EXPERIMENT MANUAL

GUMBALL MACHINE MAKER

SUPER STUNTS & TRICKS

QUICK START!

Want to get started right away without reading the manual? Scan the QR code below to view online videos showing how to assemble and use this kit.

THAMES & KOSMOS

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Safety Information

››› **Warning!** Not suitable for children under 3 years. Choking hazard — small parts may be swallowed or inhaled. Strangulation hazard — long cords may become wrapped around the neck.

››› Keep the packaging and instructions as they contain important information.

››› Store the experiment material and assembled models out of the reach of small children.

››› Clean the plastic parts before first use and regularly in lukewarm water. Do not clean in hot water. Dry thoroughly before use.

››› Refer to the packaging for the nutritional information and the ingredients list for the gumballs.

⚠ WARNING:
CHOKING HAZARD — Small parts. Toy contains a small ball. Not for children under 3 yrs.

Dear Parents and Adult Supervisors,

Physics is an exciting and expansive science that is not hard to understand, especially when you use fun models to demonstrate physics principles in action. It can be a lot of fun to figure out the astonishing physical phenomena that we encounter every day and to put this understanding to use — in a gumball machine, no less!

This experiment kit and the working models you can build with it introduce your child to physics concepts including forces, interactions, motion, and mechanical advantage. With its hands-on models, your child will gain basic insights into the world of physics principles — which will help him or her to understand and engage more deeply in the lessons taught in school.

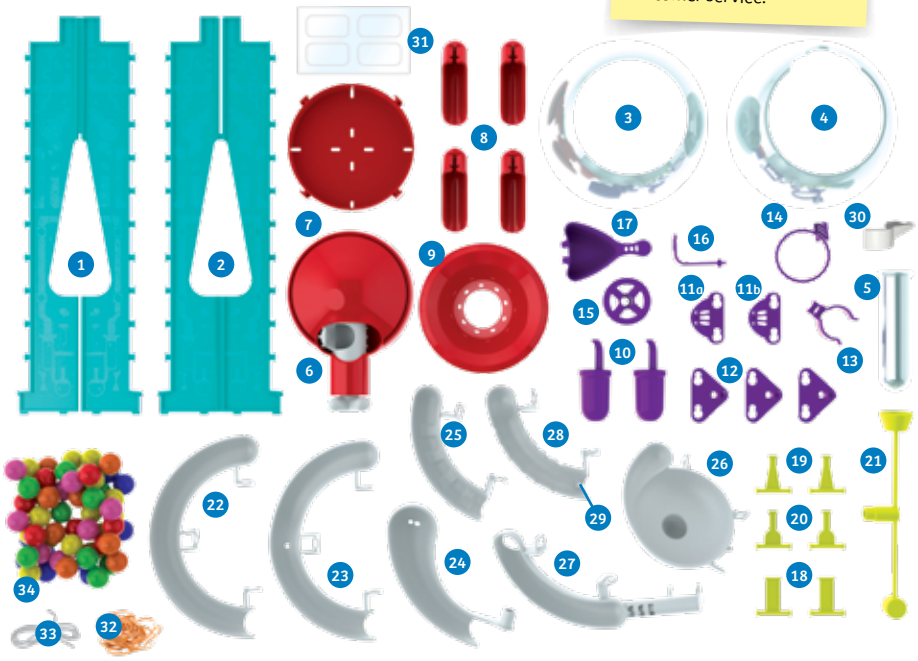
The gumball machine is assembled step by step using reconfigurable parts. It will require a little practice and patience to put it together and to get the gumball to go exactly where you want it to go. Your child will be particularly happy to have your help with the parts that he or she finds more difficult.

We wish you and your child lots of fun experimenting, discovering, and learning!

››› KIT CONTENTS

Good to know! If you are missing any parts, please contact Thames & Kosmos customer service.

