The Video Encyclopedia *of* Physics Demonstrations™

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CHAPTER 18

ELASTICITY

Demo 08-01 Hooke's Law

Weights are hung on a spring suspended from a fixed point, as illustrated in *Figure 1*, to determine the extension of the spring as a function of spring tension.† As can be seen directly from the video, the extension of the spring as a function of weight is linear, as described by Hooke's law. Two springs with different spring constants are investigated in the video.

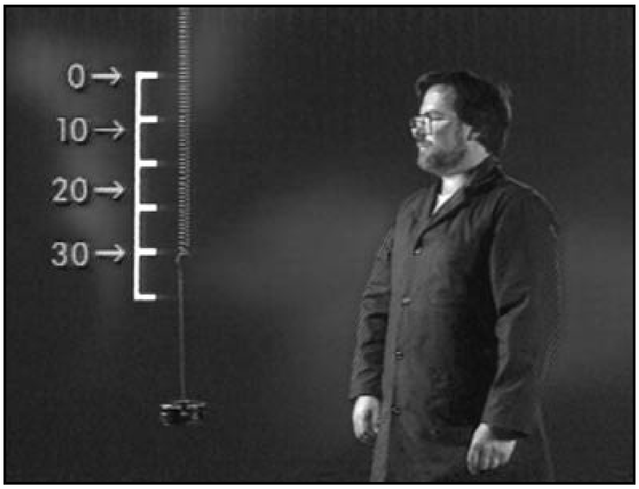

Figure 1

† Freier and Anderson, *A Demonstration Handbook for Physics*, Demonstration Mx-3, Mass on Spring.

We'll show how the stretch of a spring varies with the applied force, using this hanging spring and a set of weights. With no weights added, the bottom of the spring is here.

Here is the spring extension with 10 newtons of added weight.

20 newtons.

30 newtons.

Now we'll add the same set of masses to a different spring, leaving the markings from the first spring on the screen for comparison.

10 newtons.

20 newtons.

30 newtons.

Equipment

1. Spring.
2. Weight hanger.
3. Slotted weights.
4. Meter stick.
5. Spring with different spring constant.

Demo 08-02 Spring in Series and Parallel

The extension of a spring is compared with the extension of two identical springs in series and in parallel.† To obtain the same extension, twice the force must be applied for springs in parallel compared with a single spring, as shown in *Figure 1*. To obtain the same extension for springs in series requires only half the force required by a single spring.

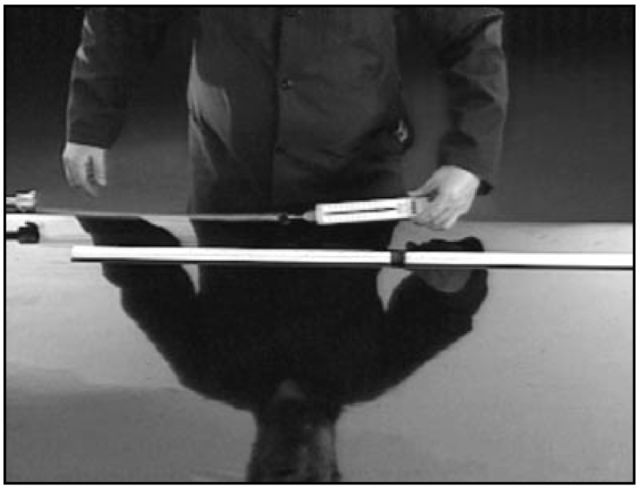

Figure 1

† Freier and Anderson, *A Demonstration Handbook for Physics*, Demonstration Mx-3, Mass on Spring.

This spring has a spring constant which tells us how much force we must exert to stretch it a given distance.

To stretch it 60 centimeters, we must exert a force of 1 newton.

Here is an identical spring. If we hook the springs in parallel, 2 newtons are required to stretch them 60 centimeters.

If the two springs are hooked in series, only ½ newton is required to stretch them 60 centimeters.

Equipment

1. Two identical springs.
2. Spring scale of appropriate size.
3. Meter stick.
4. Fixed point for spring (hook).

Demo 08-03 Torsion Rod

Using a "torsion lathe," a metal rod is twisted, and the angle of twist measured as a function of the twisting force.† The twist of the rod, shown in the animation of *Figure 1*, is proportional to the applied force. Two rods, of different diameter but the same material, are shown on the video.

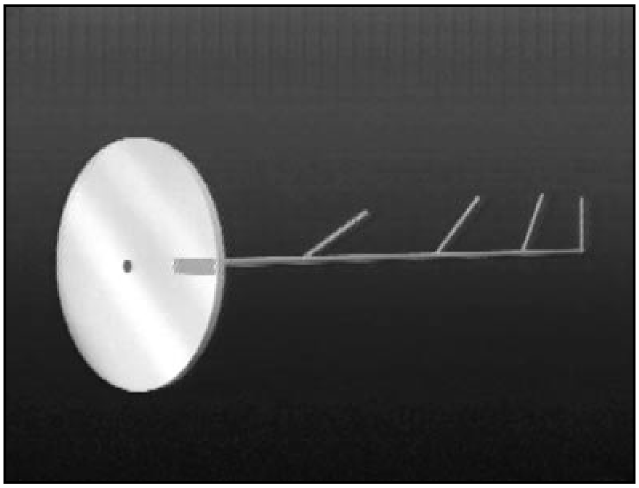

Figure 1

† Freier and Anderson, *A Demonstration Handbook for Physics*, Demonstration MA-12, Modulus of Rigidity.

This torsion lathe will be used to demonstrate how the amount of twist in a rod is related to the applied torque. A thin copper rod is held between two supports. This end is stationary, while this end is free to rotate and twist the rod. Hanging weights on a metal band wrapped around this disc supplies the torque.

