CEN Tech. J., vol. 7(1), 1993, pp. 88–92

A Time-Independent Measurement of the Speed of Light

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ABSTRACT

A technique designed to measure the speed of light without reference to absolute timing methods has been developed and performed. The technique made use of an uncalibrated quartz clock that was then calibrated using only concepts of classical physics. Relativity was also considered, but had little effect on the conclusions of the work. The value for the speed of light (in vacuum) obtained using this method was c = *(2.999±0.073) x* 10^8 *m/sec.*

INTRODUCTION

Since Setterfield first published[1,2] his hypothesis that the speed of light has decreased over time, creationists have made much of its apparent implications in the realm of cosmology. Several articles have been published recently[3–16] demonstrating exactly how vigorously the hypothesis has been debated among creationists. The hypothesis seems to have its ardent critics as well as its fervent supporters. The purpose of this paper is neither to align the author with either camp nor to try to debate the relative merits of Setterfield's hypothesis in the light of the data. Instead, this study will examine one of the critical questions that has been left unanswered since the beginning of the entire debate.

Based on Hasofer's data table[17] and Evered's graph,[18] the measured value for the speed of light has changed (in an apparently random fashion) less than 0.3% over the last 90 years. This would imply that the speed of light has been relatively constant, at least over the last 90 years. If the speed of light really has been decaying over time, why has it ceased to decay recently? The standard answer to this question, according to those who support Setterfield's hypothesis, is that the current methods used for determining the speed of light rely on the validity of either quartz-oscillation clocks or atomic clocks. If the speed of light (a fundamental constant in nature) is truly changing, then the fundamental constants that determine the frequency of quartz oscillations or the frequency of interatomic transitions are also changing. If that is the case, then the rates of change may cancel each other out, making it appear that the speed of light is constant, when in fact, all fundamental constants are decaying.

In this work, I report on a method for determining the speed of light that is completely independent of the absolute frequency of the oscillations in the quartz clock that was used to time the physical events studied. Instead, the method employs simple rules of Newtonian physics to calibrate the clock. With that independent calibration, the velocity of γ-rays from a ^{252}Cf source was measured.

EXPERIMENTAL PROCEDURE

The main experimental apparati employed in this study were two thallium-doped sodium iodide crystal[19] [NaI(Tl)] detectors. When particles (in this experiment, either γ-rays or α-particles) pass through these crystals, they lose energy via direct and indirect interactions with the atoms of the crystals. The indirect interaction is that of Coulomb repulsion between the positively-charged nuclei, whereas the direct interaction results from collisions between the electrons in the crystals and the particles passing through. During these interactions, the particles lose kinetic energy, and that energy excites the atoms in the crystals. After excitation, those atoms must decay to their ground states by emitting light. The light is then collected by a photomultiplier[20] tube which sends an electronic signal to a computer when it detects the presence of photons. Since γ-rays do not interact with these crystals via the Coulomb force, they can be easily discriminated from charged particles.

Two such Nal(Tl) detectors were placed 0.200 metres from each other in an evacuated tube (see Figure 1). The pressure inside the tube was a constant 3.2 x 10^{-7} torr throughout the entire experiment, and the distance between the detectors was variable. A ^{252}Cf source[21] was taped to the front of one of the detectors. This radioactive isotope of californium decays via either spontaneous fission (3%) or

