World Sets Atomic Definition of Time

An atomic definition of the second, the international unit of time, was authorized at 1725 Paris time, October 8, 1964, by the Twelfth General Conference of Weights and Measures, meeting in Paris. The International Committee on Weights and Measures, acting for the Conference, temporarily based the definition on an invariant transition of the cesium atom, in expectation of a more exact definition in the future. The new definition, which will facilitate the expression of the results of high-precision time and frequency measurements, is in as close agreement as is experimentally possible with the definition established in 1956, based on the annual orbit of the earth. The 1956 definition has not been formally abandoned. This action was deferred pending the possible replacement of the temporary atomic definition with a permanent one.

The move toward the redefinition was strongly urged by the American delegation to the international convention. It had previously been proposed by the American, Swiss, and German delegations at the Eleventh General Conference held in Paris 4 years ago.

The action taken increases the accuracy of time measurements to a part in one hundred billion, an accuracy two hundred times greater than that formerly achieved by astronomical means. Moreover, these measurements can be accurately determined in a few minutes, as compared to the many years required to achieve an accuracy only one-hundredth as good by astronomical means.

In the past, the unit of time had been established by astronomers observing the movement of stars across the sky as the earth rotates on its axis. A clock was used to relate the instant of meridian crossing for each individual star to the instant of crossing for other stars. By means of a long series of observations, the rate of the clock could be related to the earth's rotation. The earth itself thus became the timekeeper and the clock was used to interpolate the intervals of time between meridian crossings of different stars.

Pendulum clocks, some of which exhibit a stability of performance to within a few thousandths of a second per day, were employed for this purpose until quartz crystal oscillators having even greater stability were developed for time-interval measurements. Neither of these devices, however, maintains a rate which is as constant as that of the earth.

Prior to 1956 the second was defined as one 86,400th part of the time required for an average rotation of the earth on its axis with respect to the sun. Nevertheless, long before this date astronomers became acutely aware of irregularities in the earth's rotation as compared with the orbital motion of the moon about the earth, the earth about the sun, and various other planetary motions.

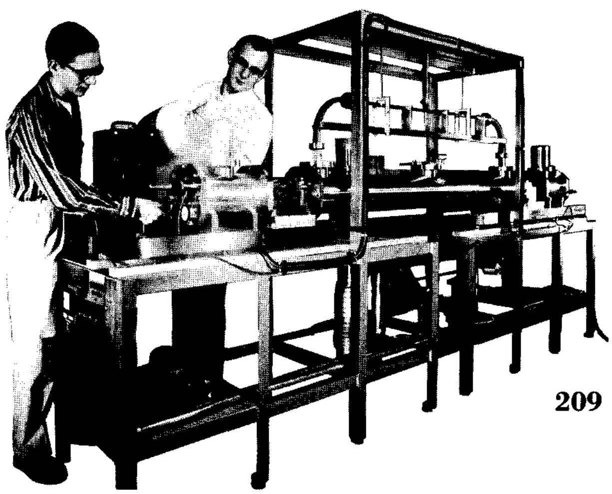
Thus in 1956 an improved arrangement was internationally agreed upon to define the second—called the ephemeris second—as 1/31,556,925.9747 of the time taken by the earth to orbit the sun during the tropical year 1900. Although very exactly stated, this definition could not be realized by astronomical observations with anything like the precision implied by so many digits.

In the 1950's, research on certain atomic transitions indicated that the oscillations associated with them could be realized with great repeatability. One of them, a hyperfine transition in the cesium atom, was related to the ephemeris second with an estimated accuracy of about two parts in a billion. Measurements made with two different instruments,[1] perfected by R. C. Mockler and R. E. Beehler working under J. M. Richardson at the NBS Boulder Laboratories, agreed with each other much more precisely than the measurements made with either instrument could be related to the ephemeris second. This agreement—found to be six parts in 10^{12}, that is, six parts in a million million—means that if two clocks are controlled separately by these two instruments, and if there are no other sources of error, the clocks will differ by only one second after running five thousand years.

The exact wording of the action of the Twelfth General Conference is: "*The standard to be employed is the transition between the two hyperfine levels* $F=4$, $M_F=0$ *and* $F=3$, $M_F=0$ *of the fundamental state* $^2S_{1/2}$ *of the atom of cesium 133 undisturbed by external fields and the value 9 192 631 770 hertz is assigned.*" This definition is tied up with atomic processes taking place in the cesium 133 atom, the only nonradioactive nuclide of cesium which is different from the radioactive cesium nuclei which are produced in atomic explosions.

How an Atomic "Clock" Operates

Since atomic nuclei and electrons have magnetic moments, they may be lined up parallel or anti-parallel with each other. The energy of one atom may differ from another one, depending upon which alinement prevails. If a transition from one energy state occurs—by reversal of alinement—the atom can emit or



Cesium atomic clock. Roger Beehler adjusts the atomic beam detector as Charles Snider pours liquid nitrogen into a cold trap at one end of the instrument. The nitrogen helps form a vacuum so that cesium atoms can be beamed through the machine without being deflected by molecules of air.

absorb radiation depending upon the direction of the change. The frequency of this radiation is proportional to the energy difference in the two states as given by Bohr's relationship.