The amount the rod twists can be read on this angle scale.

Here is the amount the rod twists when 250 grams is hung from the band.

Here is the amount of twist with 500 grams hung from the band.

We'll now repeat the demonstration using a thicker copper rod.

For comparison we'll leave the last set of markings on the screen as we take new readings.

250 grams.

500 grams.

1000 grams.

Equipment

1. Torsion rod apparatus.
2. Rods of differing materials and diameters.
3. End clamp.
4. Weights with hooks.
5. Elevated support system, if desired.
6. Rectangular Lazy Susan.

Demo 08-04 Elastic Limits

Springs of copper and brass wire are extended and then released. The brass spring is elastic, and readily returns to its original length. However, the elastic limit of the copper spring is exceeded, and it does not return completely to its original length, but remains in an extended position, as shown in *Figure 1*.

Figure 1

All materials will permanently deform or break if they are stretched too far. But the amount they can stretch and still spring back varies tremendously from one material to another.

We'll demonstrate that with these two springs, one made of brass and the other copper.

The brass spring is stretched out to a distance almost three times its original length, and it springs back unchanged.

Here's what happens when we stretch the copper spring.

Even a small amount of stretch is too much for the copper—it springs back a little but won't return to its original length.

Equipment

1. Piece of plastic Slinky.
2. Two springs with differing spring constants—brass and copper.

Demo 08-05 Young's Modulus

Weights are hung on the end of a long wire, and the increases in length measured as a function of the weight, or the tension in the wire.† The extension is measured using the deflection of a laser beam by a mirror that tilts as the wire becomes longer, as illustrated in *Figure 1*. The extension of the wire as a function of tension in the wire is observed to be linear.

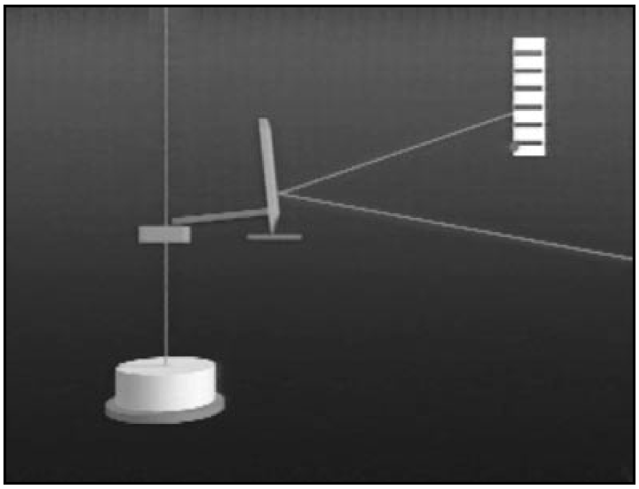

Figure 1

† Sutton, *Demonstration Experiments in Physics*, Demonstration M-63, Hooke's Law and Young's Modulus.
Freier and Anderson, *A Demonstration Handbook for Physics*, Demonstration MA-10, Elastic Limit.

All materials will stretch when pulled hard enough, even this steel wire.

We'll hang increasing amounts of weight on the wire to show how the amount of stretch varies with applied force.

This mirror is balanced on a small platform attached to the bottom of the wire.

If the wire is stretched, the mirror tips and deflects a laser beam, as shown in this animation.

The deflection of the laser beam is therefore an indicator of the amount the wire stretches.

20 newtons.

40 newtons.

60 newtons.

The amount the wire stretches is directly proportional to the applied force.

Equipment

1. Commercially available Young's Modulus apparatus.
2. Laser.
3. Slotted weights.

Demo 08-06 Bending Beams

Three beams of the same material are clamped at one end and loaded by placing weights on the free end, as shown in *Figure 1*.† The dependence of the amount of bend on the length of the beam, the cross-sectional area of the beam, and the amount of weight hung onto the end of the beam are shown in the video. The second beam has the same cross-sectional area as the first but is twice as long. The third beam has twice the length and twice the thickness. In the Figure the same weight on a beam of the same cross section but twice the length creates eight times the deflection.

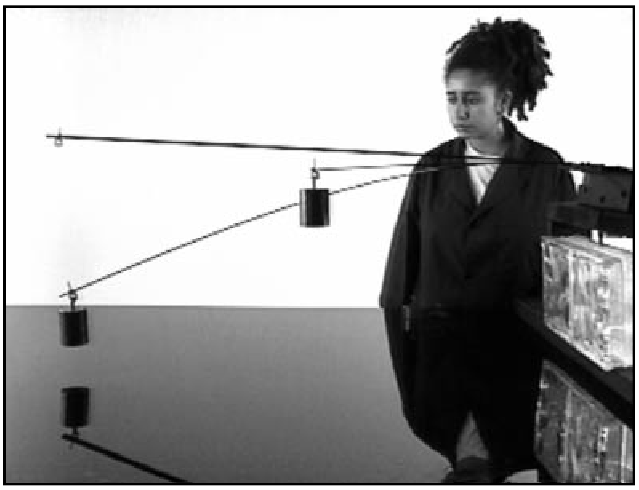

Figure 1

† Sutton, *Demonstration Experiments in Physics*, Demonstration M-66.

Beams projecting out over an edge will bend. The amount of bend will depend on the dimensions of the beam and the amount of mass loaded on the end.

We'll use these three steel beams and some weights to show how the amount of bending changes with different beam dimensions and different masses.

Here is a beam loaded with 500 grams.

Here is the same beam loaded with 1000 grams.

When we load the same mass on a beam twice as long, the deflection of the end is eight times as great.

If we load the same mass on a beam that is twice as thick, the beam bends only one-eighth as much.

