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BRIEF REPORTS

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Effect of the solar eclipse on the period of a torsion pendulum

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During the solar eclipse of 22 July 1990 in Finland the period of a torsion pendulum was measured. In previous experiments of this kind [Phys. Rev. D 3, 823 (1971)] a considerable increase was found in the period of the pendulum during the solar eclipse. In our experiment, however, no significant change in the period was observed. The relative change in the pendulum's period associated with the eclipse was found to be less than 4.3×10^{-6} (90% confidence).

I. INTRODUCTION

The behavior of a torsion pendulum during the solar eclipse has been previously studied by Saxl and Allen.[1] They found on the solar eclipse of 7 March 1970 that between the onset of the eclipse and its midpoint there was a steady increase in the observed times required for the torsion pendulum to rotate through a fixed part of its path. After the midpoint the times leveled off to values greater than those observed before the eclipse. The purpose of this work was to reexamine these effects with a similar apparatus during the solar eclipse of 22 July 1990 in Finland. Other gravity experiments during the solar eclipse have been reported by Caputo[2] and Allais.[3] Reference 4 is a review article of experiments on gravity.

II. EXPERIMENTAL PROCEDURE

The torsion pendulum used in our experiment consisted of a disk made of brass (diameter 247.0 mm, thickness 29.70 mm, mass 12 kg), and a steel wire (length 1.00 m, diameter 1.00 mm). Both ends of the wire were soldered on two bolts with silver-cadmium solder, whose melting point was clearly below the temperature which could change the elastic properties of the steel wire. The bolts were firmly fastened on the hole of the disk and the support structure.

The frame of the support structure (height 120 cm, width 35 cm, length 35 cm) was made of rectangular steel tubes, welded together. The frame was covered with aluminum sheets in order to shield the inside against static electrical field and electromagnetic radiation. The whole cabinet was coated with a 50-mm-thick polyurethan foam to avoid rapid changes in temperature. The cabinet was bolted on a heavy slab of concrete.

The period of the pendulum was measured with a light beam which reflected from a mirror attached to the rotated disk close to the wire. In the equilibrium position of the pendulum the beam fell on a sensitive phototransistor. The beam was produced by an infrared-light-emitting diode, which dissipated very little heat in the cabinet (10 mW). The distance of the light emitter and transmitter from the mirror was 15 cm. The width of the beam was 1 mm.

The signal from the phototransistor was fed into a precision comparator, whose output triggered a counter unit via flip-flop circuits. The counting started when the disk passed the equilibrium position clockwise and ended at the next clockwise pass. The following counting period started at the counterclockwise pass and ended at the next counterclockwise pass. Thus the time data consisted of pairs of passing times. This arrangement gave a possibility of checking the period measurements against systematic errors. Instead of measuring the half-period, as Saxl and Allen did, we measured the whole period, because this method was more accurate and not so prone to systematic errors, especially in the case of damping oscillations. The oscillator of the counterunit was crystal controlled with the nominal frequency 1×10^{6} Hz and a precision better than 0.05 Hz in the relevant range of temperature.

The pendulum was arrested manually at a deviation of about 90° from the equilibrium position. After the release the pendulum was allowed to swing freely. Because of friction between the disk and air, the amplitude of the oscillation decreased exponentially, if the torsional force depends linearly on the angle and the friction on the velocity. In that case the period of the pendulum should be constant regardless of the amplitude. However, the measured period decreased monotonically as the amplitude decreased. This was caused by the fact that the period was not determined exactly at the zero angle, and because of some nonlinearity in the torsional force and friction mechanism. We did not try to find any analytical solution for the period, because we were only interested in some relative changes which could correlate with the phases of the eclipse.

The initial amplitude of the pendulum was not measured, but a sensor was installed which indicated when the amplitude decreased below a certain limit (85°). This enabled us to compare directly data measured in different experiments. After releasing the pendulum, it was possible to measure the period over 21 h, but the errors increased rapidly when the amplitude decreased below about 3°. Normally, the data collected during first 12 h was used.