To realize the frequency of this transition, an atomic beam apparatus is used, commonly called an atomic "clock." Metallic cesium is placed in a small chamber which is heated, causing cesium atoms to be emitted through a small hole into a beam tube. The atoms are separated into two beams by passing through an inhomogeneous magnetic field. Those with parallel magnetic moments go into one beam; those with anti-parallel moments into the other. If now the beams are subjected to an oscillating electromagnetic field, the magnetic moments can be flipped from the parallel to the anti-parallel relationship or vice versa.

Thus when the two beams are passed through a second inhomogeneous magnetic field, parallel alined atoms appear in the beam that was previously all anti-parallel, and anti-parallel atoms appear in the other. Only those atoms that have been switched can enter a chamber containing a hot wire where they are ionized and detected. If the frequency of the oscillating field is not exactly that characteristic of the transition, none of the magnetic moments are flipped and no signal is received from the detector. The operator can adjust the frequency of the oscillator which applies the electromagnetic field until he receives a signal. Then the frequency of his oscillator is exactly that of the defined frequency and other oscillators can be adjusted to it.

By well-known electronic techniques the cycles of the oscillator can be counted—9 192 631 770 cycles of the oscillator are equal to exactly one second. In practice, however, oscillators are operated at other frequencies related to the cesium frequency by various circuit devices. These devices are used for the counting; they are operated continuously and they a-- checked from time to time against the cesium standa

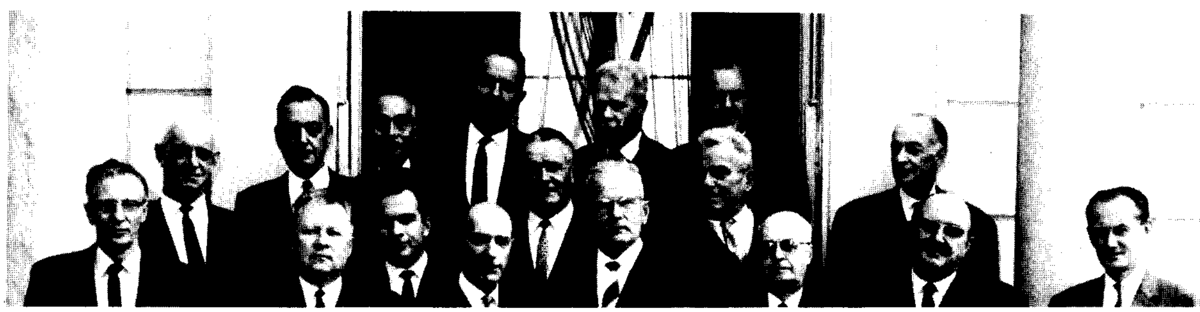
By use of this technique a very accurate scale of time can be established without reference to the earth's rotation or the planetary motions. Atomic time scales kept for several years at the National Bureau of Standards, under J. A. Barnes, and at the Naval Observatory, under William Markowitz, have shown close agreement with each other and with those kept in several European laboratories, differing by only about a millisecond during the last two years.

The atomic time and frequency are made available to users by broadcast from various radio stations throughout the world, such as NBS Station WWV and NBA, operated by the U.S. Navy.

Although the atomic definition of the second enables scientists to maintain more accurate and immediately available scales of time and of time intervals, astronomers are not put out of business in this timekeeping game. The earth's rotation is sufficiently irregular that for the navigator and the space scientist timing signals must be correlated with the earth's rotation. It is still the astronomer's responsibility to tell us when the seasons come and go, when eclipses are to be expected, and when Easter is supposed to be. The new atomic timekeeping is a great aid to the astronomer to help him keep track of the planets. Eventually, he will be faced with the problem of determining whether the time kept by an atomic standard is the same as that kept by the planetary motions.

[1] *For additional details on the NBS atomic beam spectrometers, see* Atomic frequency standards, *NBS Tech. News Bull.* **45**, *8 (1961)*.

Attending 53d Meeting of the International Committee of Weights and Measures



First row, left to right: A. V. Astin, U.S.A.; Bourdon, Russia; Terrien, Director of International Bureau; Vieweg, Chairman at time of International Committee of Weights and Measures and former President of PTB-Germany; Sandoval, Mexico; Otero, Spain; Siegbahn, Sweden. Second row: Barrell, Chief of Metrology, NPL England; Howlett, Director, Applied Physics Division, National Research Council, Canada; Interpreter for Russian Delegation; Stulla-Gotz, Austria; Nussberger, Czechoslovakia; Volet, Former Director of International Bureau of Weights and Measures (observer). Third row: Yamauti, Japan; deBoer, Netherlands; Vaisala, Finland; Lehany, Australia. Absent members: Kichlu, India; Marechal, France; Isnardi, Argentina; and Kargatchin, Yugoslavia. (Upon the resignation of Dr. Vieweg, Dr. Howlett was elected Chairman of the Committee on October 13, 1964; Otero, Vice Chairman; and deBoer, Secretary.) Photo courtesy of Comité International des Poids et Mesures.