If we load one-eighth as much weight on the beam that is half as thick, the beams bend equally.

Equipment

1. Three metal beams of the same material extend from common end clamping base, which in turn is securely clamped down. One beam is half as long as another, but has the same thickness, while a third beam is twice as thick, but equal in length to the longer of the other two.
2. Hooked weights hanging from eye screws fastened to the ends of the three beams: 125 gms, 500 gms, 1000 gms.
3. Support assembly.
4. Clamps.

Demo 08-07 2:1 Scaling

Two “bridges” are formed by rectangular aluminum sheets spanning the space between pillar supports.† The larger bridge has twice the length, twice the width, and twice the thickness of the smaller bridge. The two bridges are loaded by placing weights in the center of each, again in the ratio of two to one. The displacement of the center of the larger bridge by its weight is observed to be much greater than twice that of the smaller bridge, as shown in *Figure 1*.

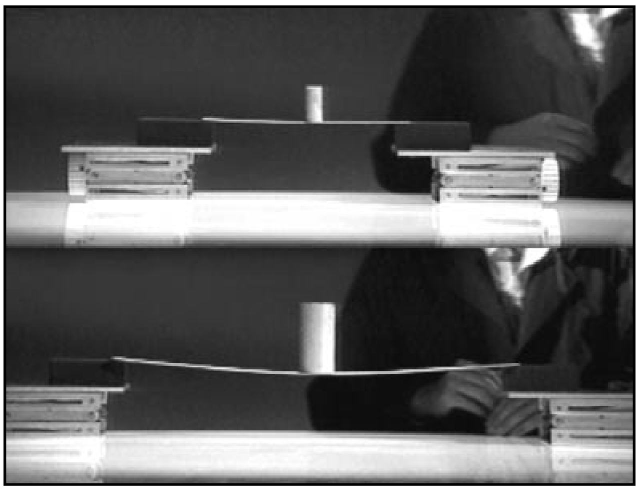

Figure 1

† Sutton, *Demonstration Experiments in Physics*, Demonstration M-66.

These two small aluminum bridges have dimensions all of which are in a 2:1 ratio. The larger bridge is twice as long, twice as wide, and is made from aluminum twice as thick.

The aluminum bars have the same 2:1 ratio of dimensions. If we put both bars on their respective bridges, will the amount the bridges sag under the weight also be in a 2:1 ratio?

The sag of the larger bridge is much greater than twice that of the smaller bridge.

If we shrink a picture of the larger bridge until it appears the same size as the smaller bridge, the difference is easy to see.

Equipment

1. Two strips of aluminum—one twice as long, twice as wide, and twice as thick as the first.
2. Two aluminum cylinders—one twice as thick as the first.
3. Two sets of end supports.

Demo 08-08 Bologna Bottle

Bologna bottles are thick-walled glass bottles that have their outside hardened and their inside very highly strained.† The outside of the bottle can be used to pound a nail into a piece of wood, as shown in *Figure 1*. However, slight scratching of the inside surface caused by pouring carborundum crystals into the bottle causes the bottle to shatter.

Figure 1

† Freier and Anderson, *A Demonstration Handbook for Physics*, Demonstration MA-6, Bologna Bottle.

Bologna Bottle / Script

We think of glass as a fragile material, but just how fragile it is depends on how it is treated during manufacture.

This glass bottle was blown out of ordinary glass then cooled rapidly. The rapid cooling leaves the glass with large amounts of internal strain. The outside of the bottle was then annealed by reheating and cooling it slowly to remove the strain.

The outer layer of the bottle is very tough, and can even be used to drive a nail.

The inner surface of the bottle still has a lot of internal strain; so much that when we scratch the inner surface by dropping sharp pieces of carborundum into the bottle…

the released strain shatters the bottle from the inside.

Equipment

1. Safety goggles.
2. Bologna bottle (commercially available).
3. Block of wood.
4. Nail.
5. Gloves.
6. Supply of carborundum.

Demo 08-09 Elasticity at Low Temperatures

Normally soft or elastic materials become rigid at the temperature of liquid nitrogen. Examples include solder, shown in *Figure 1*, coiled into a helix that supports a large weight when cold but then extends under the weight as it warms up. If a rubber hose is cooled to liquid nitrogen temperatures it can be broken into two pieces by bending it. Other examples are shown on the video.

Figure 1

Many materials which are soft and pliable at room temperature become rigid at the temperature of liquid nitrogen.

This piece of rubber normally bends easily.

If we cool it in liquid nitrogen, it loses its pliability and will snap when bent too far.

This spring made of soft solder supports a weight when it is cooled to the temperature of liquid nitrogen. We'll look at it again after it has warmed up.

This clapper is made of lead, normally too soft to emit a good tone.

When the clapper is cooled in liquid nitrogen, it becomes more rigid and emits a much higher tone.

These two hollow copper tubes emit the same note when they are struck.

When one of the tubes is cooled, it becomes stiffer and emits a higher note.

Now that the solder spring has warmed it can no longer support the weight it held after cooling in liquid nitrogen.

Equipment

1. Supply of liquid nitrogen.
2. Glove.
3. Strips of flexible rubber.
4. Spring fashioned from soft solder.
5. Weight.
6. Support system for spring.
7. Lead bell or an analog.
8. Two copper tubes.
9. Support system for tubes.
10. Wooden dowel rod to acoustically excite copper "chimes."

Chapter 19

Oscillations

Demo 08-10 Tuning Fork with Light

A large tuning fork (with a very low frequency) having a small light attached to one of the tines vibrates with a large amplitude oscillation. When the tuning fork is moved across the video screen the path traced out by the light, as shown in *Figure 1*, is a sine wave. The motion of the lines is therefore simple harmonic motion.