What's inside your experiment kit:



Checklist: Find – Inspect – Check off

✔	No.	Description	Qty.
❍	1	Vertical tower support A	1
❍	2	Vertical tower support B	1
❍	3	Globe top	1
❍	4	Globe bottom	1
❍	5	Tip-over tube	1
❍	6	Globe base with dispenser	1
❍	7	Base	1
❍	8	Leg	4
❍	9	Globe funnel	1
❍	10	Pulley cup	2
❍	11a	Pivot post, angled	1
❍	11b	Pivot post, angled with stop	1
❍	12	Pivot post, straight	3
❍	13	Tip-over tube clamp	1
❍	14	Trampoline ring	1
❍	15	Pulley wheel	1
❍	16	Variable-slope track holder	1
❍	17	Collection cup	1
❍	18	Domino piece, beaker	2

✔	No.	Description	Qty.
❍	19	Domino piece, erlenmeyer flask	2
❍	20	Domino piece, florence flask	2
❍	21	Pendulum	1
❍	22	180-degree smooth track	1
❍	23	Momentum trap track	1
❍	24	Variable-slope track	1
❍	25	Friction track	1
❍	26	Centripetal force funnel	1
❍	27	Pinball launcher	1
❍	28	Domino track	1
❍	29	Domino track post	1
❍	30	Domino track stop	1
❍	31	Rectangular sticker sheet	1
❍	32	Rubber bands for trampoline*	12
❍	33	Piece of string for pulley cups*	1
❍	34	Gumballs*	5.3 oz.

Replacement gumballs: *The gumball machine uses standard small machine-sized gumballs, which are 16 mm or 5/8 in (0.62 in) in diameter.*

*Colors may vary.

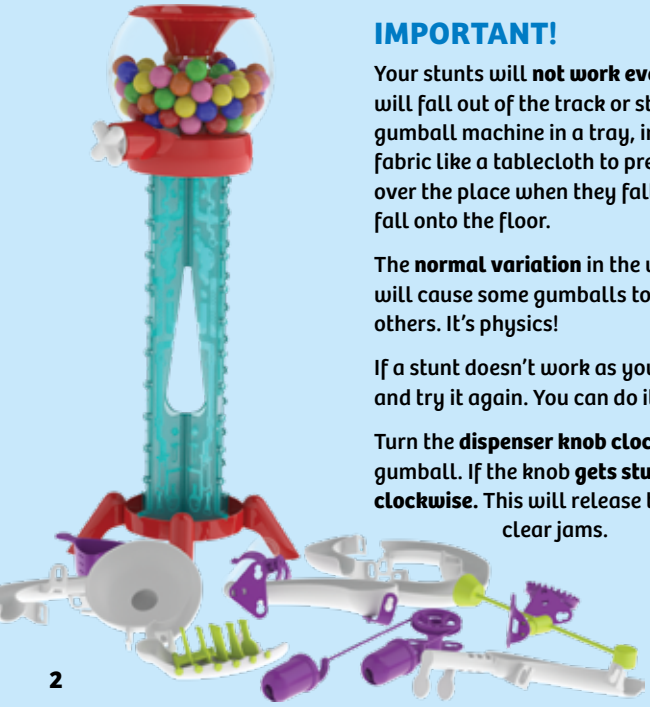
START HERE!

Welcome to your Gumball Machine Maker STEM Experiment Kit! This colorful gumball machine is not just a fun toy filled with delicious candy. It is also a set of serious scientific equipment for hands-on physics experiments!

There are 12 different segments of track and stunt devices included in this kit. Each one of these is an experiment. You must experiment with them to get them to work.

HERE'S HOW TO USE THIS KIT:

1. Build the gumball machine **tower.** Follow the instructions on **pages 3–4.**
2. Perform the **experiments** with each individual segment of track and stunt device on **pages 5–11.** You will learn how each part works and see what physics principles it demonstrates.
3. If you would like to **watch online videos** with instructions and demos for some easy track setups, scan this **QR code:**
4. Now you are ready to try the more challenging gumball machine setups on **pages 12–20.** Each of these uses multiple tracks and stunts. See if you can get a gumball to make it all the way to the bottom.
5. Test out **your own** track and stunt configurations too! Can you design a gumball machine in which the gumballs make it to the bottom every single time they are dispensed?



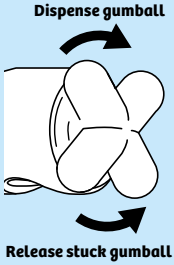
IMPORTANT!

Your stunts will **not work every time.** Sometimes gumballs will fall out of the track or stunt device. We suggest placing the gumball machine in a tray, in the lid of a box, or on a piece of fabric like a tablecloth to prevent the gumballs from rolling all over the place when they fall out. Do not eat any gumballs that fall onto the floor.

The **normal variation** in the weight and shape of the gumballs will cause some gumballs to perform better in the stunts than others. It's physics!

If a stunt doesn't work as you expected it to, adjust something and try it again. You can do it!

Turn the **dispenser knob clockwise to dispense** a gumball. If the knob **gets stuck, turn it counter-clockwise.** This will release the gumballs and help clear jams.

