611-0385 (30-205) Learning™ Tower of Pisa

Warranty and Parts:

We replace all defective or missing parts free of charge. All products warranted to be free from defect for 90 days. Does not apply to accident, misuse, or normal wear and tear.

Introduction:

The world famous Leaning Tower of Pisa in Italy presents an interesting case study in stability. This tower is 56 meters tall with walls that are 2.6 meters thick at the base. It is built entirely of marble. Its construction began in 1173 and was not finished until 200 years later. It was built as a vertical bell tower for the cathedral next door and apparently began to lean while still under construction. The original footer was inadequate and many attempts to reinforce it with concrete have been attempted. The following table shows how much the tower varied from plumb over the years.

Year	Distance out of Plumb
1298	1.43 meters
1360	1.63 meters
1550	3.77 meters
1817	3.84 meters
1911	4.04 meters
1935	4.80 meters
1997	5.20 meters

It was from the top of this tower that Galileo dropped two weights in the famous experiment to find out about falling bodies.

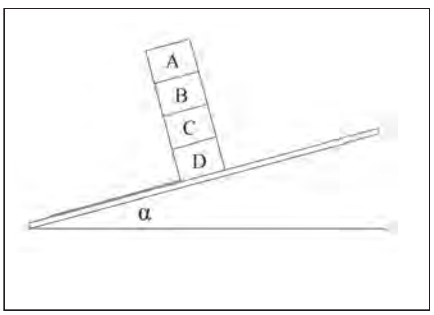
P/N 24-0205

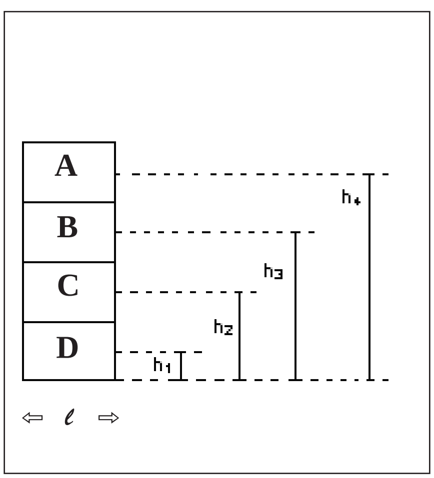
Stability:

If a solid body resting on a base returns to its original position after it has been tipped a little, it is said to be in "Stable equilibrium." Bodies that are in stable equilibrium cannot be tipped over unless their **center of gravity** is first raised.

There is a simple way of knowing in advance whether a body, resting on a given base, will be stable or topple over when released. It the plumb line through its center of gravity falls within the boundary of the base on which it rests, the body will not topple over. If however this plumb line falls outside the boundary of the base, the body will overturn automatically when released.

A body is more stable if it requires a greater force to overturn it. Of the 24 combinations of the 4 enclosed cylinders, you will quickly see that some combinations will topple with a much smaller angle of tilting (α).





How To Use:

1. Weigh each slug and measure their diameter and height.
2. Stack the 4 enclosed slugs of different materials in any combination onto the enclosed 6.4 mm dia steel pin.
3. Calculate the **center of gravity** using the following formula:
$$C_g = \frac{M_A h_4 + M_B h_3 + M_C h_2 + M_D h_1}{M_A + M_B + M_C + M_D}$$
4. To check your calculations, place the assembled tower onto our **40-250 Inclined Plane** or a suitable textbook. Gradually tilt the tower until the assembly topples. Keep track of the angle (α) at which the topple occurs.
$$C_g = \frac{\ell}{2 \tan \alpha}$$
5. Calculate the angle of incline of the Leaning Tower of Pisa at each of the years on the above table. Use the formula:
$$\alpha = \arctan\left(\frac{\text{height of tower}}{\text{distance from plumb}}\right)$$
6. The diameter of the base of the Tower of Pisa is 15.5 m. Assuming that the tower is uniform in construction, how much more can the tower lean before it topples.
7. How could you save the tower from toppling? Explain

Why the Tower Doesn't Fall:

The Leaning Tower of Pisa is a symbol of things that seem in danger of falling. Other examples in the real world can include: two-decker busses in England, a high load of hay in a wagon, a skyscraper in a high wind, a car skidding on two wheels around a curve. Just how far can such objects lean before they actually do overturn?