Figure 1

Tuning forks create sound waves because of the side-to-side motion of their tines.

But what is the exact form of that motion?

We'll use this floppy version of a tuning fork with a light mounted on one of the tines to find out.

When we set the fork vibrating and sweep it past the camera, the path of the light is a sine wave.

Equipment

"Soft" tuning fork equipped with a battery, socket, and light bulb.

Demo 08-11 Mass on Spring

A mass hanging on a spring executes simple harmonic motion when displaced vertically from its equilibrium position and released.† In this video two different masses, with a mass ratio of 2 to 1, are shown oscillating from the same spring. The period can be measured from the video. Two identical springs are placed in parallel and the experiment is then repeated.

The spring constants can be determined from the initial extension when the weight is added, as shown in Disc 8, Demonstration 1. It is thus possible to calculate the period.

† Sutton, *Demonstration Experiments in Physics*, Demonstration S-5, Springs and Pendulums. Freier and Anderson, *A Demonstration Handbook for Physics*, Demonstration Mx-3, Mass on Spring.

This heavy spring and this set of masses will be used to show simple harmonic motion. If we place 1 kilogram on the spring and set it in motion, the spring and weight oscillate with a regular period.

What will happen to the period of oscillation if we increase the mass to 2 kilograms?

The period increases.

If we put an identical spring side-by-side with the first spring and repeat the demonstration, how will the period of oscillation change?

The period decreases.

Equipment

1. Two identical springs.
2. Support system.
3. Weight hanger.
4. Slotted weights.
5. Clock and meter stick, if desired.

Demo 08-12 Air Track Simple Harmonic Motion

An air track glider is connected by two springs to fixed points at the end of the air track. When the glider is displaced from its equilibrium position and released it will execute simple harmonic motion.† Doubling the mass of the glider slows down the oscillation, increasing the period, as can be seen on the video. Using two springs in parallel on each side of the moving glider reduces the period, as can also be seen.

In the final video segment the sinusoidal shape of the curve of position versus time is illustrated using graphic overlays of the motion, as shown in *Figure 1*.

Figure 1

† Freier and Anderson, *A Demonstration Handbook for Physics*, Demonstration Mx-7, Air Cart Mass and Spring.

We'll use this glider floating on a cushion of air and these springs to investigate simple harmonic motion. If a spring is attached to each end of a glider, the glider will oscillate back and forth on the track.

What will happen to the period of oscillation if we double the mass of the glider?

The top half of the screen shows the original arrangement, while the bottom half shows the glider with twice the mass. The period has increased.

What will happen to the period if we add another spring to each end of the glider instead of more mass?

The top half of the screen now shows the original setup, while the bottom half shows the glider with another set of springs attached. The period has now decreased.

To show the form of this type of motion, we will mark one point on the glider, and use it to draw a graph of position vs. time.

Equipment

1. Level air track.
2. Blower system.
3. Glider with holes or hooks on both ends.
4. Two identical springs.
5. Masses to double the mass of number 2.
6. Two additional identical springs.
7. Clock, if desired.

Demo 08-13 Torsion Pendulum

A torsion pendulum executes rotational oscillations subject to the restoring torque of a twisted wire, small rod, or spring.† In this example a metal disc, hanging horizontally by its center from the end of a small rod, executes simple harmonic motion. Additional weight is added to the disc, increasing its moment of inertia and thus increasing the period of oscillation of the torsional pendulum, shown in *Figure 1*.

Figure 1

† Freier and Anderson, *A Demonstration Handbook for Physics*, Demonstration Mz-1, Torsional Pendulum.

Torsion Pendulum / Script

Here is a device called a torsion pendulum. It consists of a flexible brass rod which is held tightly in an upper support, and which has a heavy disc attached to its bottom end.

If we twist the rod by rotating the disc, and then release it, the pendulum oscillates.

If we double the mass of the pendulum by adding this ring to the disc, how will the period of oscillation change?

The period increases.

Equipment

1. Torsional pendulum.
2. Support system.
3. Clock, if desired.
4. Cylinder rider whose mass is equal to pendulum disc.
5. Rim markers on disc and cylinder to aid visibility.

Demo 08-14 Different Mass Pendula

Pendula with the same length but different mass, as shown in *Figure 1*, are released together so that their periods can be compared. The mass does not appear in the equation for the period of a pendulum, so the period T is independent of mass:

$$T = 2\pi\sqrt{\frac{L}{g}}$$

where L is the length of the pendulum and g is the acceleration of gravity. The pendulums oscillate together.

Figure 1

These two pendula have the same length but different mass. How will their periods of oscillation compare?

Their periods are equal. Mass has no effect on the period of a pendulum.

Equipment

1. Two equal length pendula with bobs of identical material, but appreciably different diameters.
2. Support system.

Demo 08-15 4:1 Pendula

Pendula of length ratio 4:1, shown in *Figure 1*, are released together and their periods compared. The period of a pendulum is proportional to the square root of the length, so the ratio of periods between the long pendulum T_L and the short pendulum T_S is

$$\frac{T_L}{T_S} = \sqrt{\frac{L_L}{L_S}} = \sqrt{\frac{4}{1}} = 2$$

Figure 1

These two simple pendula have different lengths, with a 4:1 ratio. If we release both at the same time, how will their periods of oscillation compare?

The two pendula are in phase on every second swing of the shorter pendulum. The longer pendulum has a period twice as long as the shorter pendulum.

Equipment

1. Two pendula with identical bobs, but one having a length four times the shorter.
2. Support system.

Demo 08-16 Hoops and Arcs

A series of four metal arcs, with angular widths of increasing portions of a circle, are suspended symmetrically from a knife edge, displaced from equilibrium as shown in *Figure 1*, and released. They all execute simple harmonic motion with the same period,† which is equal to period of a pendulum of length equal to the diameter of the hoop.