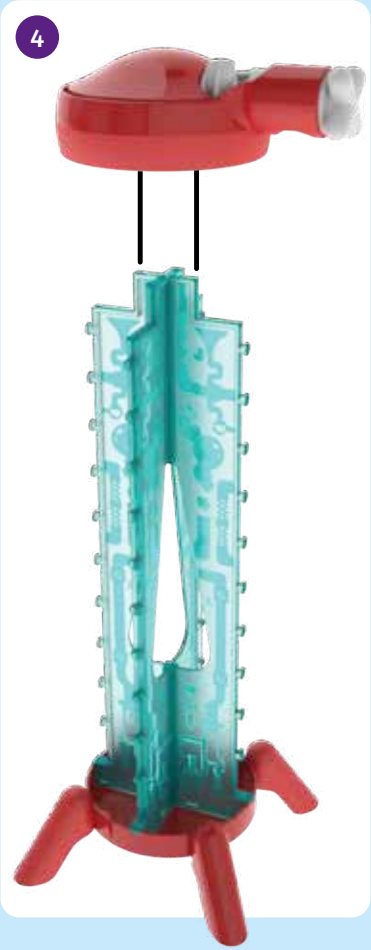


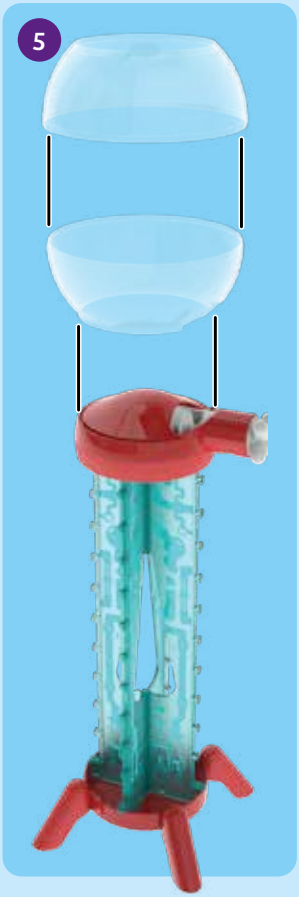
››› TOWER ASSEMBLY

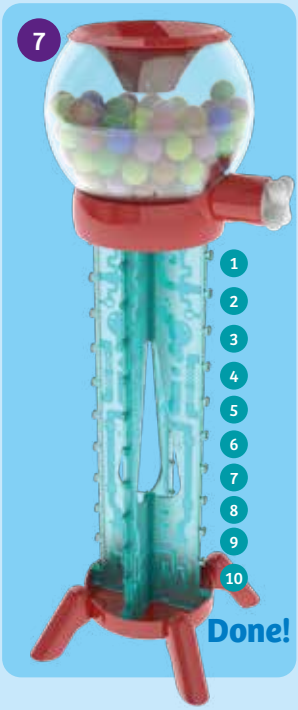
First, assemble the gumball machine tower. All of the experiments and setups use this tower.

HERE'S HOW

1. Attach the four **legs** to the **base.** Slide them down until they snap into place.
2. Slide the two **vertical tower supports** together all the way.
3. Insert the tower into the base. The tabs on the tower go into the holes in the base.
4. Slide the **globe base** with dispenser and knob onto the top of the tower.







5 Put the bottom and top halves of the globe onto the globe base. Press them in securely. For an extra-secure closure of the two halves, you can use the **four clear rectangular stickers** provided. Apply them along the seam between the two halves.

6 Attach the **globe funnel** to the top of the globe.

7 Pour some of the **gumballs** into the globe. Examine the tower assembly. The gumballs are **dispensed** from the globe at the top and gravity pulls them down the tracks, which spiral around the tower. The globe can be **rotated** around on the top of the tower so that the knob and dispenser can be positioned above any of the four sides.

There are circular **pegs** on each of the four sides of the tower. In the assembly instructions, the pegs are referred to from the top down. For example, this symbol means the second peg from the top: 2. To attach tracks and other parts to the tower, first put the peg through the round part of the hole in the track piece, then slide the track piece down to lock it in place in the narrower part of the hole.

The **globe funnel** allows you to return gumballs to the globe after an experiment.

Continue to the next page to start experimenting with the different tracks and stunt devices.

Now that you have assembled the tower, let's conduct a series of experiments to learn how each track segment and stunt device works. All of these parts attach to the pegs on the sides of the tower, and each one can be used to demonstrate physics principles.

