The Video Encyclopedia *of* Physics Demonstrations™

Explanatory Material By: Dr. Richard E. Berg
University of Maryland

Scripts By: Brett Carroll
University of Washington

Equipment List By: John A. Davis
University of Washington

Editor: Rosemary Wellner

Graphic Design: Wade Lageose/Art Hotel

Typography: Malcolm Kirton

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CHAPTER 7

FRICTION

Demo 03-01 Air Track Friction

This demonstration acts as an introduction to the idea of the air track, showing that gliders can move virtually without friction on the air track when they are mechanically isolated by a thin layer of air.

Air Track Friction / Script

Did you ever wonder why objects slow down and then stop after they are given a push?

This glider stops very quickly after it is sent sliding along the track.

But when the glider is floated on a cushion of air, friction is nearly eliminated.

Now the moving glider slows down only gradually.

Equipment

1. Level air track.
2. Blower system.
3. Glider.

Demo 03-02 Static vs. Sliding Friction

This demonstration shows that the coefficient of static friction is greater than the coefficient of dynamic or sliding friction for the same two surfaces.† A spring scale attached to a rope is used to pull a board from rest along a horizontal surface, as shown in *Figure 1*. Although it requires about 24 N to overcome the static friction, a force of only about 16 N is needed to maintain the system at a constant velocity.

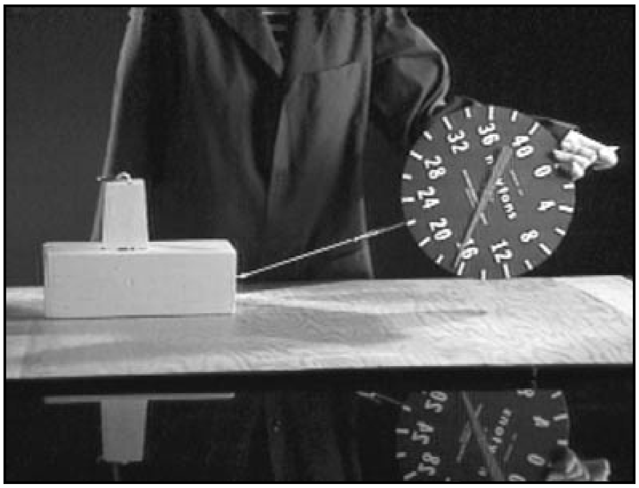

Figure 1

† Freier and Anderson, *A Demonstration Handbook for Physics,* Demonstration Mk-1, Force of Friction.

Static friction between this wooden block and the table keeps the block from moving until it is pulled by a sufficiently large force.

We'll use a spring scale to measure the force required to overcome the force of friction and move the block. In this case, the force is approximately 23 newtons.

The force needed to slide the block along the table at a constant speed is less than 23 newtons.

The coefficient of kinetic friction is lower than the coefficient of static friction.

Equipment

1. Block of wood with hook attached.
2. Short length of string.
3. Spring scale.

Demo 03-03 Area Dependence of Friction

This demonstration shows that the frictional force is approximately independent of the area of contact between two surfaces.† A wooden board with sides of approximately 5 cm and 20 cm is pulled along a table with each side, respectively, in contact with the table, as illustrated in *Figure 1*. When the larger side is in contact with the table, the sliding frictional force is about 12 N, and when the smaller side is in contact with the table the frictional force is about 16 N.

Even though the surface area is decreased to one-quarter of its former value, the frictional force increases to only one and one-third its former value. This is counter to intuition, which might expect the force to decrease, and is a good example of an empirical law. It is possible in most instances to ignore the contribution of surface area to frictional forces.

Figure 1

† Sutton, *Demonstration Experiments in Physics,* Demonstration M-49.
Freier and Anderson, *A Demonstration Handbook for Physics,* Demonstration Mk-1, Force of Friction.

Any two objects being rubbed together have frictional forces between them. How do those forces depend on the area of contact between the objects?

We'll use this long board and a spring scale to find out. If we pull the board along the table with its widest face down, the amount of force required to overcome static friction is about 12 newtons.

If we now tip the board up on its edge so that the surface area in contact with the table is decreased about four times, how much force will be needed to move the board?

The force remains about the same. To a good approximation, static frictional force does not depend on the area of contact.

Equipment

1. Length of wood (perhaps 2 x 12), with a hook.
2. Short length of string or chain.
3. Spring scale.

Demo 03-04 Weight Dependence of Friction

A board is pulled along a horizontal surface by a rope attached to a spring scale, measuring the kinematic frictional force. Weights are then added, as illustrated in *Figure 1*, to determine how the frictional force changes as the normal force between the two surfaces varies.† The experimental results clearly show that the frictional force is directly proportional to the weight, or normal force.

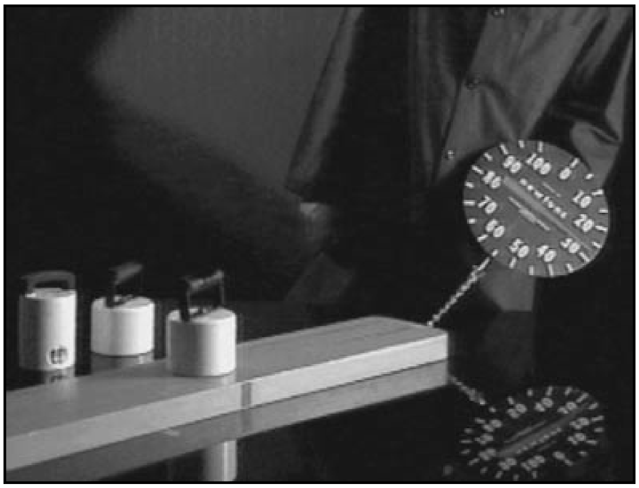

Figure 1

† Sutton, *Demonstration Experiments in Physics,* Demonstration M-50, Dependence of Friction on Pressure.