Figure 1

† Freier and Anderson, *A Demonstration Handbook for Physics*, Demonstration My-3, Oscillating Ring.

Here are four metal arcs each of which is an increasingly large portion of identical circles.

Each arc has a hole at the top for a pin support on which it can swing like a pendulum.

Which arc will have the longest period of oscillation?

All four arcs have equal periods.

Equipment

1. Four metal arcs of equal radii, each a larger section than the previous with the last a full circle.
2. Support system.

Demo 08-17 Pendulum with Large Amplitude

A simple pendulum is released as shown in *Figure 1* and allowed to oscillate at a variety of amplitudes from 5 through 80. A clock is shown on the screen to aid in making measurements of the period of the pendulum as a function of amplitude. The equation of motion is

$$\frac{d^2\theta}{dt^2} = -\omega^2 \sin\theta$$

which for small θ has the standard solution $\theta = \theta_o \sin \omega t$,

where $\omega = \sqrt{\frac{g}{L}}$, so the period $T = 2\pi\sqrt{\frac{L}{g}}$

The length of this pendulum is 95.85 cm, so in this case the period for small amplitudes is 1.965 seconds. For large amplitudes the differential equation above must be solved, either numerically or as a series derived from elliptical integrals:†

$$T = T_o\left(1 + \theta_o^2/16 + 11\,\theta_o{}^4/3072 + \,.\,.\,.\right)$$

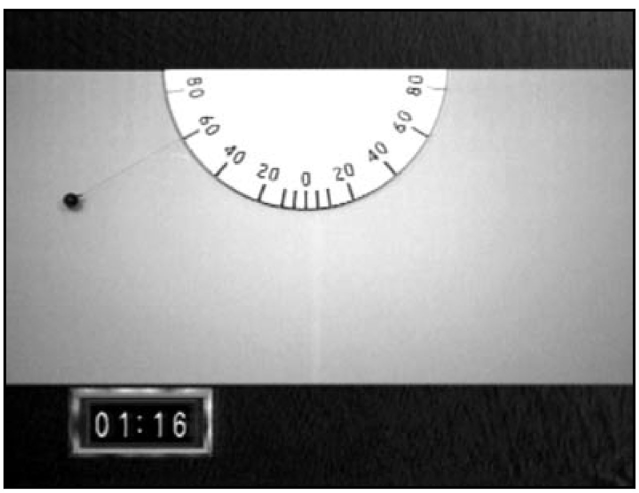

Figure 1

† Jerry B. Marion, *Classical Dynamics of Particles and Systems* (Academic Press, New York, 1965), section 7. 4, The Plane Pendulum, pp. 179-183.

An excellent summary article by Nelson and Olsson‡ provides a relatively complete discussion of the pendulum and its behavior, including sources of error, and lists over 40 references dealing with the subject.

Figure 2 defines the geometry for the differential equation above and *Figure 3* shows the theoretical period as a function of amplitude angle, obtained by integration of the equation of motion above, along with the measured results.

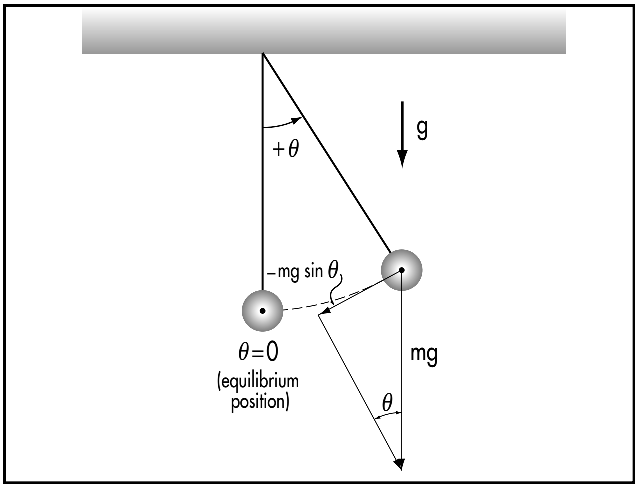

Figure 2

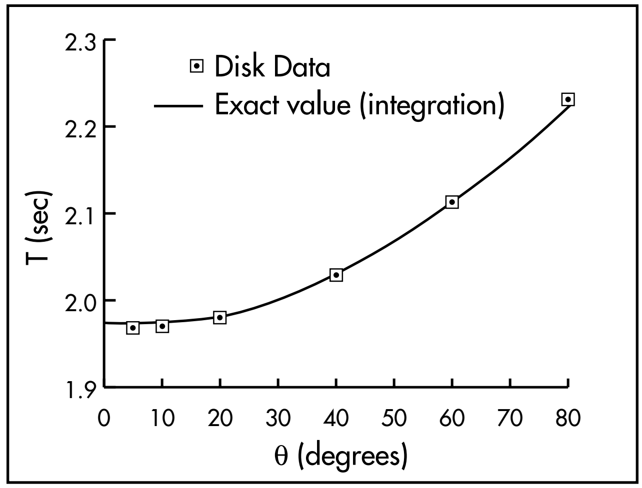

Figure 3

‡ Robert A. Nelson and M. G. Olsson, The Pendulum—Rich physics from a simple system, *Am. J. Phys.* 54, 112-121 (1986).

Demo 08-17 Pendulum with Large Amplitude / Script

This pendulum consists of a heavy ball rigidly supported on a light string. We will use this system to measure the period of the pendulum as a function of amplitude.

The distance from the support point to the center of the bob has been carefully measured to be 0.959 meters. We can measure the time for one period for different angles of oscillation. Elapsed time for each run will be shown at the lower left in seconds and frames, where one frame is one-thirtieth of a second.

