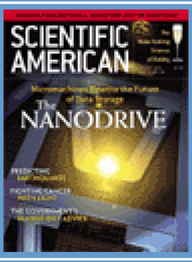

Ask the Experts: Physics

How does one arrive at the exact number of cycles of radiation a cesium-133 atom makes in order to define one second?

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Donald B. Sullivan, a physicist and chief of the time and frequency division of the National Institute of Standards and Technology, explains.

When the cesium second was defined in 1967, it was based on a measurement of the number of cycles of the radiation from a particular cesium-133 transition with reference to the second commonly used in civilian timekeeping, which at that time was based on astronomical observations. The objective was to improve the stability of timekeeping in a manner that would be invisible to the general population. The decision to redefine the second was ultimately that of the International Committee of Weights and Measures, an organization that works to standardize and coordinate measurements. At its 13th official meeting in 1967, the committee adopted the following definition: "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."

In making this decision, the committee relied primarily on a measurement first reported in 1958 that compared the cesium transition frequency to the second of ephemeris time, which is defined by the orbital motion of the earth about the sun. A collaboration between the National Physical Laboratory (NPL) in England and the United States Naval Observatory (USNO) produced the measurement. Louis Essen of NPL had just developed the world's first reliable cesium-beam atomic clock, and William Markowitz of USNO had developed a moon-position camera that provided a way to easily access ephemeris time, something that had been previously very difficult to do.

For years prior to this measurement people had recognized that the earth's motions were not sufficiently predictable for highly accurate timekeeping, and alternatives based on atomic clocks were under study. Harold Lyons and his collaborators at the National Bureau of Standards (NBS) (now renamed the National Institute of Standards and Technology (NIST)) made one of the first accurate assessments of the cesium frequency relative to earth-based time in 1952. The cesium-beam standard used for this measurement could be operated for only short periods, so the uncertainty of Lyon's measurement was too large for it to serve as the basis for a new definition.

NPL holds the distinction of developing the first operational cesium-beam atomic clock. Essen received funding for his clock project in 1953 and had a very reliable version running within two years. In a collaboration between Essen and Markowitz, the relative durations of the astronomical and atomic (cesium) seconds were measured over an averaging time of 2.75 years with a final determination that the cesium frequency was 9,192,631,770 ± 20 Hz. The definition of the second accepted internationally uses the exact number produced by this measurement. It is interesting to note that the timing comparison across the Atlantic Ocean was made using a method based on simultaneous reception of the shortwave time signals broadcast by the NBS radio station WWV, which was then located on the east coast of the United States.

The story of these measurements is nicely detailed in *Splitting the Second: The Story of Atomic Time,* by Tony Jones (Institute of Physics, 2000). The report on the measurement of the cesium frequency appeared in *Physical Review Letters,* vol. 1, p. 105, 1958.

Answer posted on December 16, 2002

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