How does the friction between two objects change as the force pushing them together is increased? We'll use this long board, a spring scale, and some weights to find out.

If we pull on the board with the spring scale, we will notice that the board always starts to slide at about the same force—this is the maximum value of static friction.

If we add enough weight to the board to double the overall weight, how will the required force change?

The force needed to move the board approximately doubles.

If we now add another weight equal to the weight of the board, tripling the original weight, we see that the force is approximately tripled.

Equipment

1. Length of wood (perhaps 2 x 12) with a hook.
2. Short length of string.
3. Spring scale.
4. Several large weights.

Demo 03-05 Surface Dependence of Friction

This demonstration illustrates that the frictional force between different surfaces is very different.† Four identical brass blocks are placed on strips of four different materials, and one end of the device is raised, as indicated in *Figure 1*, until the brass blocks begin to slide in turn. As the system is raised, the brass block slides at 18° for the Teflon strip, 22° for the wooden strip, 25° for the sandpaper strip, and 50° for the rubber strip.

The coefficient of static friction μ_s is equal to the tangent of the angle at which slipping begins.

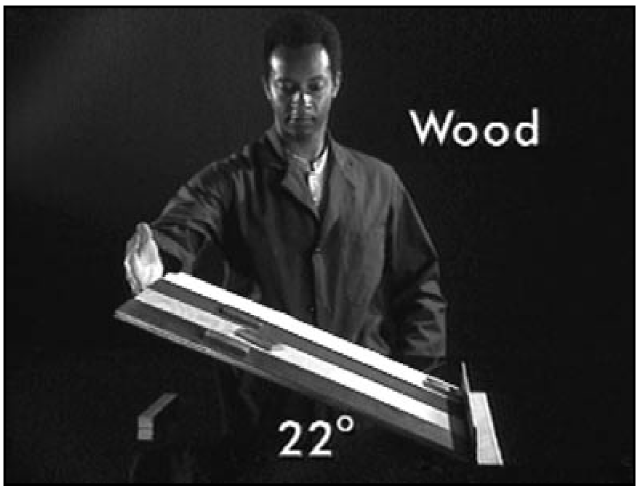

Figure 1

† Freier and Anderson, *A Demonstration Handbook for Physics,* Demonstration Mk-1, Force of Friction.

This incline has four different surface materials—rubber, wood, sandpaper, and Teflon.

Identical brass blocks are placed on the four surfaces. Now the board will be tilted until each of the blocks starts to slide down. As the board is tilted, the blocks begin to slide in a definite order.

We'll repeat this sequence with the angle of tilt displayed next to the board as each block slides.

Here are the angles at which each of the blocks started to slide on the various surfaces.

Equipment

1. A piece of half-inch plywood covered with four different materials: 1) rubber, 2) wood, 3) sandpaper, and 4) Teflon.
2. Four equal weights with flat, smooth surfaces.
3. Catcher/Pivot bar clamped to tabletop.
4. Clamps.

Demo 03-06 Stability of Rolling Car

Through an application to automotive engineering, this demonstration illustrates that the coefficient of static friction is greater than the coefficient of sliding friction.† A toy car with either its front or its rear wheels locked is allowed to slide down an inclined plane. If either the car's front or its rear wheels are locked, that pair will slide, while the other pair rolls. Because the coefficient of rolling friction is greater than that of sliding, the pair that are rolling, and therefore have greater friction with the board, will lag behind. This demonstration illustrates why it is necessary to provide most of the braking for a car at the front wheels.

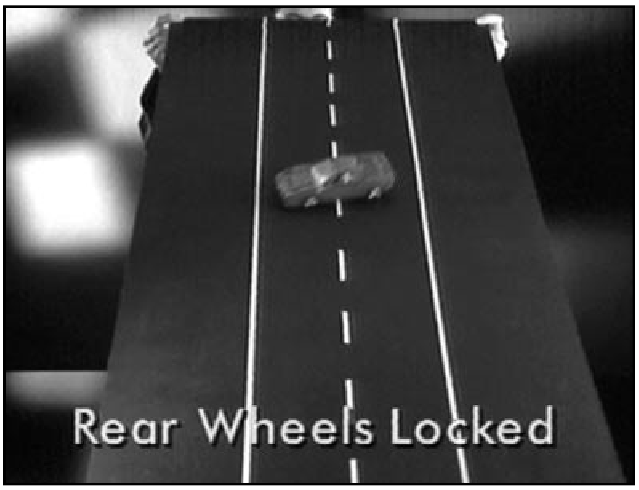

Figure 1

† Sutton, *Demonstration Experiments in Physics,* Demonstration M-53, Automobile Skidding. Freier and Anderson, *A Demonstration Handbook for Physics,* Demonstration Mk-3, Brakes on Front and Rear Wheels.

Stability of Rolling Car / Script

Each of this toy car's two sets of wheels, front or back, can be locked so that they are no longer free to roll. Which set of wheels should we lock if we want the car to roll smoothly down the incline: the front or the back wheels?

With the back wheels locked, the car skids out of control.

Locking the front wheels lets the car roll smoothly down the incline.

Equipment

1. Toy car with freely rolling wheels.
2. "Roadway" surface which can be tilted.
3. Locking bar which disables both sets of wheels—first the rear set, then the front set.
4. Catching mechanism to protect the car.