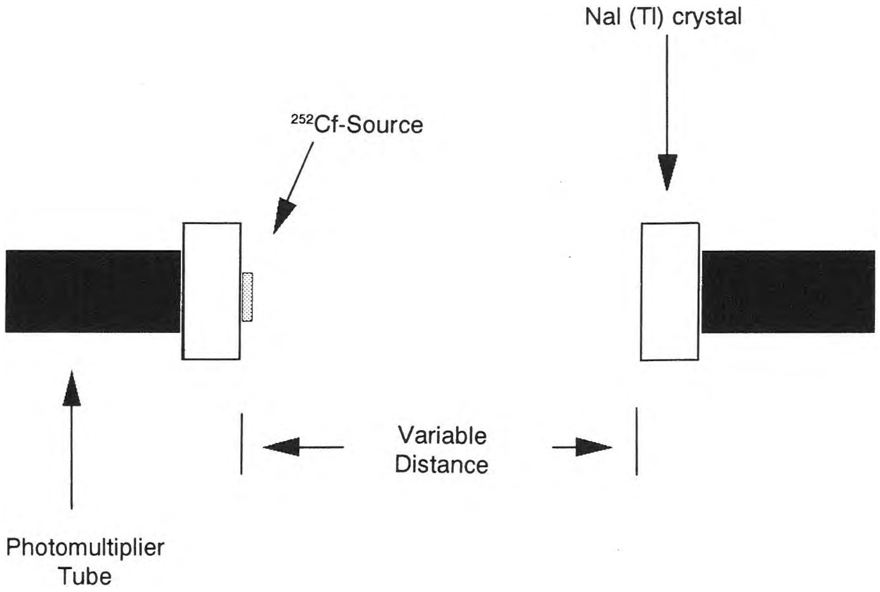

Figure 1. *A schematic diagram of the experiment. The distance between the two detectors was varied from 0.200 to 3.000 metres.*

α-particle emission (97%). No matter which decay mode is chosen by the nucleus, γ-rays are also emitted in the decay chain. This experiment exploits the α-particles/γ-ray decay scheme of the ^{252}Cf nucleus.

The NaI(Tl) detector closest to the source was covered with a shell of aluminum so that it would detect only γ-rays (α-particles are stopped in the aluminum and never make it into the crystal). When it detected a γ-ray, the detector sent an electronic signal to a quartz-oscillation clock. The clock began to count the number of oscillations in the quartz until it received an electronic signal from the other NaI(Tl) detector, indicating that the emitted α-particle had travelled the 0.200-metre distance and was detected. The face of the second NaI(Tl) detector was not covered in aluminum so that α-particles could be detected. A digital number that was proportional to the total number of quartz crystal oscillations counted by the clock during the flight time of the α-particle was recorded by the computer.

In Figure 2, a histogram of the resulting data is presented. The x-axis of the graph is proportional to the number of quartz oscillations read by the clock, whereas the y-axis reports how many α-particles hit the second detector after that many oscillations. The centroid of the large peak represents the sum of two unresolved α-particle peaks. A 6.112 MeV α-particle[22] is emitted from the source 85% of the time, whereas a lower energy, 6.069 MeV α-particle[23] is emitted 15% of the time. The centroid of this peak, then, corresponds to a weighted average between the two α-particles (6.106 MeV). Ordinarily, one would calibrate this time spectrum by dividing the x-axis by the number of quartz oscillations per second. That would then convert the x-axis into absolute time units. However, the conversion between the number of quartz oscillations and the number of seconds that have passed is what is questioned by those who hold the Setterfield hypothesis. Thus, another method must be used to calibrate the x-axis into absolute time units. The answer lies in the kinetic energy of the emitted α-particles.

The energy of these α-particles is well-known and has been measured in several different ways.[24] The α-particles have been stopped in a gas-filled proportional counter. As they are stopped in the proportional counter, they transfer their kinetic energy to the electrons in the gas, thus freeing the electrons from the gas molecules. The electrons travel in an applied electric field and are measured as electrical current. The current is directly proportional to the energy of the incident particle, and the proportionality constant is trivially calculated by simple laws of momentum transfer. Also, the α-particles have been passed through thin foils and the amount of energy lost by the particles has been measured. Once again, the amount of energy lost by an α-particle in a thin foil is easily calculated based on Coulomb's law and momentum transfer.

This author performed another experiment in order to test the value of kinetic energy assigned to the α-particles. A collimated ^{252}Cf source was placed in an evacuated tube directly in front of an electromagnet. The electromagnet was used to bend the α-particles through an angle of 90.0°. For an applied field of 0.670 Tesla, the radius of curvature of the α-particles' path was measured to be (0.534 ± 0.09) metres. This is exactly what one would expect according to the classical physics equation:

