Five parts can snap into the center piece: The long pendulum (L), the short heavy pendulum (S), one double pendulum element with a V-shaped end (V), and two double pendulum elements with a straight end (D).

The parts snap into the CC in only one direction as determined by the T slot. Any combination of S, L, D's, or V can snap into CC but there are only 4 slots so you will always have one or more parts left.

Snapping in the L or S creates a system with one degree of freedom and demonstrates the simple harmonic oscillator. Snapping in a D or V creates a system with two degrees of freedom (the "double pendulum.") Systems with up to 4 degrees of freedom can be created.

Systems with one degree of freedom exhibit regular motion; systems with more than one degree of freedom tend to be chaotic. What PENDULUM MAN shows you is chaos in the sense of our everyday usage of the word, namely, motion with no recognizable regularity. Its many configurations demonstrate that such motion is the rule rather than the exception, and that chaos increases with higher energies. For more technical details, continue in the booklet.

Now give the double pendulum a strong push, e.g. by flipping the CC with a finger. At high energies, we enter a new realm, and you will not observe the same motion twice in a row.

With high energies, particularly if an element can make a full turn, the prediction of the motion becomes impossible for a mathematician using classical analysis, but it is an easy task for the computer. The computer calculation gets into trouble only when a critical situation is approached, where an element gets to the upside-down position and could fall either to the left or to the right. This introduces a "classical element" of chaos.

The modern development in chaos theory was actually launched by the computer. For certain processes, the extreme sensitivity to initial conditions was discovered when computer calculations were derailed by rounding errors. (See recommended reading.)

THREE DEGREES OF FREEDOM

For most triple pendulum configurations, you can observe the logical extension of double pendulum properties. There are usually three principal modes for DF = 3, with the same properties as for DF = 2, and the irregular high energy motion becomes "more" chaotic. Examples are given in Fig. 4 and Fig. 5.

ONE DEGREE OF FREEDOM

The different pendulum configurations are characterized by the number of elements that can move independently. The scientific name for this number is "degrees of freedom" or DF for short. The simplest case, one degree of freedom (DF=1), is the classic simple pendulum. It performs periodic motion, also called simple harmonic oscillation, the prototype of regular motion and the opposite of chaos.

You can create a simple pendulum by inserting rigid elements (L and/or S) in the slot. There are four possible configurations (Fig. 1). The pendulum formed by L alone oscillates with a period of about 3/4 of a second. L alone moves considerably faster; it has a period of about 1/2 second. The shorter the pendulum, the faster the motion. Fundamental laws of mechanics tell us that the time period of the oscillation grows with the square root of the length (for exactly similar mass distributions).

Putting S and L in opposite slots leads to a more balanced configuration with a long period of oscillation. When the device is at rest, L is pointing down (Fig. 2). Such a state is ultimately reached by all oscillations when damped by friction and is called a "stable equilibrium." There is also an equilibrium position with L pointing up and S pointing down (Fig. 2). (To get this, put L straight up and gently let go. It may take a few tries.) This position can be realized because of bearing friction, which is higher at rest than it is with motion. With no friction we would have only a fleeting glance at an "unstable equilibrium", a state which disappears with the slightest disturbance.

Trying to balance at the unstable equilibrium point can fail in two ways: the pendulum can fall from the top position moving left or moving right. A small difference in conditions leads to a dramatically different outcome. When the pendulum system is moving, encountering such a critical point is an event that leads to chaos.

TWO DEGREES OF FREEDOM

Snapping a D or V in a slot creates a pendulum which has two pivots and thus has two degrees of freedom (DF = 2). Such a configuration is called a double pendulum. Further double pendulums are obtained by adding any rigid element (L and/or S) to a free slot.

Classical analysis dating back to the eighteenth century has shown that a pendulum with two degrees of freedom has two so-called principal modes. Each of these modes has the property that its shape reappears with the same period and frequency and is less regular than the simple pendulum. However, the shape and the frequency of the two modes are different.

For the demonstration of a typical case, put V in the CC, and hold it in an initial position as shown in Fig. 3 A (note the orientation of V). When you let go you will find that the initial configuration returns with perfect regularity. This is true for L. (You may have to make a few tries, adjusting the initial angle at the CC.) In this particular case, there is no noticeable relative motion between the two parts.

For our model, mode II is obtained with the initial configuration given in Fig. 3B. With the proper choice of the initial angle, a purely wiggly motion will emerge, periodic again but with a much higher frequency than mode I.

The general motion where both modes are present does not display the regularity of either principal mode but can be described by their mathematical combination. For example, when you try the initial conditions of Fig. 3C, you will recognize the underlying individual simple periodic motions. Any low energy motion of the double pendulum is the superposition of two oscillations with two different frequencies.

FOUR DEGREES OF FREEDOM

Put the two D's into opposite slots and snap the V into a slot between them; this makes DF = 4. Now there are three satellites which can exchange energies. (This configuration is similar to the "Chaos Pendulum" exhibit at the Exploratorium of San Francisco.) The motion of the central element becomes more vigorous if you add S in the empty slot. This is "Chaos Man" shown in Fig. 6. If you add L instead of S you can see chaos in slow motion.

There are many other possibilities. You do not have to be systematic about it - go ahead at your own pace, and have lots of fun!

- Hog Wild Creative Staff

Reference

Recommended Reading

Calling all Hogs! Visit us online at www.hogwildtoys.com

PENDULUM MAN is a collection of interchangeable parts that can be linked to create many new and unusual pendulum systems. It can be put together 66 different ways; 18 are symmetrical, 30 are asymmetrical. PENDULUM MAN will move with regular or chaotic motion depending on how it is put together and how you push it.

Attached to a magnet is the star-shaped central connection (CC) and all parts snap into it. Its bearing and all the bearings in PENDULUM MAN are dry and should not be oiled or get wet.

Warning: keep the powerful magnet away from computer floppy disks or any other magnetic devices.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6