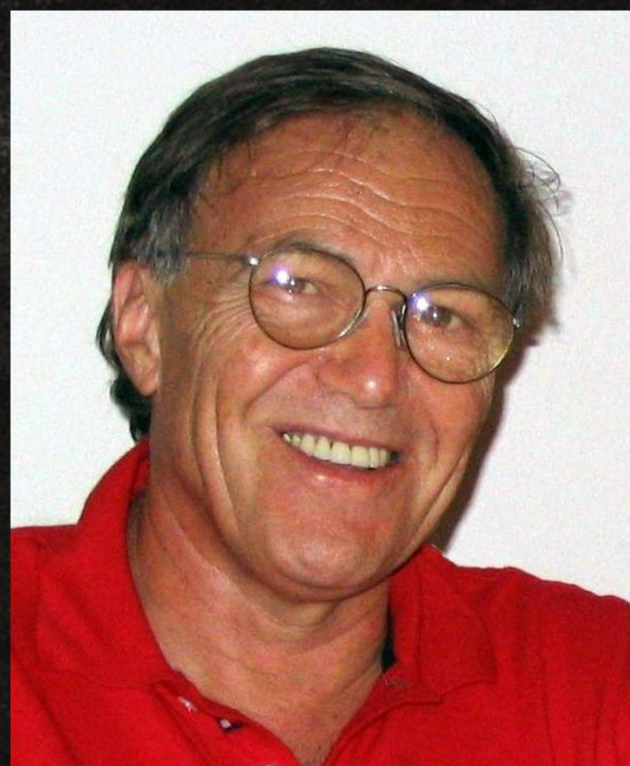
Pendulum Waves

In Memory of Dr. Robert Buchler



April 4th, 1942

October 16th, 2012

Dr. Robert Buchler

Born in the Grand Duchy of Luxembourg on April 4, 1942, he obtained his undergraduate degree in physics "avec la plus grande distinction" from the Université de Liège, Belgium in 1965, followed by a Ph.D. in physics from the University of California at San Diego in 1969. He began his career at the California Institute of Technology and later joined the University of Florida in 1974 rising to the rank of professor in 1980.

He published more than 200 articles in scientific journals in English, French and even Latin. Early in his career, he made seminal contributions to understanding the mechanism which produces supernovae, the brightest objects in the sky.

Dr. Robert Buchler

Later he turned his energy to the study of pulsating stars and fluid dynamics. He was an enthusiastic teacher, especially in developing and using lively demonstrations to illustrate important physics concepts to undergraduates.

An avid traveler, a connoisseur of fine cuisines and wines, Robert was a man of many interests ranging from playing the flute, to hiking, bicycling and flying airplanes. He is sorely missed by his family, friends and colleagues in the physics and astronomy departments.

Pendulum Waves

Button on front of display

Pendulum Waves

What you will see (Step One):

Release arms rising from the base will pull the pendulum balls back and release them all at the same time. Each pendulum ball is completely independent of the others. Also, each pendulum is supported by a string with a different length. The length of the support string determines the period, or the time, of each pendulum's swing back and forth.

Pendulum Waves

What you will see (Step Two):

The different periods (timing) of each pendulum determines it's phase relationship, or fraction of a wave cycle, relative to all of the other pendulums. Careful mathematical calculations of the appropriate string lengths gives us a smooth transition in this phase relationship between each pendulum and it's neighboring pendulums and thus creates the wave patterns you see over time.

Pendulum Waves

What you will see (Step Three):

A complete cycle to get all the balls back in sync (in phase) with each other in a straight line takes about 60 seconds. The longest pendulum has been set so that it completes 51 oscillations in 60 seconds. The next shorter pendulum is set to complete one more oscillation, or 52 in 60 seconds. This continues until the shortest (15^{th}) pendulum completes 65 oscillations in 60 seconds. Their different periods of oscillation cause the relative phase relationship between the balls to change and creates the waves.

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What you will see (Step Four):

To stop the experiment magnets will rise out of the base and approach the aluminum pendulum balls. As the balls swing past the magnets it induces an electrical current called an "Eddy Current" to flow in the balls. This electricity in the balls creates it's own magnetic field that is opposite to the magnetic field of the base magnets. Since opposite magnets attract, this creates a force on the moving balls that slows and stops the balls.

Pendulum Waves

The mathematical equation that describes the wave patterns is;

$$y(x,t) = A\cos(k(t)x + \omega_0 t)$$

Where "A" is the amplitude of the wave and "cos" is the cosine function.