Equipment

1. Pendulum with a highly dense (or otherwise large) bob.
2. Support system.
3. Clock, if desired.

Demo 08-18 Physical Pendulum

This physical pendulum consists of a rigid bar of aluminum, suspended from a point near one end. The physical pendulum is displaced from its equilibrium position and released, so that it executes simple harmonic motion. The period of the physical pendulum is compared with that of a simple pendulum (a) with the same length as the physical pendulum, and (b) with length equal to two-thirds of the length of the physical pendulum, as shown in *Figure 1*.† The period of the physical pendulum is equal to that of the simple pendulum two-thirds its length.

Figure 1

† Freier and Anderson, *A Demonstration Handbook for Physics*, Demonstration My-4, Center of Percussion and Center of Oscillation.

This aluminum bar hangs from a bearing support so that it swings like a pendulum. If we compare the period of this physical pendulum with that of a conventional pendulum made of a string and mass, we see that the physical pendulum has a shorter period.

To match the period of the physical pendulum, we need a string pendulum that is two-thirds the length of the physical pendulum.

Equipment

1. Physical pendulum made from aluminum bar stock with a bearing assembly for a pivot point.
2. Simple pendulum whose length matches that of the physical pendulum.
3. Another simple pendulum whose length is two-thirds that of the physical pendulum.
4. Support system.

Demo 08-19 Variable Angle Pendulum

A physical pendulum is mounted rigidly to a bearing such that the angle of the plane in which the physical pendulum swings can be adjusted, as shown in *Figure 1*. Increasing the angle θ of the plane of the pendulum with respect to the vertical has the effect of decreasing the acceleration of gravity acting on the physical pendulum, so that its period increases:

$$T = 2\pi\sqrt{\frac{L}{g\sin\theta}}$$

The period can be measured as a function of angle from the video.

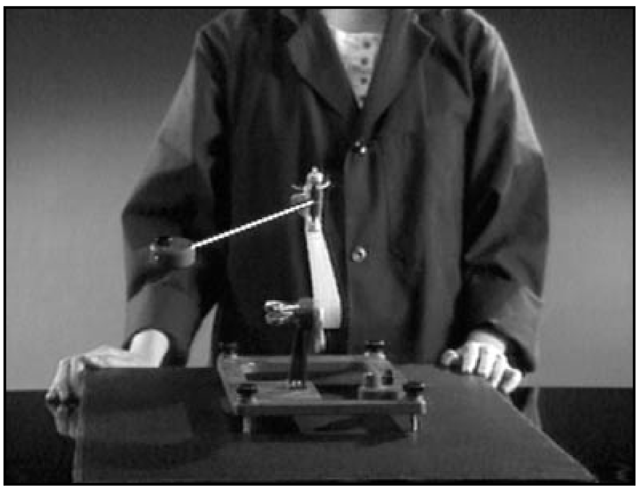

Figure 1

This physical pendulum has a heavy bob mounted at the end of a light rod which rotates freely in a bearing.

When we set the pendulum in motion in a vertical plane, it has a period of about a second.

The pendulum is designed so that the angle of the plane of oscillation can also be changed. If we set the pendulum with its plane of oscillation at 45 degrees to the vertical, how will the period of the pendulum change?

The period is now longer.

If we increase the angle to 60 degrees from the vertical, the period becomes still longer.

Equipment

1. Physical pendulum with a massive bob and a bearing pivot point.
2. Support system whose angle can be adjusted from the initial vertical, to the desired angle; all of which is mounted on a broad stable base that has level screws serving as short legs.
3. Lazy Susan of appropriate size to enable viewing from multiple angles.

Demo 08-20 Circular Motion vs. Spring and Weight

Simple harmonic motion is the projection of uniform circular motion along a line.† This demonstration compares the projection of a spot executing uniform circular motion with the projection in the vertical plane of the motion of an oscillating mass hanging on a spring,‡ as shown in *Figure 1*. Since their motions in the vertical direction are the same, the mass on a spring must be executing simple harmonic motion.

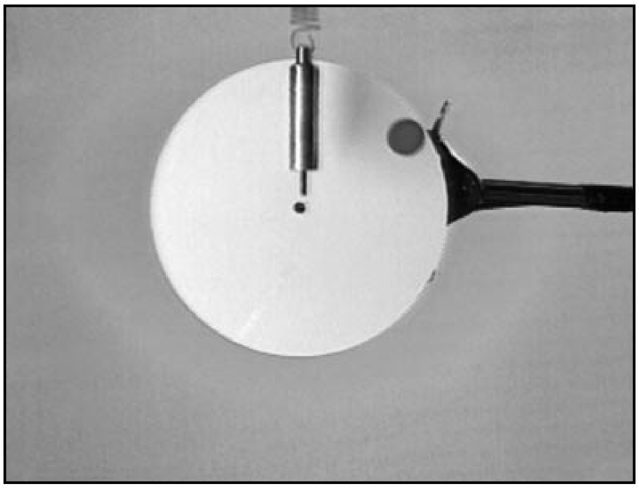

Figure 1

† Freier and Anderson, *A Demonstration Handbook for Physics*, Demonstration Mx-2, Projection Model of SHM.

‡ Sutton, *Demonstration Experiments in Physics*, Demonstrations S-1, Shadow Projection of Circular Motion, S-2, Simple Harmonic Motion Machine, and S-5, Springs and Pendulums.

This rotating disc and a weight on a spring will be used to show the similarity between uniform circular motion and simple harmonic motion.

A spot on the edge of the disc allows us to see the constant rotational speed of the disc.

If we set the weight oscillating in time with the spot on the disc, the weight is always at the same horizontal level as the spot.