Experiment 1: Force and Motion

HERE'S HOW

1. Attach the **180-degree smooth track** to the tower at any height. Two of the holes attach to pegs on the same level, and the third attaches to a peg one level down. You have to stretch the track a little to get it to fit onto the pegs.
2. Position a gumball at the top of the track. Have your hand ready to catch it at the end of the track. Let it go. What do you observe?

At the end of the 180-degree smooth track, you'll notice the presence of friction ridges. These have been added to slightly decelerate the gumball exiting the track and improve the performance.

WHAT'S HAPPENING?

The **180-degree smooth track** is the simplest track segment. A gumball rolls from the top to the bottom, 180 degrees around the tower. This simple motion demonstrates many things. The gumball has mass. **Mass** is the quantity of matter in an object or a **body**, which is a physics term for a physical thing. **Matter** is any physical substance that occupies space. Mass can also be thought of as the ability of a body to be heavy. Mass should not be confused with weight though. **Weight** is a measure of the force that gravity exerts on mass.

A **force** is the cause of a change in a body's state of movement. A force can be thought of as a push or a pull on an object. A push of the gumball causing it to roll across the table is a force.

Gravity is also a force. It is Earth's force of attraction on mass. Gravity is a fascinating thing: All mass attracts each other. The larger the mass, the greater its force of attraction. Earth has a huge mass: 5.9 trillion trillion kilograms, or 13 billion trillion tons! The gumball has a very small mass: about two grams. Therefore, Earth pulls the gumball toward it. This is the force of gravity!

A gumball rolls down the track because gravity is pulling it. On Earth, the gravity at the surface is a downward force that causes an acceleration equal to about 9.8 meters per second per second (m/s/s or m/s^2).

To understand acceleration, we have to understand speed. **Speed** is the distance traveled by a body in a certain amount of time. **Velocity** is a physics term for speed that also takes into account the direction of motion.

If a gumball travels five inches in one second, its speed is five inches per second, or 5 in/s — which is equal to about a quarter of a mile per hour.

Acceleration is the measure of the change in speed (or more accurately, velocity) over a certain amount of time. So, what is gravity again? Earth's gravity causes a body to accelerate to a speed of 9.8 meters per second for every second that gravity acts on the body — regardless of the mass of the body. If you drop a gumball and it falls for three seconds, by the end of its fall, it is moving at a speed of 29.4 meters per second ($9.8\ m/s^2 \times 3\ s = 29.4\ m/s$).

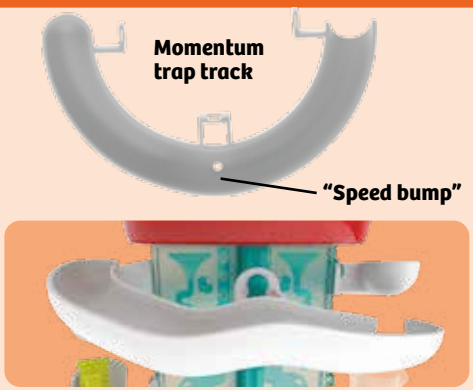
As the gumball rolls down the track, gravity accelerates it and it moves faster, unless it encounters obstacles.

Amazing! This one simple segment of track has allowed us to define all these physics terms.

Experiment 2: Momentum

HERE'S HOW

1. Attach the **momentum trap track** to the tower at any height. Two of the holes attach to pegs on the same level, and the third attaches to a peg one level down. You have to stretch the track a little to get it to fit.
2. Place a gumball on the little "speed bump" in the middle of the track. Position another gumball at the top of the track. Have your other hand ready to catch the gumball at the end of the track. Let go of the gumball at the top of the track. What do you observe?



At the end of the momentum trap track, you'll notice the presence of friction ridges. These have been added to slightly decelerate the gumball exiting the track and improve the performance.

WHAT'S HAPPENING?

The **momentum trap track** demonstrates a few more important physics principles. The momentum trap looks like the 180-degree straight track, but with one important difference. It has a little "speed bump" in the middle of it. When you place a gumball on this speed bump (or even in the little trough in front of the bump) and release another gumball to roll down from the top of the track, the rolling gumball will collide with the stationary gumball. The stationary gumball will then be knocked into motion and continue down the track, while the previously moving gumball will now be stuck in the trough. To understand what happened here in terms of physics, you have to understand momentum and inertia.

Inertia is the tendency of a body to remain at rest or in motion. It can also be thought of as the amount of resistance to a change in velocity. The more mass a body has, the more inertia it has. Since both gumballs have the same mass, they have the same inertia.