CHAPTER 8

WORK, ENERGY, AND POWER

Demo 03-07 Pile Driver

A pile driver consists of heavy weights that are dropped onto nails, driving the nails into a block of wood, as shown in *Figure 1*.† When the weight is increased or weights are dropped from a higher position, the nail is driven further into the wood. This demonstration illustrates that the greater the original potential energy of the weight, and thus its kinetic energy at impact, the further the nail is driven into the wood.

The depth of penetration is not exactly proportional to the KE of the weights because the force required to drive the nails is not constant, but varies with speed and depth of penetration.

Figure 1

† Sutton, *Demonstration Experiments in Physics,* Demonstration M-133, Pile Driver.
Freier and Anderson, *A Demonstration Handbook for Physics,* Demonstration Mv-1, Pile Driver.

This pile driver will be used to show how the energy put into raising a weight can do work, such as driving a nail into a piece of wood.

Weights will be dropped from various heights to strike a nail at the bottom of the fall.

Here is the single weight dropped 35 centimeters.

Here is the single weight dropped 70 centimeters.

Here is the double weight dropped 70 centimeters.

The greater the kinetic energy of the falling weight, the farther the nail is driven into the wood.

Equipment

1. Pile driver apparatus. One with two equal mass drivers which a can be independently dropped.
2. Block of wood with several nails predriven to equal initial depth.

Demo 03-08 Spring Pong Gun

A "spring pong gun" is a toy gun that uses a compressed spring to shoot small balls. The potential energy of the compressed spring is converted into kinetic energy of the ball being shot by the gun. In this demonstration two balls are shot, a light ball and a similar ball filled with epoxy to make it heavier. When the potential energy of the spring is converted into kinetic energy of the ball, the heavier ball is projected with much lower speed, and does not rise as high.

Figure 1

These two balls are of unequal weight. The lighter one is hollow and the heavier one is filled with epoxy.

When the spring inside this toy gun is compressed, energy is stored. We can use that energy to launch these balls into the air.

First, the hollow ball.

Next, the epoxy-filled ball.

This ball doesn't go as high, even though it receives about the same amount of energy from the spring as did the hollow ball.

Equipment

1. Toy spring pong gun.
2. Two balls of differing weights.
3. Pan balance.

Demo 03-09 Spring Jumper

This demonstration makes use of the potential energy stored in a spring to launch a small toy, as shown in *Figure 1*. The spring, attached to the toy, is compressed underneath a suction cup that holds the toy down on the surface of a table. The spring then pushes upward on the suction cup, eventually causing it to break free from the table. The toy then is ejected some distance into the air, much to the delight of the demonstrator.

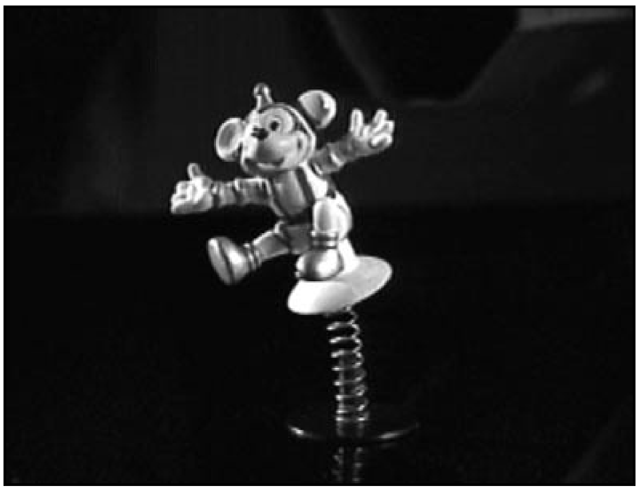

Figure 1

This small toy is used to demonstrate that the energy stored in a compressed spring can be enough to launch the spring into the air.

The spring is compressed, and a suction cup holds it down.

After a few seconds, the suction cup lets go and the toy leaps into the air. The energy stored in the spring was enough to launch both the spring and the heavy toy into the air.

Equipment

Spring toy with suction cup base.

Demo 03-10 X-Squared Spring Energy Dependence

This demonstration illustrates that the energy stored in a spring is proportional to the square of the distance the spring is compressed. An air track glider is attached to an arm that compresses a spring. When released it moves up the inclined air track, as illustrated in *Figure 1*. In this case the distance the glider travels up the incline is proportional to its final gravitational potential energy, which is linearly proportional to vertical height and therefore to distance along the incline. The energy stored in the compressed spring increases as the square of the compression, so compression ratios of 1:2:3 units respectively produce energies in the ratio of 1:4:9, and the glider moves up the incline by distances in the ratio of 1:4:9, as seen from the scale provided along the air track.

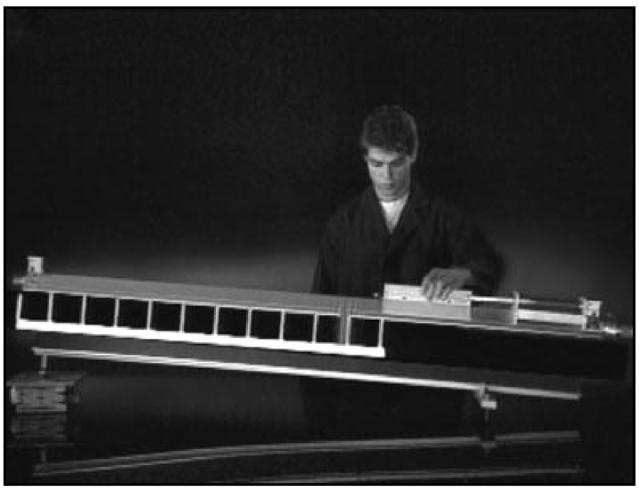

Figure 1

Energy can be stored in many ways—compressing a spring, for example. We'll use this glider floating on an air cushion to show just how much energy is stored in a spring for a given amount of compression.