Equipment

1. Motor-driven rotating disc bearing a single rim marker.
2. Spring and weight carefully chosen so its period of oscillation matches that of the rim marker on the disc.
3. Support system for both 1 and 2.

Demo 08-21 Circular Motion vs. Pendulum

Simple harmonic motion is the projection of uniform circular motion along a line.† This demonstration compares the projection in the horizontal plane of a spot executing uniform circular motion with the motion of a pendulum of the appropriate length,‡ as shown in *Figure 1*. Since their motions in a horizontal direction are the same, the pendulum must be executing simple harmonic motion.

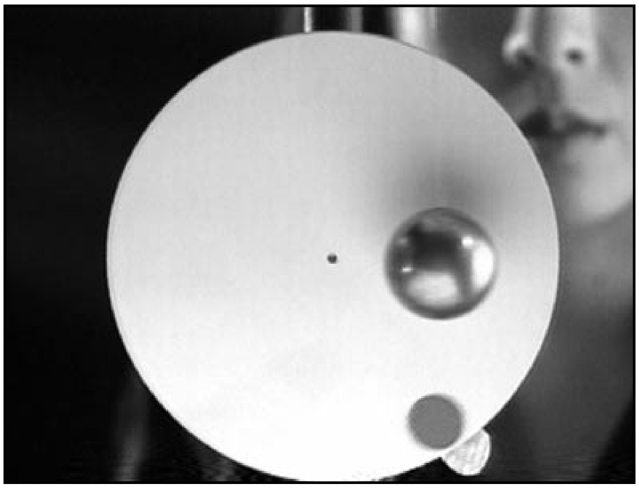

Figure 1

† Freier and Anderson, *A Demonstration Handbook for Physics*, Demonstration Mx-2, Projection Model of SHM.

‡ Sutton, *Demonstration Experiments in Physics*, Demonstrations S-1, Shadow Projection of Circular Motion, S-2, Simple Harmonic Motion Machine, and S-5, Springs and Pendulums.

This rotating disc and this pendulum will be used to show the similarity between uniform circular motion and simple harmonic motion.

A spot on the edge of the disc allows us to see the constant rotational speed.

If we start the pendulum swinging just as the spot passes the pendulum, the pendulum stays in a vertical line with the spot.

Equipment

1. Motor-driven disc (same as Demonstration 08-20).
2. Simple pendulum whose length is carefully adjusted to match the period of revolution of number 1.
3. Support system for both.

Demo 08-22 Phase Shift

Two balls are mounted along the periphery of a rotating disc, which is shadow projected to show the simple harmonic motion of the balls. The angular separation of the balls around the circumference of the disc determines the phase difference between their harmonic oscillations, as illustrated in *Figure 1*. A variety of phase differences are illustrated.

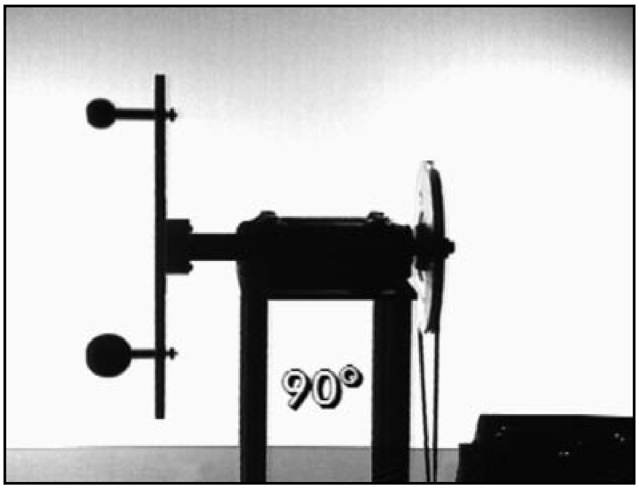

Figure 1

These two spheres on the edge of a disc rotate with the same period. We'll back light the spheres so that their motion appears one dimensional and simulates simple harmonic motion. We can change the relative phase of the spheres by moving them to different parts of the disc.

Here the spheres are moving in phase.

Here they are moving with a phase difference of 45 degrees.

Here is a phase difference of 90 degrees.

135 degrees.

180 degrees.

Equipment

1. Motor-driven disc whose rim has drilled holes (at relative positions of 45°, 90°, 135°, and 180°) allowing for quick and easy remounting of one sphere in relation to a larger one (for ease of distinguishing the two apart in a shadow projection).
2. Support system.
3. Light source.

Demo 08-23 Periodic Non-Simple Harmonic Motion

A spring pendulum,[†] as shown in *Figure 1*, is driven by a physical pendulum with a frequency different from the normal frequency of the spring pendulum. The resulting complex motion of the spring pendulum is a non-simple harmonic oscillation.

Figure 1

† Freier and Anderson, *A Demonstration Handbook for Physics*, Demonstration Mx-6, Clockspring Pendulum.

The motion of this heavy pendulum bob can be described by a sinusoidal function of time. This special type of motion is known as simple harmonic motion.

The motion of the flexible wire at the top cannot be described by a sine function; it is not simple harmonic motion.

Equipment

1. A very massive pendulum with a bearing assembly support (which is securely clamped down) serves as a driver for a companion vibrator.
2. Secondary vibrator is made from a flexible rod whose lower end is firmly attached to the pendulum, and whose upper end is carrying visible flags.
3. The secondary vibrator passes through a motion restriction that in turn gives rise to its periodic but non-simple harmonic motion.
4. Entire assembly needs to be clamped to non-moving table.

Demo 08-24 Inertia Balance

An inertia balance[†] is a device by which two masses can be compared independently of the existence of a gravitational field. Placing a mass on the platform between the two springs, as shown in *Figure 1*, and starting the platform into horizontal vibration, the frequency is determined only by the rigidity of the springs, the mass of the platform, and the mass placed on the platform. Two masses are compared on the video.

