Measurement At Home

Report on ‘Give me a second’

1. Overview

The challenge was to build a frequency standard: a pendulum giving a 1 second swing. A physics model (section 4) predicts a frequency value, and we wanted to see how close constructed pendulums performed to this prediction. We have results received within a few days of issuing the challenge. **Thank you: Adam F, and Charles Oliver, Richard and Richard.** Two thirds of results were close to the value physics predicts: 24.9 cm.

A 2 second pendulum swing period is 0.994 m, curiously close (by coincidence) to a metre. In 1660, the Royal Society proposed this method as a length standard, though it was found that length varied depending on where the experiment was done because the Earth’s gravitational force (‘g’ in our model) differs with location.

2. Measured pendulum values

The table here (right), shows values people obtained. (B) didn’t quite follow our instructions but used a more complicated approach with results from 8 pendulums from 13-50 cm to create a mathematical model giving the 24.0 cm answer.

Entry	**Pendulum length /cm**	Bob type	Bob mass /g
A	**23.0**	Meccano pinion on sewing thread	-
B	**24.0**	Meccano pinion on sewing thread	-
C	**25**	2.5 cm conker, sphere with 1 flat side	10
D	**26.2**	Lego two 8 pip blocks	6
E	**84**	Disco ball. Sphere. 20 cm	670
F	**100**	Lego	6

3. Why did results vary and differ from the one predicted by physics?

The spread in results and difference from the physics predicted value (in section 4) may relate to the following:

Errors in length measurement

All measurements rely on a good standard (in this case a ruler) and being able to read the values properly. In most cases, rulers can be read to a couple of millimetres. String stretchiness can also lead to uncertain length measurements.

Pendulum length is defined as being between the pinion and the centre of mass (the point where there is equal mass either side). If the string has significant mass, the centre of mass will be higher up the pendulum. Perhaps we should have asked for string mass, though we felt it would be too small to measure. Mass may not be distributed evenly within the bob - perhaps that was the issue with the flat conker (C). Similarly, Lego may not have even distribution of material, and thus mass.

Errors in time measurement

The task asked for swings to-and-fro rather than just one swing. If we double the swing time, the physics predicts a value of 99.4 cm so perhaps misunderstanding the instructions explains the (E) and (F) results.

Our method used 10 swings (rather than 1) as increasing the number of measurements improves accuracy. Operating timers accurately is tricky as it involves human reaction time. High quality measurements use sensors.

Errors in the physics model

Swing width: to simplify the maths, we used a model that is only truly correct for zero swing width, with an error increasing as swing widens. A more detailed model could include swing width, which (for reasons below) decrease with each swing, as well as being tricky to measure. In science we often simplify!

Energy leaving the pendulum: swing width decreases each time due to friction in the pinion and air resistance acting on the pendulum – we call this 'damping'. If pendulums change swing orientation, other forces are acting too. Higher density bobs are preferable as the air resistance effect is reduced (though pivot friction increases with mass). String stretchiness can also cause the pendulum to bounce as it swings, which changes both the length of the pendulum, and the force acting on it as it swings. The model assumes that the string is light (weightless), inextensible (not stretchy), and that energy ***only*** shuffles between gravitational potential (as the bob is raised) and kinetic (as the bob moves). Again, a more complicated model could be used, though we decided to keep it simple.

4. What does physics predict the result should be?

In physics, the ***simple pendulum equation*** states: $L = T^2g/4\pi^2$	Where: L = pendulum length (in metres), between pivot point and centre of mass T = swing time (both to and fro in seconds) g = acceleration due to gravity (which we can take to be **9.81** metres/second^2) π is a 'constant' related to motion in circles, with a value of **3.14** **(values here are given to 3 significant figures).**

As our value of 'T' is 1 this equation predicts a value of: **$(1 \times 9.81)/(4 \times 3.14^2) = 0.249$ m**	**= <u>24.9 cm</u>**

Notice how the equation does not contain mass. Tiny changes to bob mass (e.g. pennies on the bob for the clock tower in the Palace of Westminster containing Big Ben) fine-tune the centre of mass and thus pendulum length.

Pendulum clocks have drive mechanisms to move hands and keep the pendulum swinging. Forces provided to the pendulum by these mechanisms means the pendulum will not exactly follow this simple pendulum equation.

5. How can we measure time accurately? (And why?)

NPL plays a key role developing accurate frequency measurement. In the 1950s Louis Essen and his team created the worlds' first operational atomic clock. The pendulum of an atomic clock is created by a wave of light oscillating back and forth. Only light oscillating at very specific frequencies can excite atoms. Waves of light can be tuned to match this frequency and these produce our "ticks". The most accurate atomic clocks use light that ticks at a frequency 1 quadrillion Hertz or 1,000,000,000,000,000 "ticks" a second. The precision with which we can measure this frequency means that our system can be said to lose less than a second in ~ 10 billion years. With such high precision, frequency measurements often underpin others like length and electrical. More accurate measurements enable science and engineering with increasing precision.

6. What do we mean by 'Measuring time?'

Although time can be measured more accurately than anything else, philosophically and physically it is hard to say what time actually is. The more you think about it, the harder it is to find an answer. Clocks mark out the passage of time, though time is not like length where we can measure the distance between two marked points, or like electric current where we count the passage of charged particles. The unit of time (the second) is purely a human construct and yet the frequency of natural cycles (like the atomic pendulum) are crucial for the universe to work the way it does.

It was very well said by Tim Folger in 'Newsflash: 'Time May Not Exist', Discover Magazine (Jun 2007):

"Our clocks do not measure time. ... Time is defined to be what our clocks measure."

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