This arm attached to the glider will compress the spring contained inside this glass tube. To determine how the energy stored in the spring varies with different compressions, we will compress the spring by three different distances and then use the energy stored in the spring to launch the glider up a tilted track. The spring energy will be converted into kinetic energy then into gravitational potential energy, which is directly proportional to the height of rise of the glider.

We launch the glider with the spring compressed one unit and it rises up the track one unit, as measured on the bottom scale.

If the spring is compressed two units, how high will the glider rise?

If the compression is increased three units, how high will the glider rise?

The energy stored in a compressed spring is proportional to the square of the compression distance.

Equipment

1. Tilted air track.
2. Blower system.
3. Calibrated spring launch mechanism.
4. Glider with attached launching rod.
5. Appropriate scales for the launching mechanism and the air track distances.

Demo 03-11 High Bounce Paradox

Normally a ball can only bounce up to a maximum height equal to the height from which it was dropped, and this can only occur in the virtually non-existent case of a perfectly dropped ball. This demonstration shows the case of an object that “bounces” higher than it started originally.

One half of a handball is flipped inside out and dropped onto the floor. The mechanical potential energy stored in the ball when it was distorted is released as the ball hits the floor. This energy is converted to kinetic energy of the ball, increasing its upward speed after the collision with the floor and causing the ball to bounce higher than the position from which it was dropped.

When a ball bounces after being dropped, it will not normally bounce higher than its original height.

When we drop this object, it bounces higher than its original height.

How can we explain this behavior?

The object is a handball cut in half.

Before it was dropped, it was flipped inside out, storing energy in the elastic material.

When the half-ball hops back to its normal shape, it has enough energy to go higher than the original height.

Equipment

1. A ball.
2. A handball-type hemisphere that can be turned inside out.

Demo 03-12 Energy Well Track

A ball is allowed to roll back and forth in a V-shaped track, shown in *Figure 1,* to illustrate transformation between mechanical potential energy and kinetic energy.† When the ball is released from rest at a horizontal level below the peak at the right side of the track, its original potential energy will be converted into kinetic energy at the bottom of the V and then back into potential energy as it rises up the second side. However, it does not have sufficient energy to escape from the well. If the ball is released from rest at a point above the peak at the right side of the track, as shown, it has enough energy to escape from the well, as the video demonstrates.

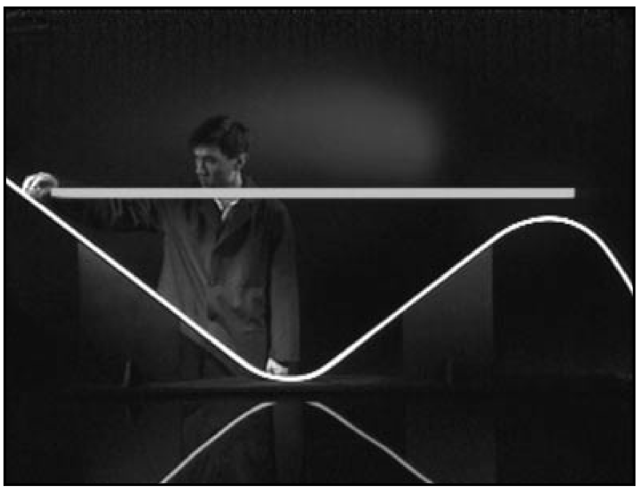

Figure 1

† Freier and Anderson, *A Demonstration Handbook for Physics,* Demonstration Mr-2, Conservation of Energy.

Energy Well Track / Script

Here is an arrangement called an energy well. The V-shaped bottom of this track is a potential well in which a ball can roll back and forth.

If the ball has insufficient energy to escape over the top, it is trapped in the well and can only oscillate back and forth. How much higher than the low side would it have to be released from in order to escape?

A release point only slightly higher than the low side is sufficient for the ball to escape.

Equipment

1. Piece of U-channel bent into the desired shape of an energy well.
2. Support mechanism for track.
3. Ball.

Demo 03-13 Galileo's Pendulum

A simple pendulum is raised and released from rest such that when it reaches its lowest point the string is intercepted by a post, effectively creating a pendulum with a shorter length, as shown in *Figure 1*.† The height to which the bob rises after the string is intercepted by the post is the same as the original height at which the bob was released, illustrating conservation of mechanical energy.

Figure 1

† Sutton, *Demonstration Experiments in Physics,* Demonstration M-132, Galileo's Pendulum Board.
Freier and Anderson, *A Demonstration Handbook for Physics,* Demonstration Mr-3, Stopped Pendulum.

This pendulum ball will be released from the height marked on the screen. When it reaches the bottom of its swing, a post will stop the top part of the string but the ball will continue moving.

How high will the ball rise on the other side of the swing? Lower, higher, or the same as the release height?

The ball rises to the same height because the energy is conserved.

Here's the demonstration repeated with a different initial height.

Equipment

1. Tall ring stand.
2. Simple pendulum with massive bob.
3. Set of horizontal grid lines to compare the far end positions of a swing.
4. A pivot bar whose vertical height can be easily adjusted.

Demo 03-14 Bowling Ball Pendulum

A pendulum formed from a bowling ball on a long rope is released from rest directly in front of the demonstrator's nose.† When it swings back, it comes up to its starting point in front of his nose, but does not hit him, due to conservation of mechanical energy.

Figure 1

† Freier and Anderson, *A Demonstration Handbook for Physics,* Demonstration Mr-6, Large Pendulum.

Bowling Ball Pendulum / Script

This person will put his face on the line to demonstrate faith in the principle of energy conservation. A bowling ball pendulum is released from rest directly in front of the person's face.