"K" is the wave number as a function of time and represents the wave repetition in space (x) and is related to the wavelength (λ) of the wave by $k = \frac{2\pi}{\lambda}$.

Finally, "$\omega_0 t$" is the angular frequency as a function of time and represents the wave repetition in time where $\omega = \frac{2\pi}{T}$ using the period, T.

Pendulum Waves

The mathematical equation to calculate the strings length is;

$$L(n) = g\left(\frac{T_{cycle}}{2\pi(N+n)}\right)^2$$

Where "$L(n)$" is the length of the n^{th} pendulum you are trying to calculate the length of string for with $n = 0$ for the longest string, all the way to $n = 14$ for the shortest string. "T_{cycle}" is the total time to complete a cycle, in our case 60 seconds. "N" is the number of oscillations of the longest pendulum in 60 seconds, in our case 51, and "g" is the value of gravity ($9.8\ m/sec^2$).

Pendulum Waves

Based on the original design by:

Wayne Easterling
Gary Jarrette
Tim Cook

From Arizona State University

THANK YOU FOR SHARING THE DESIGN

Pendulum Waves

Design Improvements and Built By:

Marc Link
Bill Malphers
Ed Storch
John Vanleer
Pete Axson
John Mocko
David Hansen
Tristen Horton

Pendulum Waves

Build Your Own Pendulum Wave!

Credit to Paul Liu who wrote an excellent online mathematical analysis of the pendulum wave;

http://hippomath.blogspot.com/2011/06/pendulum-waves-mathematical-description.html

And instructions on how to build your own;

http://hippomath.blogspot.com/2011/06/making-your-own-pendulum-wave-machine.html

Pendulum Waves

Experiment Starting!

Step One

The silver magnets on posts below the balls will start dropping to start the experiment.

Pendulum Waves

Experiment Starting!

Step One

Release Arms will rise from the base to pull the pendulum balls back and release them all at the same time.

Pendulum Waves

Pendulums are Swinging!

Step Two

The wave patterns are forming as the phase relationship changes. You can clearly see one, two, and three distinct waves at different times as it moves.

Pendulum Waves

Pendulums are Swinging!

Step Two

The halfway point of the cycle occurs at the 30 second mark when the balls divide into two straight lines.

Pendulum Waves

Pendulums are Swinging!

Step Three

A complete cycle of the demo to get all the balls back in sync, or “in phase”, with each other in a straight line is approaching and takes about 60 seconds.

Pendulum Waves

The mathematical equation that describes the wave patterns is;

$$y(x,t) = A\cos(k(t)\,x + \omega_0 t)$$

The mathematical equation to calculate the string lengths is;

$$L(n) = g\left(\frac{T_{cycle}}{2\pi(N+n)}\right)^2$$

Pendulum Waves

Pendulums are Stopping!

Step Four

Magnets are rising out of the base and approaching the aluminum pendulum balls, generating Eddy Currents and creating the force that stops the balls.

Pendulum Waves

Experiment has finished,
we hope you enjoyed it!

Pendulum Waves

Please wait:

Resetting Experiment
To Starting Position
After First Boot Up!

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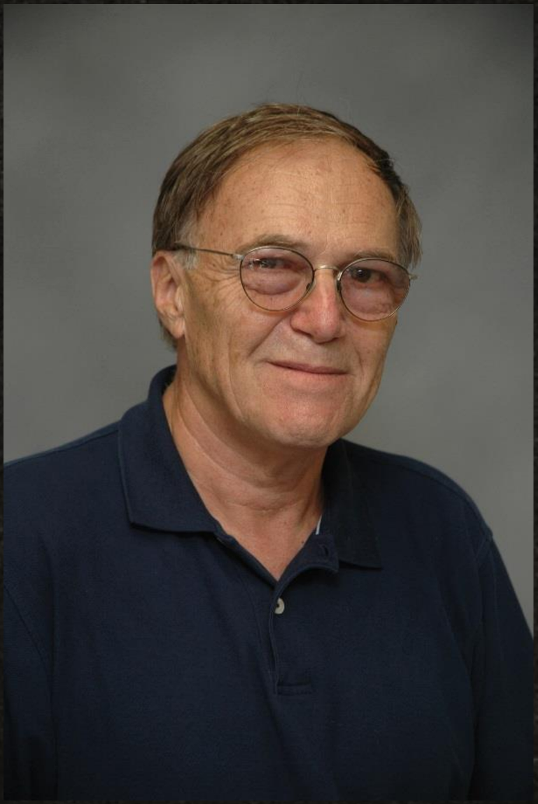

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