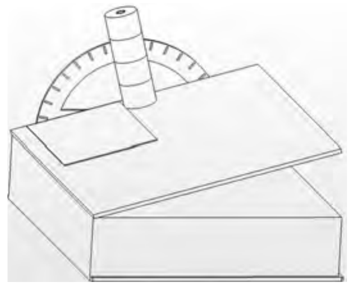
An object can lean without falling as long as a straight line leading from its center of gravity to the center of the earth passes through the object's base.

This *center of gravity* is an imaginary point at which you can consider the entire weight of an object to be concentrated.

The drawings below can show you how to locate the center of gravity. Suspend the object (a cut-out representation of the Leaning Tower, in these drawings) successively from two or more points (for example, A, B and C). Hang a weighted thread from the point of suspension and draw a line behind the thread as the object hangs from each point. The point where the lines intersect marks the center of gravity.

If you suspend your weight on the thread so that it hangs freely from the center of gravity point and lean your tower against a wall while its base stands on the edge of a book, for example, you can find out for yourself. As long as the line remains within the base line of the tower, the tower keeps its footing. The instant the line remains within the base line of the tower, the tower keeps its footing. The instant the line passes outside, the tower tumbles!

The lower the center of gravity, the farther over an object can lean. Thus, by concentrating the weight of buildings, cards and boasts as low as possible, designers make them more stable.



Related Products:

Science First® manufactures low-cost science labs that are available from most science education distributors.

611-0110 Second Law of Motion Apparatus - Is the horizontal component of force independent of the vertical ? Shoot one ball outward, drop second ball, time both impacts. Plastic molded base, spring plunger, 2 balls, instructions.

611-0350 Roman Arch - 23 hardwood blocks in 6 unique shapes. Build a working model of the famous arch strong enough to stand on.

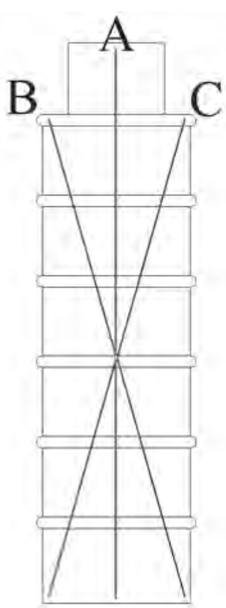
611-1050 Build-A-Pulley - Modular block and tackle set large enough to do real work. 2" sheaves, brackets.

611-1215 Ring and Disc - 3" diameter PVC ring and wood disc. Roll them together down an incline, which is faster?

611-0035 Inclined Plane - Solid aluminum inclined plane and full range of accessories. Investigate acceleration, friction and gravity. Folds for storage, clamps up to 45°, removable protractor and low-friction pulley.

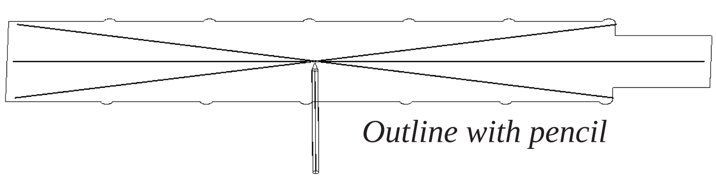
611-0040 Halls Car - Use with inclined plane, pulley and weights to analyze link between work and energy. Nearly frictionless due to oil-free sleeve bearings. ABS plastic car has deep well for weights, wheels snap into place even if dropped.

611-1220 Variable Inertia - Instantly change distribution of mass with 8 balls inserted into your choice of compartments. Load each of two discs unevenly, roll together down an incline. Which is faster? Why? *Includes:* 8 balls, two discs with hardware, instructions.



Tower outline with lines

You can find out how far any object can lean without falling by first finding (left) its center of gravity, or the point at which it balances perfectly (below). The object will not fall as long as a plumb line dropped from this center passes inside the base.



Outline with pencil

Leaning Tower of Pisa, the site of Galileo's experiment