If energy is conserved, the ball cannot rise higher than its release point, and his face is safe.

Should he be willing to bet on that? Let's find out.

The ball is released. . . . and misses by a nose.

Equipment

1. A simple pendulum using a 16-pound bowling ball as the bob.
2. A secure support system—multistand preferable—that has little or no frictional losses (we used a bearing filled airplane control pulley).
3. A "true-believer" demonstrator with a disciplined straight face.
4. Reference system for the demonstrator's head. We used a solid wall!

Demo 03-15 Triple Track

Balls are released from rest at the tops of three tracks, shown in *Figure 1*. Because of conservation of mechanical energy, the height to which the ball rises on the other side of the tracks is the same, and does not depend on the angle of the track.†

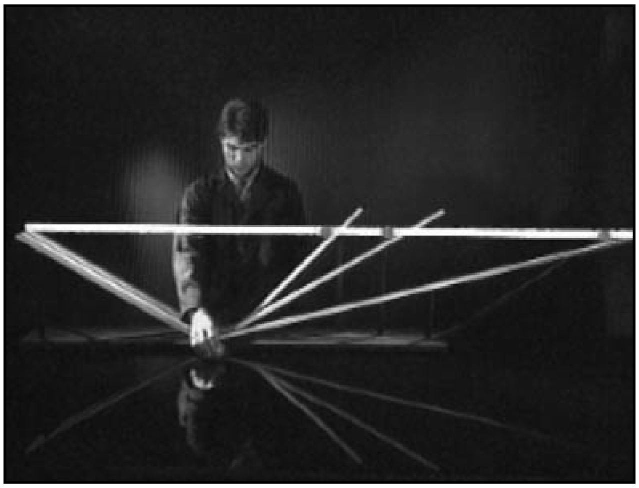

Figure 1

† Freier and Anderson, *A Demonstration Handbook for Physics,* Demonstration Mr-2, Conservation of Energy.

Raising a mass increases its gravitational potential energy.

We'll use this triple track to show that this energy is conserved as it changes from one form to another.

We'll release a rubber ball down each of these three tracks. Each track has a similar downhill section, but the uphill sides have different slopes.

If a ball is released from the top of each track, how high will it rise on the other side in each case?

Here's the ball rolling down the first track.

The second track.

The third track.

The ball rises to the same height from which it was released in each case.

Equipment

1. Three lengths of U-channel with identical lengths and angles on one end and differing angles and lengths on the other.
2. Suppport system for the three tracks.
3. Position marking riders which nestle inside the channel and reflect the end points of travel.
4. A ball that will roll, not slide on the tracks.
5. Long bar showing riders lie on a horizontal line.

Demo 03-16 Hand Cranked Generator

An electrical generator has two large weights attached to its shaft at a small distance from the shaft, as shown in *Figure 1*. It can be cranked by hand to a speed at which it contains a significant amount of rotational kinetic energy. When it is released after rotating it to a large angular speed with the generator not under a load, it slows down and stops in about five seconds. However, if a light bulb is connected to the output of the generator, the load on the generator consumes energy, which is obtained from the rotational kinetic energy of the weights, and the system slows down and stops in about one second.

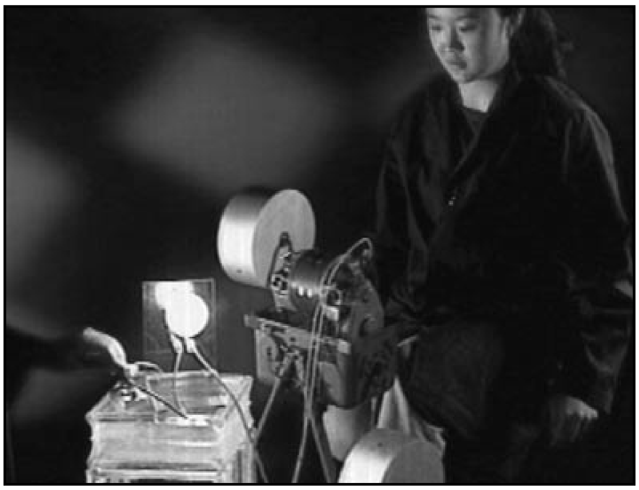

Figure 1

This electrical generator can be used to power a light bulb.

If we spin the generator and release the handles with the light bulb not connected, the heavy weights on the handles will act like a flywheel and keep the generator spinning for a long time before it stops.

When the generator is spun and released and the light bulb is switched on, the generator stops spinning almost immediately.

Lighting the filament of the bulb requires energy, energy which is obtained from the rotational energy of the generator.

Equipment

1. Surplus electrical generator.
2. Large masses mounted on handles of generator.
3. Light bulb and socket.
4. Pair of long leads.
5. Short lead.
6. Switch.
7. Assistant to close the switch.

Demo 03-17 Generator Driven by Falling Weight

This demonstration illustrates conversion of energy between mechanical energy and electrical energy. A weight is attached to a string wrapped around a pulley on the shaft of an electrical generator, as illustrated in *Figure 1*. When there is no load on the generator, the weight is released and falls rapidly downward. When a light bulb load is attached to the output of the generator the weight falls much more slowly, as seen in the video. *Figure 2* shows the generator under load, while *Figure 1* shows the weight with the generator not under load.

Figure 1

Figure 2

We'll hang a heavy weight on the end of a string wrapped around the shaft of this electrical generator. As the weight falls, the string will spin the generator.

Here's the weight falling with no electrical load on the generator.

Note the speed at which the weight falls.

If we repeat this with a light bulb drawing current from the generator, the weight falls more slowly because the generator is more difficult to turn.