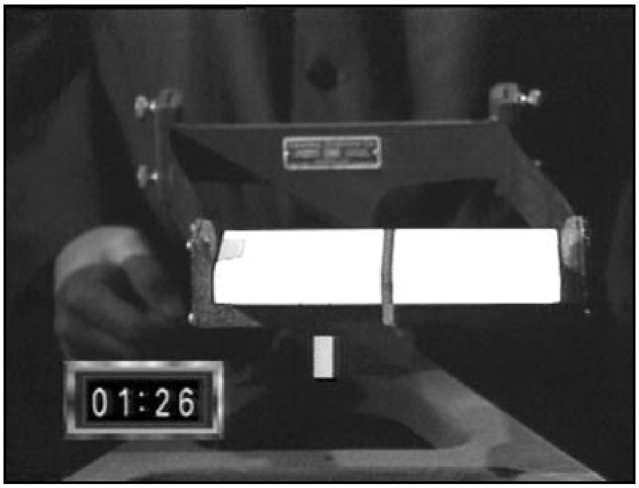

Figure 1

† Sutton, *Demonstration Experiments in Physics*, Demonstration M-106, Inertia Balance.

Most methods of determining an object's mass actually measure its weight, the gravitational force the Earth exerts on the mass. Is there any way to determine the mass of an object in a weightless environment like outer space?

This inertia balance is one way. These two flexible metal arms support a small platform which can hold various masses. If we put this mass on the platform and give it a push, the platform oscillates at a regular frequency.

What will happen to the frequency of oscillation if we add more mass to the platform?

The frequency decreases. This technique is used by NASA scientists to determine the mass of astronauts while they are in orbit around the Earth.

Equipment

1. Platform spring scale.
2. Two masses with center markings and identical physical dimensions, but radically different densities.
3. Inertia balance.
4. Clock, if desired.

Demo 08-25 Pendulum Waves

A series of independent simple pendula of monotonically varying length, are attached as shown in *Figure 1* to a rigid support. When they are displaced perpendicular to the support and released, the pendula undergo phase changes such that they create a series of traveling and standing waves.†

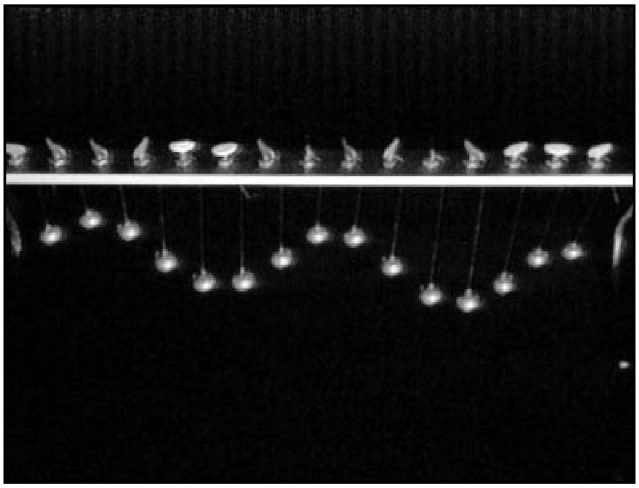

Figure 1

† Richard E. Berg, Pendulum waves: A demonstration of wave motion using pendula, *Am. J. Phys.* 59, 186-187 (1991).

Fifteen independent simple pendula are suspended from a rigid frame. The lengths of the pendula have been carefully chosen so that the phase change per oscillation between any two adjacent pendula is the same.

Notice that as they oscillate they create a continuously changing pattern of traveling and standing waves.

Equipment

1. Series of fifteen independent simple pendula with identical bobs whose lengths generate the desired apparent progression of identical phase changes.
2. Rigid support system.
3. Starting bar.

Demo 08-26 Lissajous Figures

Lissajous figures are produced on an oscilloscope screen, as shown in *Figure 1*, using two sinusoidal oscillators.† A variety of figures are shown, corresponding to different vertical to horizontal frequency ratios.

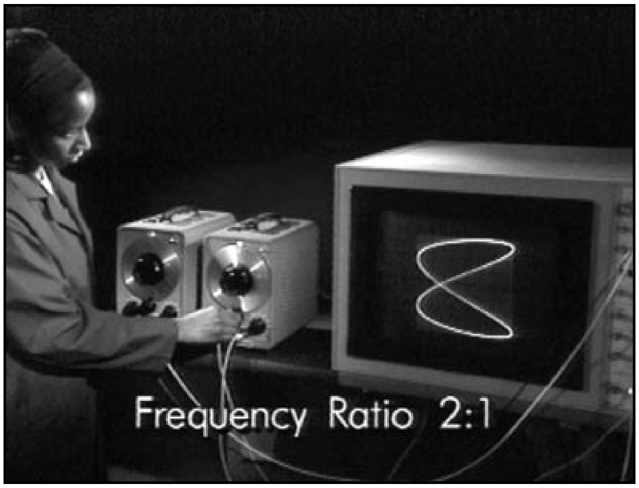

Figure 1

† Freier and Anderson, *A Demonstration Handbook for Physics*, Demonstration Sn-3, Lissajous Figures on an Oscilloscope.

We'll use two audio oscillators of adjustable frequency to produce Lissajous figures on this oscilloscope screen.

This oscillator drives the vertical motion of the oscilloscope spot.

This oscillator drives the horizontal motion of the spot.

When the two motions are combined, the pattern is chaotic until the frequencies of the oscillators are equal or are integer multiples of one another.

Equipment

1. Two audio oscillators.
2. Four leads.
3. Oscilloscope.