Momentum is the combined effect of the mass and velocity of a body. All moving bodies have momentum. A fundamental rule of physics says that momentum is always conserved when two bodies collide. When the gumballs collide, the momentum from the moving gumball is transferred to the stationary gumball, causing the latter to move. The first gumball loses its momentum and slows down. This describes a perfect **elastic collision.** If the bodies were to deform, or change shape, on impact, the result would be different. This is an **inelastic collision.**

The momentum trap can also be used to show how a gumball must have a certain amount of momentum if it is to make it over the hill. If it has too little momentum, it will get stuck in the trap.

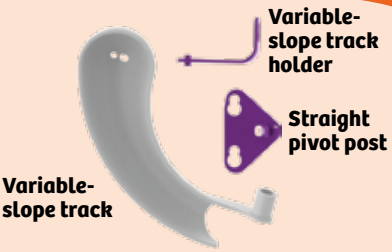
WORK AND ENERGY

Every track and stunt also enables us to investigate work and energy. **Work** is force exerted over a distance. When you move a gumball from the bottom of the tower up to the top with your hand, you perform work. Moving a body requires work.

Energy is the capacity of a body to do work. Energy is required to move a body over a distance. Energy comes in many different forms, and it can be converted from one form to another. This gumball machine demonstrates two types of energy: potential energy and kinetic energy.

Potential energy is stored energy. **Kinetic energy** is the energy of motion. The gumballs at the top of the machine have potential energy. When a gumball starts rolling down the track, its potential energy is converted into kinetic energy. At the bottom of the track, it has less potential energy than at the top. You must put energy back into it with your hand by raising it back up to the top.

Experiment 3: Inclined plane



HERE'S HOW

1. Attach the **variable-slope track** to the tower. Connect it to the tower with a **straight pivot post** and the **variable-slope track holder.** Attach the hole of the track holder to a peg on the same level as the **upper hole** in the straight pivot post. This results in a track with a high slope.
2. Roll a gumball down the track and catch it at the end. Observe what happens.
3. Change the location of the track holder so that its hole is on the same level as the **lower hole** in the straight pivot post. This changes the slope of the track.
4. Roll a gumball down the track again. Observe what happens this time. Increase the slope of the track until the gumball rolls out of the track again.

WHAT'S HAPPENING?

The **variable-slope track** helps you perform experiments on the force of gravity. The track can be set at different **slopes,** or degrees of steepness.

At a less-steep setting, gumballs will roll down the track slower than at a more-steep setting. This is because the slope prevents the full force of gravity from pulling the gumball down the track. The steeper the track, the more gravity can pull the gumball along the direction of the track. The flatter the track, the more gravity will try to pull the gumball into the track itself, where it cannot go. This variable-slope track is a **simple machine** called an **inclined plane.**

At its lowest setting, gumballs actually get caught in the track because gravity pulls them away from the open end of the track.

Experiment 4: Friction

HERE'S HOW

1. Attach the **friction track** to the tower at any location.
2. Place a gumball at the top of the track. Have your other hand ready to catch it at the end of the track. Let it go. What do you observe?

WHAT'S HAPPENING?

The **friction track** has raised bumps on it. These cause the gumball to slow down as it travels down the track. They increase the friction between the track and the gumball. **Friction** is the force resisting the motion of objects sliding past each other. As the gumball rolls down the track, it is releasing its potential energy as always. It makes more noise than on a smooth track. The increased friction is causing energy to be lost to heat and sound. There is less energy to convert into kinetic energy, so the gumball moves slower.

Experiment 5: Centripetal force

HERE'S HOW

1. Attach the **centripetal force funnel** to the tower at any location.
2. Toss a gumball into the funnel. Have your hand ready to catch it beneath the funnel spout. What do you observe?

Centripetal force funnel

WHAT'S HAPPENING?

The **centripetal force funnel** demonstrates rotational inertia, or moment of inertia, and centripetal force. When a gumball enters the funnel, the shape of the funnel causes the gumball to curve around in a circular motion. As the gumball slows down, it circles closer and closer to the center, and then falls into the hole.

Centripetal force is the reason the gumball doesn't just roll straight into the hole.

Centripetal force is a force that makes a body follow a curved path. Like inertia, the **rotational inertia** of the gumball describes its tendency to remain in motion and resist slowing down. But because friction and gravity work to overcome its inertia, the gumball slowly gets closer to the hole in the center.

