MEASUREMENT OF LIGHT FREQUENCIES

Zoltan Bay alines a KDP crystal with the active beam of a helium-neon gas laser in preparing to redetermine the velocity of light.

A Method for Obtaining Precision Measurements of the frequency of visible light, by directly relating these measurements to the microwave frequency standards provided by atomic clocks,[1] is being developed at the NBS Institute for Basic Standards. The method was conceived by atomic physicists Z. Bay and G. G. Luther[2] of the Institute's Atomic and Molecular Physics Division. The aims of the method extend beyond frequency measurements to include the establishment of reference lines for spectroscopy and length measurements, and to improve precision in measuring the speed of light, c. Subsequently, time-of-flight measurements by terrestrial and space radar may be translated to direct distances using the new method.

The main pieces of apparatus used in this method include a helium-neon gas laser, a microwave modulated electro-optic crystal, and a Fabry-Perot interferometer. Extremely sensitive servo systems that position the reflecting mirrors of both the laser and interferometer are responsible for the great precision in measurements using the new method.

The laser beam of frequency ν is modulated electro-optically at the microwave frequency ω, by a potassium-dihydrogen-phosphate (KDP) crystal placed inside the laser cavity. The modulation generates two sidebands having frequencies, $\nu+\omega$ and $\nu-\omega$, which are separated from the main laser beam by passage through a birefringent calcite plate. The two sidebands then enter an evacuated Fabry-Perot interferometer of very high finesse. A double servo system adjusts the length of the interferometer and simultaneously the length of the laser cavity so that both sidebands are transmitted with maximum transparency through the interferometer. From the theory of the Fabry-Perot interferometer, the ratio of the two measured sideband frequencies $(\nu+\omega)/(\nu-\omega)$ can be deduced to equal the ratio of two known integers —the so-called order numbers, N, that refer to the total number of wavelengths of each frequency analyzed by the interferometer. Since the difference of the two frequencies, 2ω, is known very precisely with respect to the frequency standard, one is able to compute the stabilized optical frequency, ν, as a rational multiple of ω. Thus the measurement of the very high optical frequencies (as high as 10^{14} to 10^{15} Hz, for which no direct measuring devices, operating fast enough, are known at present) is reduced to the known techniques of the measurement of the relatively low (10^{10} to 10^{11} Hz) microwave frequencies.

The computation for determining the laser frequency requires neither the knowledge of c nor the use of any length measurements. This suggests that the new method may have interesting applications for future measuring techniques.

The present experiments have incorporated the 6328 Å red line of a helium-neon laser, but the stabilization and frequency measurement is applicable to any laser line. Reference lines for spectroscopy can be established throughout the spectrum in terms of stabilized laser lines of known frequencies.

Combining corresponding wavelength (λ) and frequency (ν) measurements leads to a redetermination of c by applying the equation $c=\lambda\nu$. Since the expectation is that the new method can provide frequency measurements with a precision of one part in 10^9, or better, the limiting accuracy in the measurement of c will be given by that of the krypton-86 line that defines the meter at present to one part in 10^8. In the future two different approaches to the problem of improving the length standard are possible.

In the first approach, the precision of the length standard can be improved by choosing one well stabilized laser line, instead of the krypton-86 line emitted by a gas-discharge lamp.

The second approach is to base the new definition of the meter on a specified value of c such that it is compatible with the present meter. Then all the reference lines of known frequencies can serve simultaneously as reference lines for length measurements because their wavelength is known as $\lambda=c/\nu$. It follows from a basic contention of present theoretical physics that the value of c remains the same regardless of the local frame of measurement reference.

The comparison of frequencies represents an easier task for future metrology than the intercomparison of wavelengths in distant parts of the spectrum. Therefore, Drs. Bay and Luther prefer the second approach for a new and final definition of the meter.

[1] Atomic second adopted as international unit of time, Nat. Bur. Stand. (U.S.), Tech. News Bull. 52, No. 1, 10-12 (Jan. 1968).

[2] Bay, Z., and Luther, G., G., Locking a laser frequency to the time standard, Appl. Phys. Letters 13, No. 9, 303-304 (Nov. 1968).