$$r = mv/(qB) \qquad (1)$$

if the α-particles, indeed, had a kinetic energy of 6.106

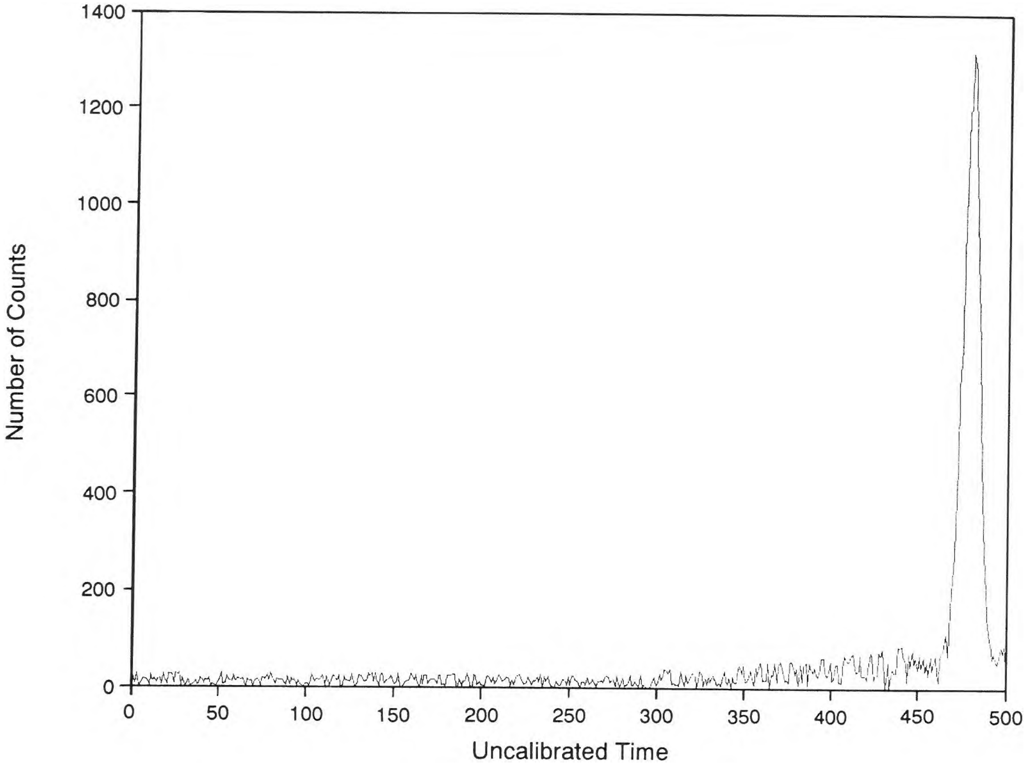

Figure 2. *Time of flight spectrum for the α-particles from a ^{252}Cf source. The flight distance for the α-particles was 0.200 metres.*

MeV. Clearly this method is independent of all atomic-clock-related constants. The mass, charge, magnetic field, and radius of curvature are all experimentally measurable variables, thus the resulting velocity **must** be correct. With these three different methods of measuring the kinetic energy of the α-particles, all of which are independent of the value of atomic-clock-related constants, we can be very confident that these α-particles have an average kinetic energy of exactly 6.106 MeV.

According to Newton, the kinetic energy of a particle is related to its velocity via the equation:

$$\textit{Kinetic Energy} = \tfrac{1}{2}mv^2 \qquad (2)$$

thus, since we know both the kinetic energy and the mass of the α-particles, the velocity can then be calculated. Once the velocity has been calculated, the time it takes those α-particles to travel 0.200 metres can be calculated. The position of the time peak in Figure 2 will correspond exactly to that time.

This procedure was repeated for various distances between the detectors. A total of seven distances were chosen: 0.050 metres, 0.070 metres, 0.100 metres, 0.130 metres, 0.160 metres, 0.190 metres, and 0.200 metres. These different distances, of course, led to different α-particle flight times. These different flight times, all of which can be calculated with equation (2), provide a nice calibration curve between the electronic readout of the quartz-oscillation clock and the absolute time. This curve is illustrated in Figure 3. Notice in this figure that the calibration curve is exactly linear. The offset in time at an electronic readout of zero is a reflection of the inherent time delays in the electronic cables used in the experiment and, of course, does not affect the reliability of the data collected. This method, then, gives an absolute calibration for the quartz-oscillation clock that is completely independent of any fundamental constants. The only physical concepts used to calibrate this clock were the known energy of the ^{252}Cf α-particles, equation (2), and the assumption that the frequency of the quartz-oscillations was constant (to within 2.4%) over the 20-day period of the experiment.

Given the above calibration, the experiment was then turned around to measure the speed of the γ-rays (light) emitted by the ^{252}Cf source. In this experiment, the detector closest to the source detected the α-particles emitted in the decay, and that signal was used to start the quartz-oscillation clock. When the second detector measured a γ-ray, the clock was stopped. Because the γ-rays travel much faster than the α-particles, the distance between the detectors was expanded to 3.000 metres. This is absolutely necessary because the results depend on the time calibration given by the first experiment, thus, none of the electronic data acquisition could be changed between the two experiments.