This split screen shot of both drops shows the difference.

Equipment

1. Electrical generator securely mounted well above the floor.
2. An extension for the generator's shaft, about which the driving string can be wrapped.
3. String and closeable hook.
4. Heavy weight with eye screw.
5. Catching device for falling weight.
6. Light bulb for the socket wired in series with the generator.

Demo 03-18 Prony Brake

A prony brake is a device for applying a constant frictional resistance force, which can be adjusted in amplitude, to a rotating shaft.† Such a device is used in the classical experiment for determining the mechanical equivalent of heat by Joule's method and in providing the resistance on some exercise bicycles. The device used in this video is shown in *Figure 1*, taken from the animation. Overcoming the frictional force provided by the prony brake requires a calculable power, which the video shows. Note that the frictional force required to rotate the device increases slightly with angular speed, leading to an even greater increase in the required power for higher angular speeds.

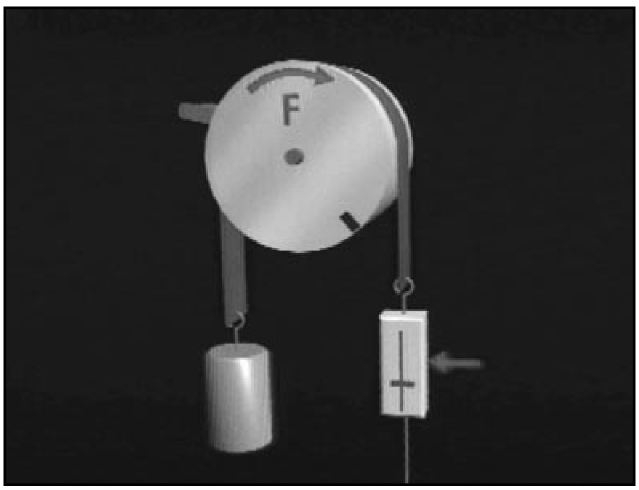

Figure 1

† Freier and Anderson, *A Demonstration Handbook for Physics,* Demonstration Mv-2, Power.

This device, known as a Prony brake, is used to demonstrate the concepts of work and power output.

This metal disc is cranked by hand and rubs against a leather strap under tension.

The amount of force required to turn the disc against friction can be read from the change in tension on this spring scale.

Here's an animation showing the frictional force acting on the spinning disc.

The work done in one rotation is equal to the required force multiplied by the distance the disc travels in each rotation.

Power can be found by dividing the amount of work done by the time of one rotation.

These two graphs show the amount of work done with each turn, and the power output, first at a low turning speed, and then at a higher speed.

Equipment

1. Prony brake.
2. Spring scale.
3. Leather strap.
4. Heavy weight.

CHAPTER 9

CENTER OF MASS

Demo 03-19 Stability

This demonstration illustrates the concepts of stable, neutral, and unstable equilibrium, using a cube, a sphere, and a cone, respectively, as illustrated in *Figure 1*.† The cube is in stable equilibrium, and returns to its original position if it is lifted slightly along one edge. The sphere at rest is in neutral equilibrium, and will remain at rest if given a slight displacement. The cone is in unstable equilibrium if carefully balanced on its tip, and will fall over if displaced very slightly from that position.

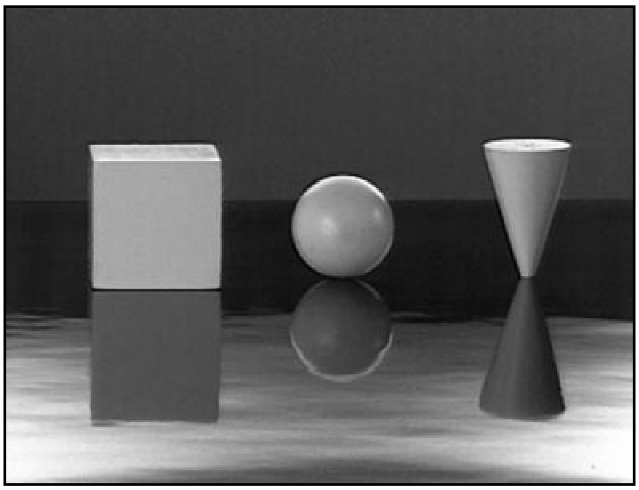

Figure 1

† Freier and Anderson, *A Demonstration Handbook for Physics,* Demonstration Mq-2, Stability of Cone and Sphere.

We'll use these objects to demonstrate three different types of equilibrium. This cube is in stable equilibrium. If it is displaced by a small amount, it returns to its original orientation.

This sphere is in neutral equilibrium. It is stable in its original orientation, and in any other orientation.

This cone is in unstable equilibrium.

If it is displaced by even a small amount, it falls over instead of returning to its original orientation.

This animation shows the weight that acts on the center of mass of each of the objects as it is tipped.

Equipment

1. A cube.
2. A sphere.
3. A cone.

Demo 03-20 Irregular Object Center of Mass

When a plane irregular object is suspended from any point on the object, it will hang such that the center of mass is directly below the point from which it is suspended.† An irregular object is suspended from two such points, locating the center of mass, as shown in *Figure 1*. When the object is then suspended from its center of mass, it is stable in any orientation, as shown in the video.

Figure 1

† Sutton, *Demonstration Experiments in Physics,* Demonstration M-31, Center of Gravity, and M-32, Equilibrium.
Freier and Anderson, *A Demonstration Handbook for Physics,* Demonstration Mp-7, Irregular Shape.

Is there a simple way to locate the center of mass of an irregular flat object?