The apparatus was equipped with optical position sensors which measured the position of the wire in two orthogonal horizontal directions (x and y). These sensors were positioned 9 cm above the disk, and so they could indicate rather well the position of the center of the mass of the disk. The resolution of these sensors was 0.005 mm. Apart from using the sensors to register the movements of the disk during oscillation, they were also used for minimizing undersirable oscillation modes on the initializing procedure. The maximum initial amplitude of the horizontal oscillation was smaller than 0.05 mm. The position sensors also revealed that the fastening point of the wire was 0.03 mm aside from the center of the mass of the disk. The position sensors made it possible to find any changes in the support structure or the wire, which can alter the equilibrium position and produce spurious changes on the period.

The period of the torsion pendulum depends on temperature because the length, thickness, and torsional stiffness of the wire and the dimensions of the disk vary with temperature. We therefore installed two temperatures sensors inside the cabinet, at the bottom and on the top, and one sensor outside. The maximum change in the temperature inside the cabinet during a measurement (12 h) was 0.2 °C. According to the analyses of several runs at different temperatures, the temperature coefficient of the period turned out to be 1.5 ms/°C.

During one swing of the pendulum, the data from the position sensors were recorded about 700 times and the temperature once. The sensor data and content of the counters were collected automatically by a microcomputer and saved on a magnetic disk.

III. RESULTS

The experiment was made in Finland in the city of Turku which lies 25 km from the zone of the totality of the eclipse (99.8% of the Sun was obscured). The first contact happened at 4:04 (local time), when the Sun and Moon were 3.8° below the horizon. At 4:47 the partially obscured sun rose above the horizon. The maximum occurred at 4:54, when the sun was 0.5° above the horizon, and the last contact at 5:46.

The measurement was started 4 h before the first contact, and it was stopped 5 h after the last contact. Figure 1 shows the period of the torsion pendulum as a function of the (local) time. The entire data set consists of 1200 points. The clockwise and counterclockwise data are presented together, as the two data sets did not reveal any systematic discrepancies. The moment of the first contact is marked with a, the maximum with b, and the last contact with c. The measured period decreases exponentially for the reasons explained previously. There

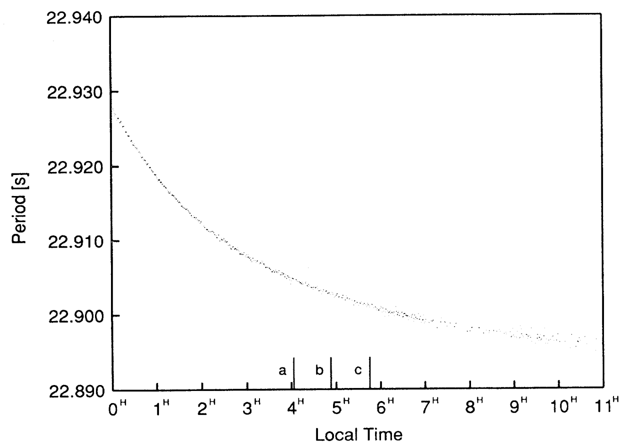

FIG. 1. Period of the torsion pendulum as a function of the (local) time. The first contact is marked with a, the maximum with b, and the last contact with c.

are no obvious anomalies in the smooth behavior of the period curve.

In order to examine more closely possible effects of the eclipse on the period, we eliminated the regular amplitude dependence of the period from the measured data. This was done by calculating the Fourier transform of the experimental data. The result was multiplied by a smooth low-pass filter function, which removed all frequency components above 2.8×10^{-4} Hz (about 1 h in the time scale). After filtration, the output was transformed back to time-series data. This smoothed curve was then subtracted from the original data. The results are shown in Fig. 2. Each dot represents the mean of 20 measurements, and the vertical lines show the mean deviation (90% confidence). As it is expected that the change in the period has the maximum value at the central time of the eclipse, we calculated the mean of the three points nearest to time b in Fig. 2. To estimate the experimental errors, the standard deviation was deter-