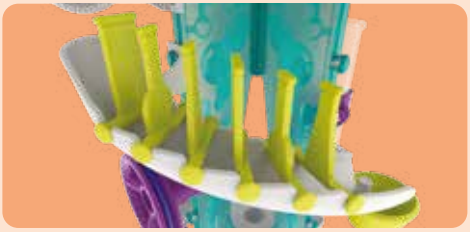
Experiment 6: Collisions

HERE'S HOW

1. Attach the **domino track** to the tower at any location. Insert the six **dominos** by carefully clicking them into the slots. Insert the small **domino track post** at the end of the track. Flip all the dominos so they are standing upright.
2. Balance a gumball on the domino track post. Have your hand ready to catch it when it falls. Gently tap the uppermost domino over with your finger. What do you observe?
3. Reset the dominos into their upright positions. If the gumball fell off the post, reposition it. Now try dropping a gumball into the top of the domino track. What happens now?

6 Dominos

Domino track with post



WHAT'S HAPPENING?

The **domino track** offers another lesson in transfer of momentum. When you knock over the domino with your finger, it causes the other dominos to fall, but it probably doesn't push the gumball off the post. Then, when you drop a gumball into the top of the domino track, it knocks down the dominos, and the last domino pushes the gumball off the post.

In both cases, when the first domino falls over, a chain of collisions follows, in which each domino knocks down the next. The final domino falls over and collides with the gumball positioned on the post. Whether or not the final domino pushes the gumball off the post is determined by the momentum of the domino. The momentum from your finger push or the first gumball falling into the track is transferred through the dominos. Thus, you can conclude that the falling gumball has more momentum than your gentle finger tap.

Experiment 7: No obstacles

HERE'S HOW

1. You can also use the **domino track without the dominos and post** as a simple 90-degree smooth track. Test it out!

Experiment 8: Pendulum

HERE'S HOW

1. Attach the **pendulum** to the tower at any location using the **angled pivot post.**
2. Drop a gumball into the pendulum cup. What happens?
3. Add a segment of track to the tower in a location such that it will deposit a gumball into the pendulum cup. Roll a gumball down the track into the pendulum cup. What happens now?

WHAT'S HAPPENING?

When a gumball enters the cup at the top of the pendulum at the right angle and the right speed, it causes the pendulum to turn on its axis and the gumball is dropped down to a lower track. When a gumball is dropped straight down into the pendulum cup, it often is not enough to make the pendulum tip over on its own.

A **pendulum** is a weight suspended from a pivot that can swing freely. It demonstrates center of mass and stable equilibrium. **Center of mass** is a point on a body representing the mean (or middle) position of the mass of the body — mass on all sides of this point balances out. When the pendulum is stationary, it is said to be in stable equilibrium. **Equilibrium** is the state of a body at rest or in unaccelerated motion in which the result of all forces acting on it is zero. A body is in **stable equilibrium** if its center of mass is located vertically above its base of support. If its center of mass lies vertically above its tipping line (the edge of the base), then it will wobble or fall over. The slightest movement will make it tip over. But its stability also depends on the force needed to push it off balance.

The pendulum has been specifically designed with a counterweight at the bottom that offers just enough inertia to keep the pendulum stable until the gumball enters the cup and knocks it out of stable equilibrium.

Tips for the pendulum:

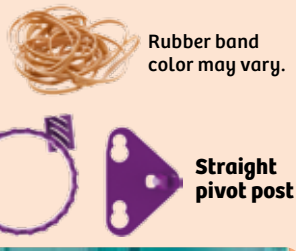
The pendulum might need a little push to get it moving if the gumball doesn't fall into it at the right angle or the right speed.

The pendulum might not always dump the gumball into the same spot below. This depends on the rotational speed of the pendulum!

Experiment 9: Springs

HERE'S HOW

1. Attach the **trampoline** to the tower at any location using the **straight pivot post**. Stretch the rubber bands around the trampoline ring. The notches in the ring keep the rubber bands from slipping off. Try to evenly space the rubber bands around the surface of the ring. Position the trampoline at an angle such that when a gumball falls on it, the gumball bounces into the next track segment.
2. Drop a gumball onto the trampoline. Repeat with the trampoline set at different angles.



WHAT'S HAPPENING?