We'll hang the sheet from a support point near its edge. Since it is in stable equilibrium, we know that its center of mass is directly below the point of support. A plumb bob is hung from the same support point, and we snap the chalk-filled string to put a line on the sheet.

Then we repeat the same action from another point of support.

Since the center of mass must be located on both these lines, it must be at their intersection.

If we suspend the sheet from the intersection point, it is stable in any orientation.

This animation shows the forces acting on the sheet, and the net restoring force that results when the center of mass is not below the point of support.

Equipment

1. Tall ring stand.
2. Support rod.
3. Irregular shaped body.
4. Plumb bob on string.
5. Soft chalk supply.

Demo 03-21 Center of Mass Disc

For a complex object in a gravitational field, the weight of the object—the gravitational force on the object—acts as though it were concentrated at the center of mass.† This means that if the object rotates as it flies through the air, its center of mass will move in a parabolic path, the same as that of a small but massive projectile. A disc is thrown through the air, first with its center of mass at the center of the disc, then with its center of mass displaced from the center of the disc, and the paths of the center of mass are traced out in each case. The latter case is illustrated in *Figure 1*.

Figure 1

This symmetrical foam disc has a heavy weight at its center. The center of mass is therefore at the center of the disc. When the disc is thrown, that point moves in a smooth parabola.

When the weight is shifted to the edge of the disc, the center no longer moves smoothly.

This point marks a new center of mass of the disc. When the disc is thrown, that point now moves in a smooth parabola.

Equipment

1. Cardboard or Styrofoam disc.
2. Disc weight to move from center on one side of disc to the near edge position on the opposite side.
3. Mark the new center of mass to aid visibility.

Demo 03-22 Chair on Pedestal

An upright chair is balanced on a vertical rod supporting the chair at a point under the seat at the center of the legs, as shown in *Figure 1*.† This seemingly impossible equilibrium position is achieved by placing heavy weights in holes strategically drilled in the ends of the chair legs, thus lowering the center of mass below the point at which the chair is balanced.

Figure 1

† Freier and Anderson, *A Demonstration Handbook for Physics,* Demonstration Mp-12, Center of Gravity of a Stool.

Chair on Pedestal / Script

This chair can be mounted on a sharp point at the top of this bar.

The chair is now stable in all orientations and can be swung vigorously without tipping from support. Why is the chair so stable?

Weights have been added inside the legs, which lowers the center of mass to below the point of support.

Equipment

1. Vertical support rod with point and heavy base.
2. Wooden chair—optimize by presetting dimple plate on the underside of the chair's seat and implanting weights within each of the chair's legs.

Demo 03-23 Clown on Rope

A toy clown holding a rod with weights on its ends, like the traditional tightrope walker, rolls upright on a pulley along a rope, as shown in *Figure 1*.† It remains stable because the weights lower the center of mass to a point below the point at which the pulley contacts the rope. When the rod and weights are removed from the grasp of the clown, its center of mass is above the contact point and it becomes unstable.

Figure 1

† Freier and Anderson, *A Demonstration Handbook for Physics,* Demonstration Mp-6, Unicycle.

This toy clown is stable when placed on a tight string.

Why doesn't the clown fall off the string?

These weights shift the clown's center of mass to a point below the wheel. If we remove the weights, we shift the center of mass to a point above the wheel. Here's what happens without the weights.

With its center of mass above the wheel, the clown is no longer stable.

Equipment

1. Toy clown on unicycle with balance bar and counterweights.
2. Long length of string.
3. Place to tie far end of string or an assistant to hold it.

Demo 03-24 Double Cone on Incline

A double cone rolls on a pair of rails, as shown in *Figure 1*, in such a way as to appear to roll uphill.† In reality the center of mass becomes lower as the double cone rolls along the rising rails, because of the geometry of the system. A cylinder rolls downhill, as expected.

Figure 1

† Sutton, *Demonstration Experiments in Physics,* Demonstration M-37.
Freier and Anderson, *A Demonstration Handbook for Physics,* Demonstration Mr-1, Rolling Uphill.

When we place a cylinder on this pair of inclined rails, it rolls down the incline.

If we place this double cone on the incline, it rolls up the incline.

Why does this object appear to defy gravity? The rails spread apart in the uphill direction.

This and the shape of the double cone allows the center of mass of the cone to go lower as it moves “up” the rails.

Here’s a shot from the side.

Equipment

1. Inclined rails whose distance of separation decreases to a near point at opposite lower end.
2. Cylinder.
3. Double cone.

Demo 03-25 Loaded Disc

A wooden disc is loaded with a heavy weight near its perimeter, causing the center of mass of the disc to be located well off the center of the disc. By carefully positioning the disc on an incline, we can then make it roll both down and *up* the incline,† as shown in *Figure 1*.

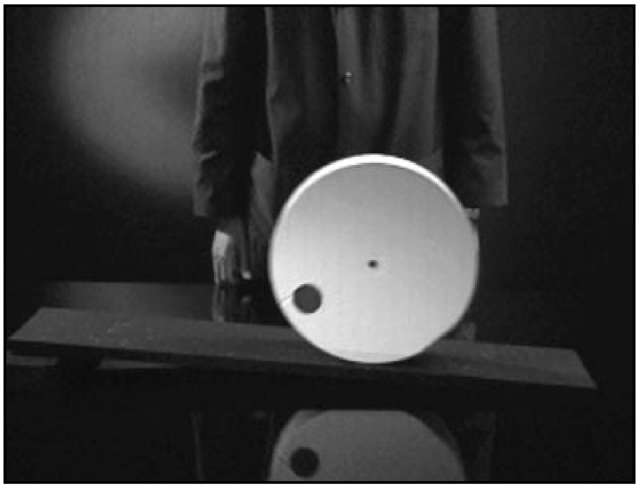

Figure 1

† Sutton, *Demonstration Experiments in Physics,* Demonstration M-35.
Freier and Anderson, *A Demonstration Handbook for Physics,* Demonstration Mp-3, Disc Rolling Uphill.

