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APPARATUS NOTES

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Kater pendulum modification

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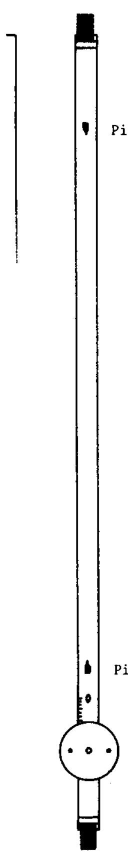
This note describes the modification of a Welch[1] Kater pendulum so that it may be used more systematically and with improved precision to measure the acceleration due to gravity.

As supplied by Welch, the pendulum consists of a plated steel bar approximately 150 cm long and 2.5 cm wide equipped with two large and one small adjustable weights. A wall bracket is also included on which the pendulum is pivoted on either of the two knife edges attached to the bar. These knife edges are not symmetrically located on the bar but their separation is approximately 100 cm (see Fig. 1.).



(b)

Fig. 1. (a) Kater pendulum with weights removed showing location of engraved tick marks below lower knife edge (pivot A). (b) This shows the pendulum equipped with the one weight necessary for its operation along with the black paper flags.

The experiment consists of carefully measuring the distance l between knife edges and measuring the periods of the pendulum about each knife edge. The position of the weights are adjusted until the periods about both knife edges are equal. This value for the period T is combined with l in the simple pendulum formula to obtain[2] g:

$$g = 4\pi^2 l/T^2.$$

The distance between the knife edges can be measured optically with good precision using a cathetometer with a range of 1 m. Difficulty may arise in the adjustments of the moveable weights to make the periods about both knife edges equal. This difficulty was overcome by first removing all three weights and having a machinist engrave approximately 50 tick marks 1/8 in. apart beginning about 10.5 cm from the bar's end and ending about 26.5 cm from its end. The end of the bar on which the tick marks are engraved has a span of about 32 cm from knife edge to the bar's end. The bar's other end has a span of about 19 cm from knife edge to end. The tick mark closest to the knife edge is considered number zero and the others are numbered sequentially toward the end of the bar.

Only one large weight is needed to utilize the pendulum throughout an appropriate range of measured period, the other two weights are not used. The top edge of the weight is used as the position index. A black paper flag approximately 5 cm long is taped to each end of the bar to act as a light shutter in the photocell timing arrangement. The light source was a low-power laser and the photocell was the de-

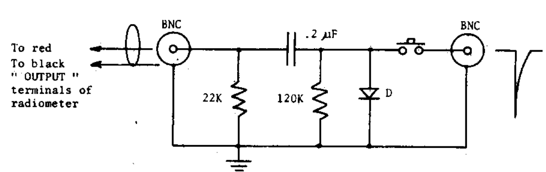


Fig. 2. Negative pulse forming network. The resistor values are in ohms. D is a small signal germanium diode. Shielded cable is used to couple the radiometer output to this circuit's input connector.

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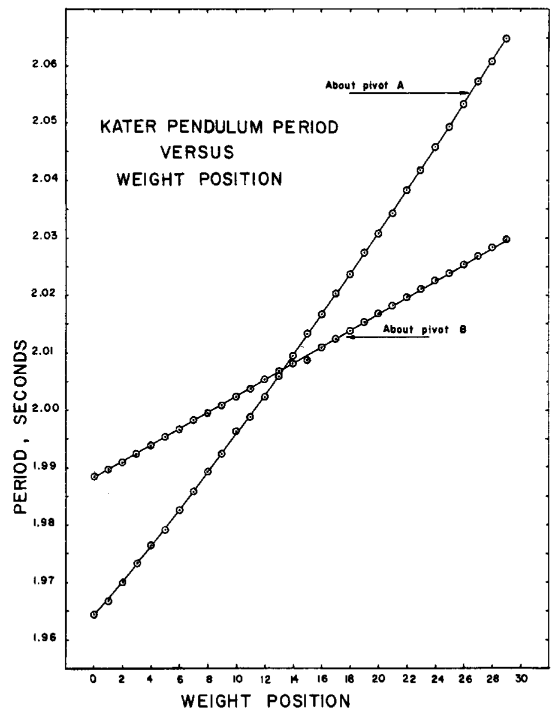