The resulting data is presented in Figure 4. Using the calibration curve discussed above (which is independent of the value of any fundamental constants), the time it took the γ-rays to travel 3.000 metres was 1.000 x 10^{-8} seconds. This corresponds to 3.000 x 10^{8} m/sec. for the velocity of light,

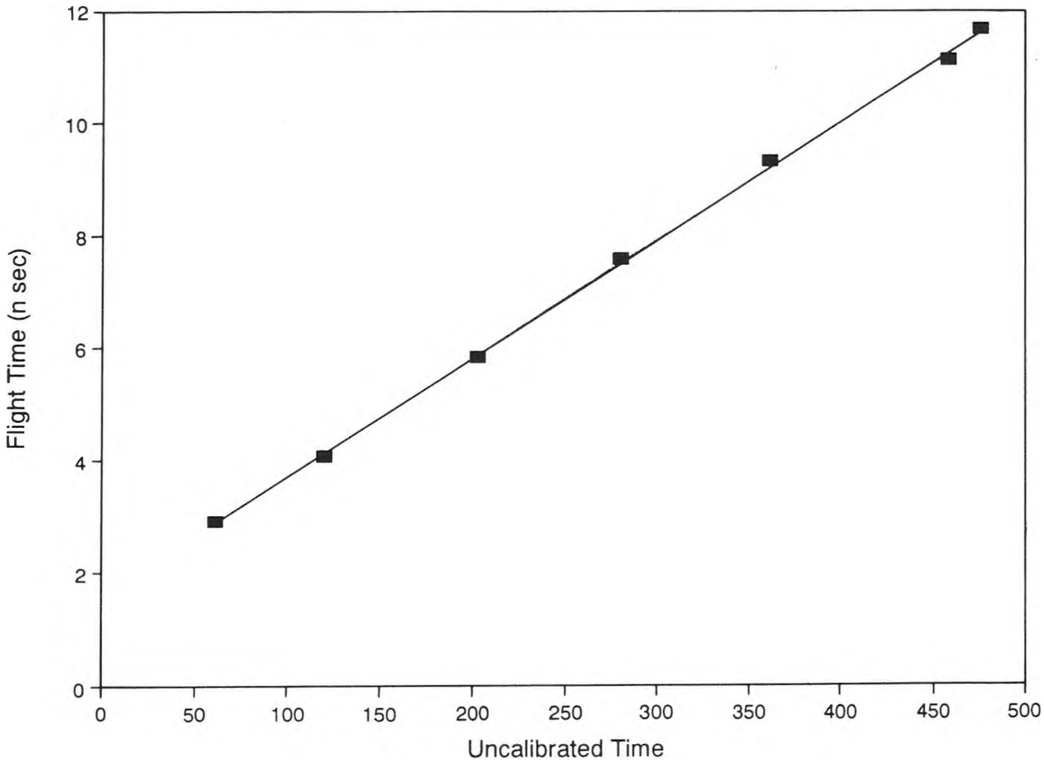

Figure 3. *The calibration curve for the quartz-oscillation clock used in the experiment. The line is the result of linear regression performed on the data. The formula from the linear regression was used to analyze the γ-ray data.*

