Measurement of *g* Using a Flashing LED

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In one of the classic free-fall experiments, a small mass is attached to a strip of paper tape and both are allowed to fall through a spark timer, where sparks are generated at regular time intervals. Students analyze marks (dots) left on the tape by the timer, thereby generating distance-versus-time data, which they analyze to extract the acceleration due to gravity *g* with good results. The apparatus, however, is cumbersome and often frustrating for students.[1] High-tech versions of this experiment are done with an object dropped and followed by a motion sensor connected to a computer. The sensor relies on ultrasonic ranging to record distance and time data, which may then be displayed graphically. Students inspect the graphs to determine the value of *g*. Although the results are excellent, the emphasis on the computer's ability to collect and analyze data leaves little analysis for the students to perform.[2] Furthermore, neither technique gives an intuitive display of what is happening. The motivation for our work was to overcome these issues by developing an innovative method for measuring *g*. In our version of the experiment, students drop a flashing LED at a known frequency and record its trajectory using long exposure photography with a digital camera. Proper choice of flashing LED timing parameters produces an image that allows for an accurate measurement of *g* and at the same time helps to explain what happens during free fall. The experiment remains high-tech in the sense that students learn to use updated equipment to record data and to carry out the analysis.

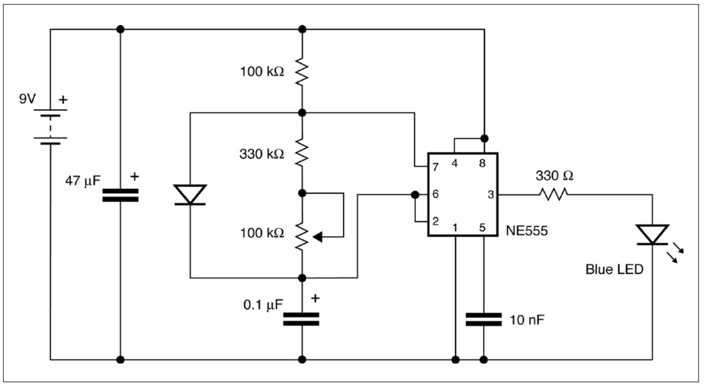

Fig. 1. Electronic circuit for the flashing LED. The diode can be any signal diode.

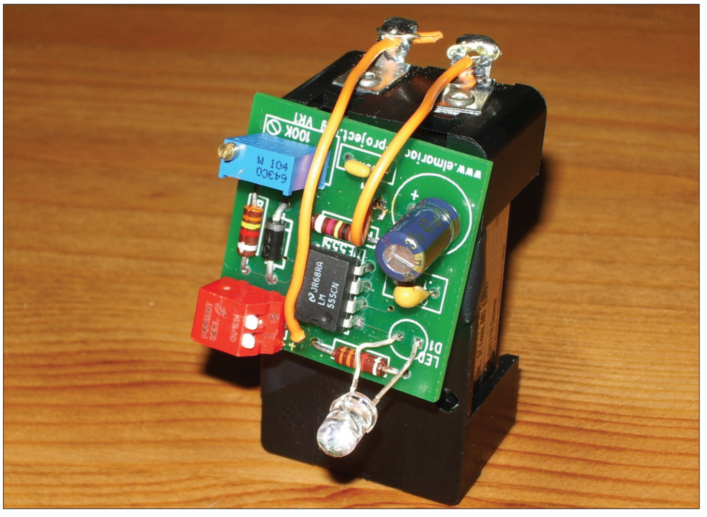

Fig. 2. The flashing LED assembly. Once the circuit is manufactured, it is glued to the 9-V battery case.

