atom through the beam clock, the longer time that the atoms of the fountain clock spend rising up, turning around and then falling back through the microwaves, increases the accuracy of the oscillator. The progress in timekeeping since the 1930s has been stunning. The pendulum clock is accurate to about 15 seconds per day. If you could run an atomic clock the entire age of the universe, it would be accurate to 1 second.

One of the remaining limits to clock accuracy could be lifted by increasing the frequency of the atomic resonance from the microwave region into the optical region, thereby making better use of the time that an atom spends under observation. Clock designs now being considered by scientists, such as Dr. David Wineland, include the change into the optical region.

Another limitation is a very surprising one: The theory of relativity describes effects that usually can be seen only in situations that include very high speeds or very large masses. In ordinary situations, the effects of relativity are unobservably small. However, the precision of existing clocks is already very high, making even the tiny effect of temperature on the flow of time cause an important error. Although they are carefully cooled in current generation clocks to a temperature near absolute zero, the atoms are not yet cold enough to avoid any error. Dr. David Wineland has originated techniques for getting them even colder. In some new atomic clocks, light both contains and cools the atoms, with the optical signal derived from the tick rate of the oscillator matching the inherent optical resonance of the atoms. Dr. Wineland and his colleagues, along with many other groups around the world raise the prospect of an atomic clock of unprecedented accuracy.





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Alexandra Haslam
Associate Director of Advancement, Natural Sciences
UW College of Arts & Sciences

alexeck3@uw.edu
206-616-1989