Fig. 3. Kater pendulum period as a function of the weight position about the two knife edges (pivot A and pivot B).

tector of a Metrologic Radiometer.[3] The output of the radiometer was fed to the negative trigger pulse forming network shown in Fig. 2 which is housed in an aluminum minibox. The push button is depressed just before the black flag breaks the light beam which starts the electronic timer. It is repressed just before the same edge of the flag breaks the light beam one period later. This trigger pulse forming network produces a negative pulse which can be utilized by the counter operated in its time mode to start and stop the timing. The counter used in this case was a Hewlett–Packard model 5302A 50-MHz Universal Counter. Other counters with comparable features can also be used for timing the period.

The periods as a function of weight position is shown in Fig. 3. These data represent the average of five measurements taken at each position of the weight. The error bars on the data points are too small to be indicated on the graph. The intersection of the two curves identifies the desired equal periods which can be determined to good accuracy directly from the graph. In this case it is 2.0070 ± 0.0001 sec. When this is combined with the distance between knife edges of 99.985 ± 0.001 cm for this pendulum it results in a measured acceleration of 979.941 ± 0.107 cm/sec^2 for the location of this measurement (40° 31′ north latitude and 2.64×10^4 cm above sea level).

[1]Sargent–Welch Scientific Company, Skokie, Illinois 60076. These pendulums have not been listed in the company catalog for the past several years.

[2]Wallace Arthur and Saul Fenster, Mechanics (Holt, Rinehart and Winston, New York, 1969), p. 455.

[3]Metrologic Instruments, Inc., Bellmawr, New Jersey 08030.

Demonstration of the first overtone transverse vibrational mode in a stiff solid bar

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Resonance and vibrational phenomena afford interesting and instructive classroom demonstrations. Transverse one-dimensional waves are particularly useful since they are easy to visualize and model mathematically. Annett[1] reported the observation of the first overtone vibrational mode in an automobile whip antenna, which illustrates a seldom observed mode of vibration for a solid bar fixed at one end. I would like to share a simple demonstration which clearly illustrates for the student the fundamental and first overtone transverse vibrational modes in a stiff solid bar fixed at one end. This case, where one end is a node and the other an antinode, can be contrasted with standing waves in a string fixed at both ends and having nodes at both ends.

The only equipment required is a flexible aluminum yardstick or meterstick. The particular one that I use is an aluminum yardstick 0.075 in. thick and 1.10 in. wide, manufactured by Johnson Products Co., Inc., Milwaukee, Wisconsin. The fundamental mode can be excited by holding the end of the stick in either hand and slowly shaking it back and forth in the same way that a vibrator is used to excite standing waves in a string. The first overtone can be excited in a similar manner noting that the resonance frequency for the first overtone is approximately $6.3f$, where f is the fundamental frequency.[2] It is quite simple to excite the first overtone into large amplitude vibration with the first node clearly visible.

One advantage to using the yardstick or meterstick is that the position of the node can be measured to within ± 0.5 in. or ± 1 cm with little difficulty and compared to the expected location of $0.226L$ from the free end,[2] where L is the length of the stick. I have observed the node to be 8.5 ± 0.5 in. from the free end which compares well with the predicted value of 8.1 in. It should be emphasized that exciting the stick in the manner described does not require that the held end be a node, however the node will generally be within several centimeters of the held end depending on exactly how the stick is excited.

[1] C. H. Annett, Am. J. Phys. **47**, 820 (1979).

[2] H. F. Olsen, *Music, Physics, and Engineering*, 2nd ed. (Dover, New York, 1967), p. 77.

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