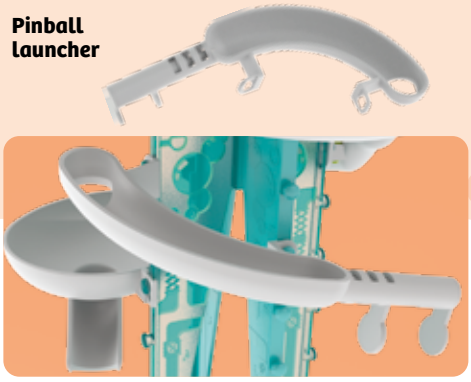
The **trampoline** is a window into two more huge realms of physics: springs and projectiles. The rubber bands in the trampoline work like a **spring**. When a moving body stretches or compresses a spring, it converts its kinetic energy into potential energy stored in the spring. Then, the spring bounces back and pushes back on the body. The amount of force exerted on a spring is proportional to the amount, or distance, that the spring stretches or compresses. The more momentum a gumball has when it hits the trampoline, the more the rubber bands will stretch. The more the rubber bands stretch, the more force they will have to push back on the gumball.

When the trampoline bounces the gumball into the air, the gumball becomes a projectile. A **projectile** is a body upon which only the force of gravity is acting. The path that projectiles take as they move through the air can be predicted based on the speed, angle, and height at which it was launched.

Experiment 10: Projectiles

HERE'S HOW

1. Attach the **pinball launcher** to the tower at any location.
2. Place a gumball in the launcher. Pull back on the trigger and release. What happens?



WHAT'S HAPPENING?

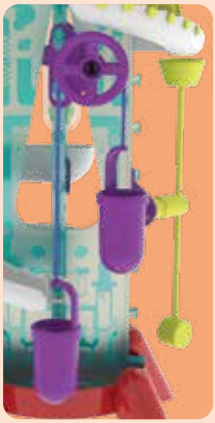
When a gumball lands in the pinball launcher, you can manually pull back on the trigger and release to launch the gumball back up and out of the track and down to another section of track.

The **pinball launcher** is similar to the trampoline in that it demonstrates the principles of springs and projectiles. In the pinball launcher, there is a metal spring. When you pull the trigger back, the spring compresses and stores energy. When you release the trigger, the stored energy is released and converts into kinetic energy, which is transferred to the gumball, pushing it along the track. The gumball is a projectile that glides along the track, like a ball inside a pinball machine.

Experiment 11: Pulleys

HERE'S HOW

1. Attach the **pulley wheel** to the tower at a relatively high location using the **straight pivot post**. Tie one end of the **string** to the arm of one **pulley cup**. Tie the other end of the string to the arm of the second cup. Hang the string from the pulley wheel with a cup on either side.
2. Drop a gumball into one of the cups. Drop a gumball into the other cup. What happens?



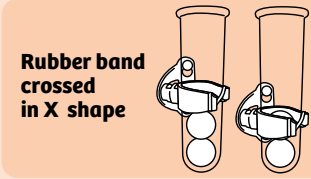
WHAT'S HAPPENING?

The **pulley cups and wheel** demonstrate a **simple machine** called a **pulley**. This setup shows how a downward force (the weight of a gumball) applied to one side is transformed into an upward force of the cup on the other side. Pulleys can change the direction of a force, and also the amount of force needed, to perform work. If you place two gumballs in the second pulley cup, you probably will need two or more gumballs to fall in the first pulley cup before it exerts enough weight to lift up the second.

Experiment 12: Center of mass

HERE'S HOW

1. Attach the **tip-over tube** to the tower at any location using the **angled pivot post with stop**. If the tube slides down in the clamp, stretch a **rubber band** in an X shape over the ends of the clamp to hold it in place. The tip-over tube should be positioned high up in the clamp. More of the tube should be above the clamp than below the clamp.
2. Drop gumballs into the tube one at a time. After each drop, try to tip the tube over. As the tube fills up, what do you notice?



WHAT'S HAPPENING?

Like the pendulum, the **tip-over tube** demonstrates center of mass and stable equilibrium. When gumballs fall into the tube, they will stay in the tube until the center of mass extends outside of the stable equilibrium point and the tube tips over, dumping the gumballs into the track below.