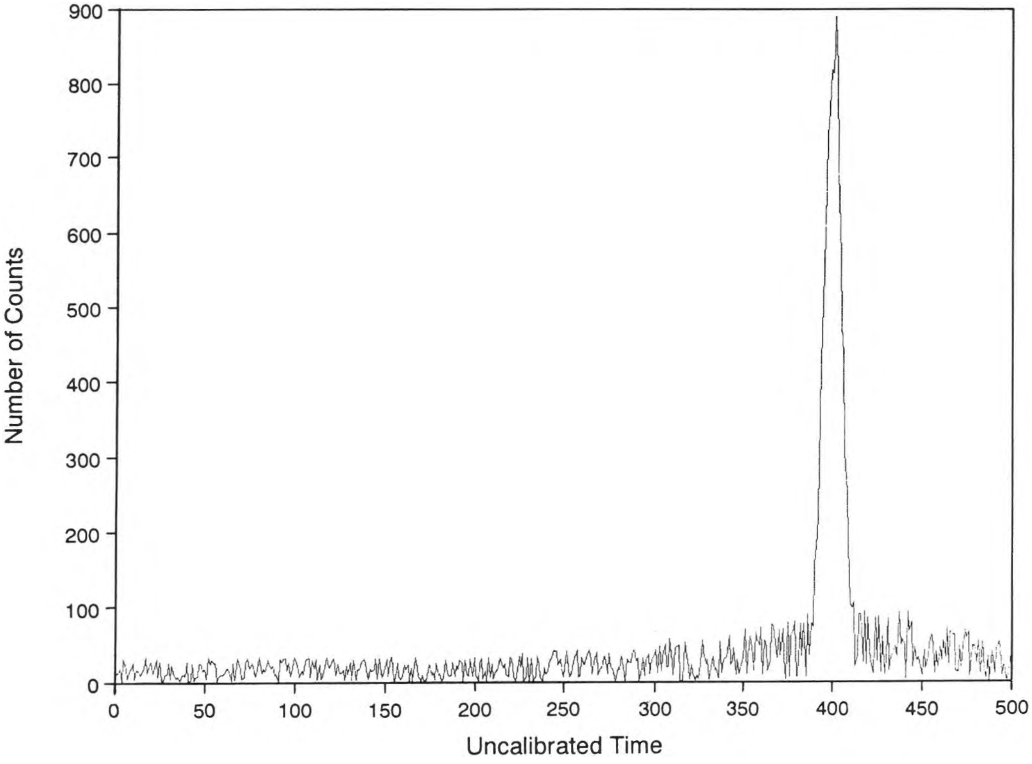

Figure 4. *Time of flight spectrum for γ-rays from a ^{252}Cf source. According to the calibration, the centroid of this peak lies at **10.0** nanoseconds. The flight distance was **3.000** metres.*

which is perfectly consistent with the conclusion that the speed of light has not changed over the last 90 years.

One correction must still be made, however. It is well known[25] that when massive particles (such as α-particles) travel near the speed of light, equation (2) begins to break down. According to equation (2), the α-particles which were used to calibrate the clock were travelling at 1.716 x 10^7 m/sec. That is more than 5% of the speed of light. Thus, one must use the following relativistically correct equation in order to convert from particle kinetic energy to particle velocity:

$$Kinetic\ Energy = \left[\frac{mc^2}{\sqrt{(1-\frac{v^2}{c^2})}}\right] - mc^2 \qquad (3)$$

where *m* is the mass, v is the velocity, and c is the speed of light. Using the above listed value for the speed of light, one calculates that the true velocity of the α-particles is 1.714 x 10^7 m/sec. Even though this is only a 0.1% change in the velocity, the calibration was redone and the resulting speed of light was 2.999 x 10^8 m/sec. Clearly, whether one believes in the special theory of relativity or not, the conclusions of the study remain unchanged when relativity is taken into account.

Finally, the issue of errors must be addressed in this study. The best indication of the time resolution is the width of the γ-ray time spectrum presented in Figure 4. According to that width, the time resolution achieved in the experiment was 0.0230 x 10^{-8} seconds. This time resolution would cause a maximum error of 0.067 x 10^8 m/sec. Due to the excellent statistical quality of the data, the statistical error was a mere 0.006 x 10^8 m/sec. Thus, an absolute upper limit to the experimental error is 0.073 x 10^8 m/sec. This corresponds to an upper limit of 2.4%. This error is, of course, an absolute maximum. Since the data comes from the average of over 15,000 events, the time resolution does not play such a crucial role in the experimental error. In my opinion, the true experimental error is closer to 0.5%.

CONCLUSIONS

This experiment, which measures the speed of light using calibration methods that are independent of the values of any fundamental constants, gives a value of $c = (2.999 \pm 0.073) \times 10^8$ m/sec. This value for c is perfectly consistent with the conclusion that the velocity of light has not changed significantly in the past 90 years. In addition, since this method confirms the velocity of light as measured by other methods that use quartz-oscillation and atomic transition clocks, one can further conclude that, indeed, the fundamental constants which determine the absolute frequency of these physical phenomena have also not changed significantly. Thus, any attempt to formulate a physical/mathematical description of the Setterfield hypothesis must somehow explain why the speed of light has remained constant in the recent past.

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