When we place this disc on an incline, it rolls downhill.

If we place the same disc on the incline again, it rolls uphill. What could account for this unusual behavior?

If we turn the disc around, the reason becomes clear.

A heavy weight has been added to the disc near its edge, shifting the center of mass. The center of mass of the disc can drop as the disc rolls uphill.

Equipment

1. Low angle incline plane.
2. Heavy wooden disc that bears a massive slug implant near its edge.

Demo 03-26 Toppling Cylinders

This demonstration illustrates the effect of the center of mass and torques using two "toppling cylinders," constructed from aluminum tube, in a surprising way.[†] *Figure 1* illustrates the two toppling cylinders.

The first cylinder, at the right in *Figure 1*, is a standard "leaning tower" demonstration in which the addition of a cap to a tilted cylinder moves the center of mass outside of the volume directly above its base, causing the cylinder to topple.[‡] The second cylinder stands vertically with its cap on, but topples when the cap is removed. This is due to two balls of the appropriate mass and radius that are properly positioned in the tube with the cap on. For the vertical cylinder to topple when its cap is removed, the relationship between the radius r_1 of the lower ball, the mass M_2 and the radius r_2 of the upper ball, and the mass M and inside radius R of the cylinder is:

$$M < M_2\left\{2-\left[\frac{r_1+r_2}{R}\right]\right\}$$

In the case on the video $r_1 = r_2 = 1.9\,\text{cm}$, $R = 2.5\,\text{cm}$, $M_2 = 230.5\,\text{g}$, $M = 68.5\,\text{g}$, and the mass of the cap is 85.5 g.

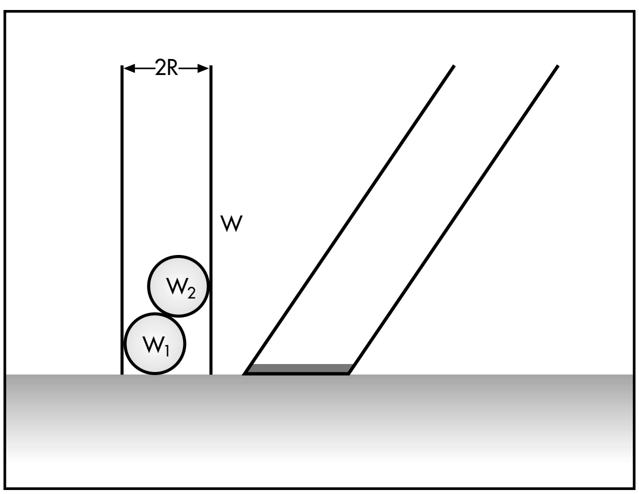

Figure 1

† M.E. Gardner, Falling Cylinders, *Am. J. Phys.*34, 822 (1966).
‡ Sutton, *Demonstration Experiments in Physics,* Demonstration M-34.
Freier and Anderson, *A Demonstration Handbook for Physics,* Demonstration Mp-9, Leaning Tower of Pisa.

Here are two aluminum cylinders.

The tilted cylinder topples when its cap is removed.

Inside the vertical cylinder are two balls with the same radius, a Ping-Pong ball on the bottom and a steel ball on the top.

The torque on the aluminum tube caused by heavy ball on top is sufficient to tip the tube without the weight of the cap.

Here is what happens if the lighter ball is put on top.

Equipment

1. Aluminum cylinder fitted with a cap and a hollow lower half.
2. Aluminum cylinder fitted with a cap and its two ends cut at an angle whereby it tips over with the addition of its cap.
3. A Ping-Pong ball.
4. A steel sphere the same size as the Ping-Pong ball.

Demo 03-27 Air Table Center of Mass

A long flat piece of wood, weighted at one end, is slid across an air table while it is rotating. The center of mass moves in a straight line, as shown in *Figure 1*, taken from the video.

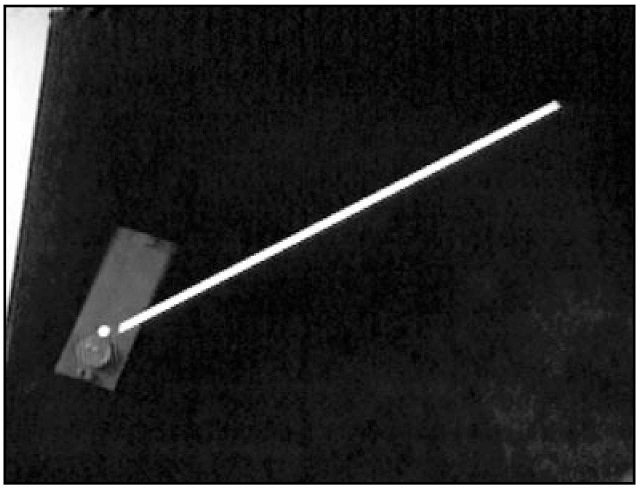

Figure 1

We'll use this air table to demonstrate the motion of an object's center of mass.

A flat piece of acrylic has been weighted on one side so that the center of mass is located beneath this orange spot.

To show that the center of mass is located at the spot, we can balance it on a finger at that point.

Now the acrylic is placed on the air table and given a push. The acrylic and the weight move in circles, but the center of mass moves in straight lines.

Equipment

1. Level air table.
2. Blower system.
3. Rectangular flat glider with an off-center attached weight, plus bumpers.
4. Mark center of mass of system to aid visibility.