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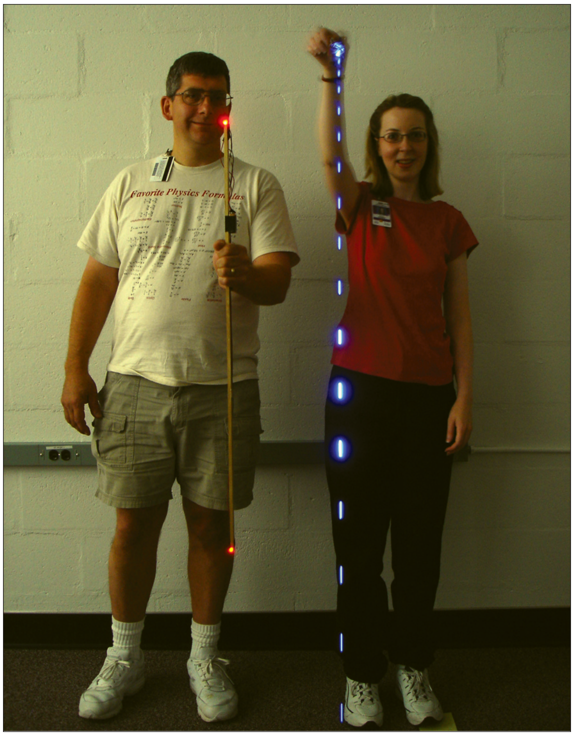

Fig. 3. Typical photograph of the falling LED flashing at 30 Hz. Note the increase in the length of the streaks as the assembly moves toward the ground.

Flashing LED Circuit

The circuit used to flash the LED is shown in Fig. 1. It is based on a well-known 555 oscillator with a turn-on and turn-off time of approximately 50 ns. The printed circuit board and the final assembled circuit, powered by a 9-V battery, are shown in Fig 2. To calibrate the circuit, we measure the flashing frequency using an oscilloscope with probes connected to the LED leads. Alternatively, a frequency meter can be used. The circuit has a nominal flashing frequency of 30 Hz or a period of 33 ms. However, due to the precision of the components, it is necessary to adjust the variable resistor in the circuit in order to achieve this nominal value. When choosing the LED, we find that a super bright blue LED yields the best results.

Experimental Procedure

Figure 3 shows the basic setup of our experiment. A red LED is taped to each end of a meter stick and then connected to a 9-V battery. This meter stick is used as a reference to determine the actual distance the flashing LED has fallen. It is important that the meter stick be held in the same plane (same distance from the camera) as the falling LED. The assembly should be dropped with the LED toward the bottom, facing the camera.

The camera is mounted on a tripod with the timer and f-stop adjusted according to the amount of light in the room. We did our experiments in a room with two windows, covered with blinds, and two doors, which had windows to the hallway. We found that an exposure time of 2 seconds and an f-stop of 5.6 produce good results. We also found that 4 or 5 meters is the optimal distance between camera and LED.

Before beginning the experiment, the person who is dropping the circuit should practice. We found that the best technique is to pinch the battery between the thumb and index finger, and then release it without moving the arm. This method minimizes both sideways drift and rotation of the LED as it falls.

Analysis

Once a photograph of the falling LED is taken, several methods may be employed to measure the acceleration due to gravity, depending on the skill of the students and the intent of the instructor. We outline a simple method in which students construct and analyze graphs of position and velocity as functions of time. To maximize accuracy, an LCD projector is used to enlarge an image of the falling LED on a wall in the classroom. Using the meter stick as a reference, the image is enlarged to its actual size such that distance measurements may be made directly on the wall. An alternative would be to use a hard copy of the photograph, which not only requires converting distances but also increases the error associated with measuring. Note that a turn-on time of 50 ns corresponds to a spatial displacement of 5×10^{-7} m for a velocity of 10 m/s. The calibration accuracy of the flashing frequency is typically 1 part in 3000, and, therefore, the determination of g depends entirely on the precision of the distance measurements.