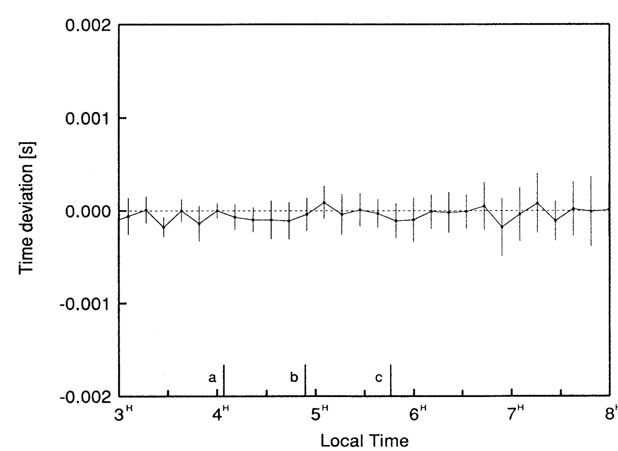

FIG. 2. Normalized period as a function of the (local) time.

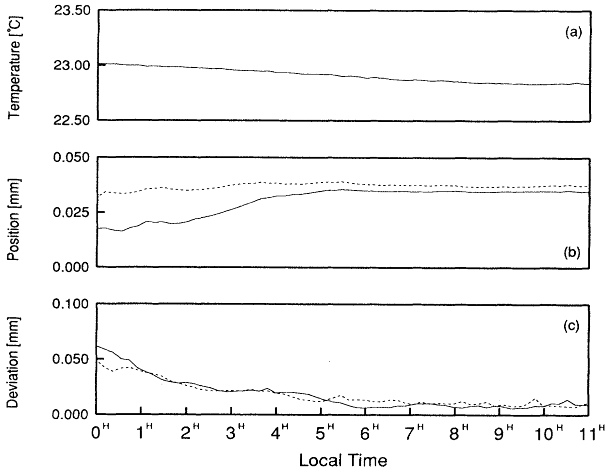

FIG. 3. (a) Temperature of the cabinet; (b) mean x and y positions of the wire in the horizontal plane (x positions, solid line; y position, dashed line); (c) maximum deviation of the position of the wire from the mean value (x deviation, solid line; y deviation, dashed line).

mined for the points in Fig. 2 in the region from 3 to 4 h and from 6 to 8 h, determined from their scatter about the fitted line (in these regions the smoothed curve can explain the time dependency of the period). The calculations showed that the change in the pendulum's period was -0.03 ± 0.07 ms (90% confidence). We can conclude that the deviations are consistent with zero within the experimental errors of ± 0.10 ms, or $\pm 4.3\times 10^{-6}$ when times are normalized with the period of the pendulum (≈ 22.9 s).

The temperature of the cabinet as a function of the time is shown in Fig. 3(a). The temperature change was only 0.1 °C during the experiment, producing a shift of about 0.1 ms on the period of the pendulum. This is smaller than the errors caused by the system measuring the period. The mean x and y positions of the wire in the horizontal plane are presented in Fig. 3(b). The small drift in the x position during first 4 h is possibly connected with the damping of the amplitude. The mean position of the wire changed only 0.025 mm during the measurement period. The maximum deviations from the mean position are shown in Fig. 3(c). The maximum deviations decrease slowly as the undesirable oscillation modes damped away. Obviously, there have not been any essential changes in the support structure or remarkable external disturbances.

Our experiment shows that there is no relative change in the period of the pendulum larger than 4.3×10^{-6}. In the previous experiment,[1] the relative increase was about 2.7×10^{-4}. The dimensions of the pendulum in Ref. 1 were rather similar to ours.[5] It is unlikely that the dimensions are critical. One hypothetical explanation for these two contradictory results is the position of the solar moon system during the eclipse. In the previous work the height of the Sun in the eclipse was 36°, but in our experiment only 0.5°. If the effect is real, it is likely that the angle between the wire of the pendulum and the direction of the Sun is significant.

IV. CONCLUSION

The period of a torsion pendulum was measured during the solar eclipse of 22 July in Finland. Contrary to previous experiments, no increase in the period was observed. The relative change in the pendulum's period associated with the eclipse was found to be less than 4.3×10^{-6} (90% confidence).

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