A matter of time

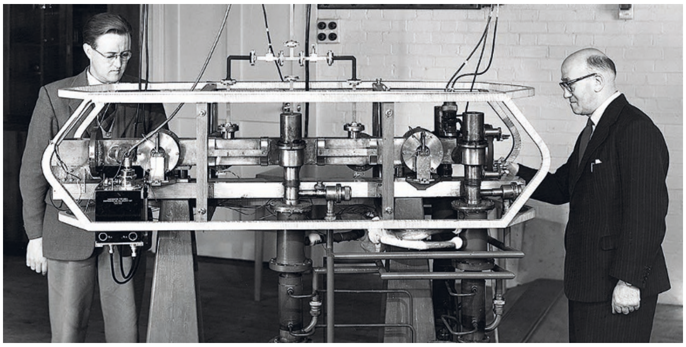
The arrival of a new type of timekeeper heralds the end of the second as we know it, as **Helen Margolis** explains.

Fifty years ago, the General Conference on Weights and Measures decided that the time had come for a new definition of the second[1], and declared that "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." This decision marked a fundamental shift in philosophy — a move away from previous astronomical definitions to one based on a quantum phenomenon.

The underlying principle — that a transition between discrete atomic energy levels could serve as a natural unit of frequency — had been understood for decades. But it was only twelve years previously that Louis Essen (pictured, right) and Jack Parry (left) had built the first caesium atomic clock at the UK's National Physical Laboratory (NPL). They first observed the atomic resonance line in May 1955 and Essen later wrote[2]: "We invited the Director to come and witness the death of the astronomical second and the birth of atomic time."

By carefully studying the dependence of the resonance frequency on environmental conditions, Essen and Parry definitively showed that their new clock was much more stable than astronomical timescales based on the motion of celestial bodies. But this was not enough. A basic tenet of metrology is that a new definition of any measurement unit should be consistent with the old one to within the measurement uncertainty.

It was therefore necessary to measure the frequency of the caesium clock against the astronomical second. For Essen and Parry, this meant the timescale disseminated by the Royal Greenwich Observatory (RGO), which was based on observations of the Earth's rotation about its axis. Their first report on the operation of their caesium clock[3], including a preliminary frequency measurement, appeared in August 1955, and was later followed by a more detailed paper and an improved frequency measurement[4].



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However, the Earth's period of rotation is not constant. Although the RGO applied corrections for seasonal fluctuations and movement of the rotation axis, it was known that such astronomical timescales also suffered from long-term drift. Seeking a more stable unit of time, astronomers had chosen to move to ephemeris time, based on the period of the orbital motion of the Earth around the Sun. In 1956, the International Committee for Weights and Measures followed suit, selecting the second of ephemeris time to be the base unit of time in the International System of Units.

Although ephemeris time was more stable, the period of the orbital motion of the Earth about the Sun was impractically long for most measurement purposes. Nevertheless, Essen now needed to link the caesium frequency to the ephemeris second. He achieved this by collaborating with William Markowitz from the United States Naval Observatory (USNO), who used a novel type of moon camera to observe the Moon's position over a three-year period, thus obtaining a precise realization of the ephemeris second. Long-range radio time signals were used to compare the timescales at NPL and USNO, enabling the frequency of the NPL caesium clock to be measured relative to the ephemeris second[5]. The measurement uncertainty of 20 Hz was dominated by the uncertainties of the astronomical observations and the timescale comparisons rather than by the uncertainty of the caesium clock itself, and the numerical value obtained is the one that appears in the 1967 definition of the second.

The choice of the caesium transition as the basis for the definition has proved in hindsight to be a very good one. The accuracy of caesium clocks has steadily improved, and today's best caesium fountain primary frequency standards are now accurate to one part in 10^{16}.

Recently, however, a new generation of optical atomic clocks has surpassed the performance of caesium atomic clocks in both stability and estimated uncertainty[6,7], raising the prospect of a future redefinition of the second. These new clocks derive their improved precision from their much higher operating frequencies — about five orders of magnitude higher than the microwave absorption frequency in caesium. Although significant work remains to validate the uncertainty budgets of the optical clocks via international comparisons, to incorporate them into international timescales and to establish the leading contender for a new definition, the days of the caesium-based definition are almost certainly numbered. ❐

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