Starting with the first distinct bright light streak, we label each one starting from 0 (zero). The first point is taken as $t = 0$ s, and subsequent points are taken as n cycles of the flashing LED, where the time interval is 33 ms. Next, we measure the distance from the first point to each subsequent point. With these measurements in hand we can construct a graph of

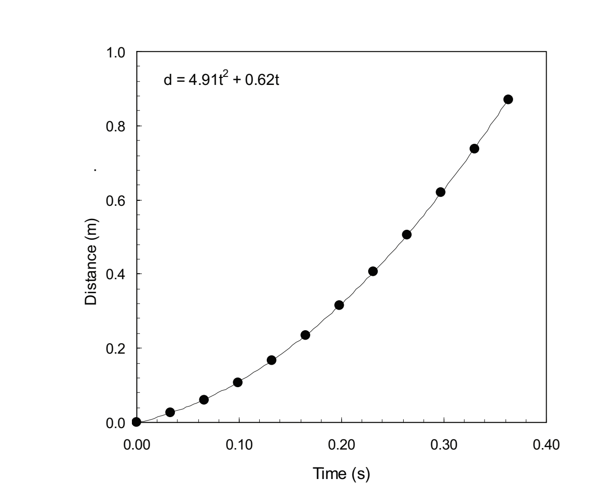

Fig. 4. Position of the falling LED as a function of time. The dashed line shows the best fit to the data points, which gives g = 9.82 m/s^2.

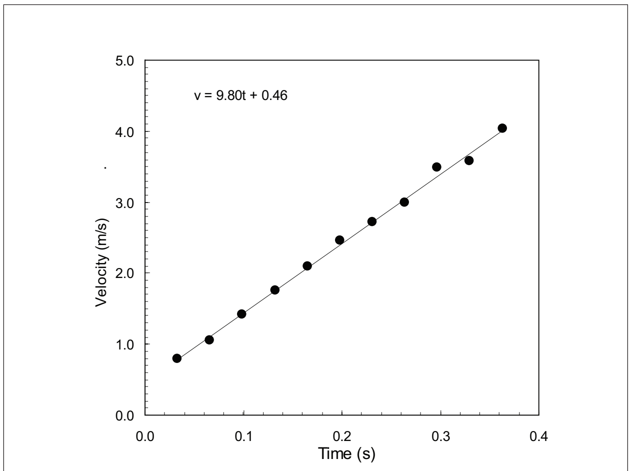

Fig. 5. Velocity of the falling LED as a function of time. The dashed line shows the best fit to the data points, which gives g = 9.80 m/s^2.

position as a function of time or velocity as a function of time, defining velocity as the ratio of the distance between points to the time interval. We extract the value for g by fitting a parabola in the first case and a line for the latter. To facilitate data manipulation, it is convenient to use a spreadsheet such as Microsoft Excel. The results we obtained from our analysis are shown in Figs. 4 and 5. The values obtained for the acceleration due to gravity are g = 9.82 m/s^2 and g = 9.80 m/s^2, respectively. These values are in good agreement with the adopted value[3] of g = 9.806 m/s^2.

Discussion and Conclusions

With the aid of our flashing LED assembly, we have updated the traditional free-fall experiment. However, we have not relied on a computer for data collection. Instead, the students begin by recording the data using a digital camera and complete the experiment by graphing and analyzing the data using a computer.

Once each lab group completes the analysis, we suggest calculating a class average, which may then be compared to the accepted value for g. In addition, regardless of which instrument is used to measure the period of the LED, either a frequency-meter or an oscilloscope, we recommend that this measurement be carried out in a large group setting prior to the start of the experiment. Finally, it may be interesting for students to explain why the falling LED produces bright lines in the photograph, even though it is essentially a point source. And why should the length of these bright lines increase as the LED falls? This sort of qualitative discussion is often left out, yet it is an invaluable part of the learning process.

The flashing LED assembly produces very precise time marks that can be used in other kinematics experiments. By attaching a parachute to the assembly it is possible to study air resistance and terminal velocity. The assembly attached to a string can be used to study the motion of a simple pendulum. Equally interesting is its use in the study of the motion of an object on an inclined plane.

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