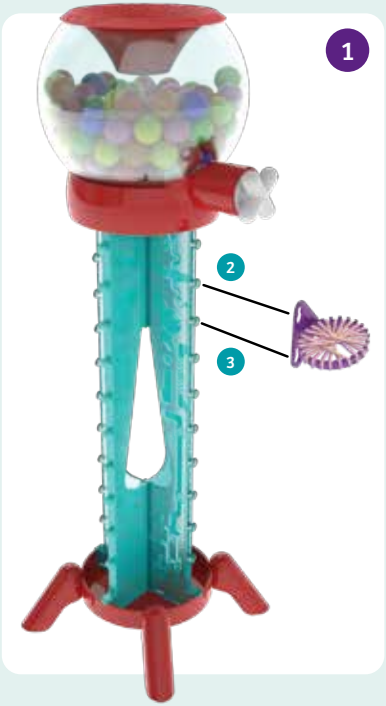
Tips for the tip-over tube:
If the tip-over tube doesn't rotate in the correct direction check to make sure that you have the clamp attached to the pivot post correctly. If it doesn't tip over at all, try moving the angled pivot post down one peg on the tower, and positioning the tube higher up in the clamp. Also, experiment with starting with different numbers of gumballs in the tube.

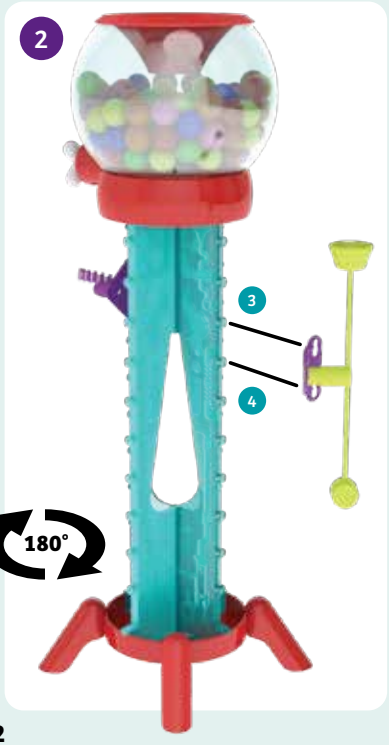
Now that you know how all the tracks and stunts work, follow the step-by-step assembly instructions on the following pages to set up three expert-level gumball machines that use many of the parts together.

After you have conducted the experiments on pages 5–11, you can try out these more challenging setups. Use what you have learned from the previous experiments to adjust the setups until they work properly. Can you get a gumball to make it all the way to the bottom, landing every stunt?

HERE'S HOW

1. With the rubber bands wrapped around the trampoline ring, and the trampoline attached to the straight pivot post (as described on page 10), attach the trampoline with the pivot post to the tower. Attach it to the side of the tower under the dispenser knob, on the second and third pegs from the top; that is, pegs 2 and 3.
2. Rotate the model 180 degrees so the knob is facing backward. Attach the pendulum with the angled pivot post to pegs 3 and 4 on the side of the tower opposite the knob.





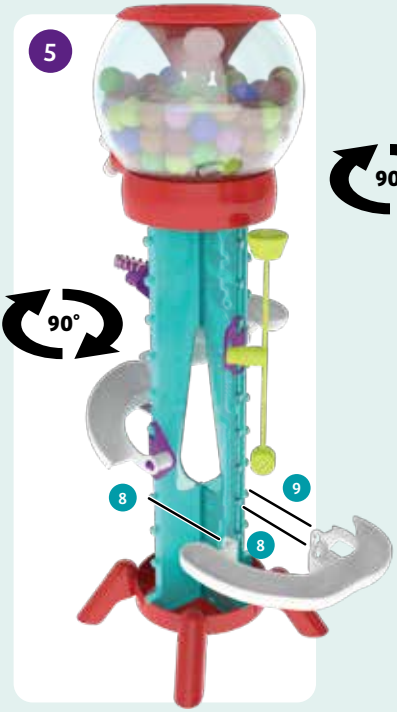
3. Rotate the model 180 degrees so the knob is facing forward again. Attach the centripetal force funnel to peg 4 on the side of the tower under the knob, and peg 4 on the side to the left of that, as shown.

››› EXPERT SETUP 1

4 Rotate the model 90 degrees clockwise. Attach the variable-slope track holder to peg 6 on the side of the tower under the knob. Attach the variable-slope track with the straight pivot post to pegs 6 and 7 on the side to the right of that, as shown. Attach the variable-slope track to its holder by putting the peg on the holder into the hole in the track.

5 Rotate the model 90 degrees clockwise again. Attach the momentum trap track to pegs 8, 8, and 9 on the three sides of the tower shown in the image.

6 Rotate the model 90 degrees clockwise again. Attach the pulley wheel with the straight pivot post to pegs 7 and 8 on the side of the tower to the left of the knob, as shown.



Tie one end of the string to the arm of one pulley cup. With a ruler, measure five inches on the string starting at the point where you tied the string to the first pulley cup. Tie the other end of the string to the arm of the second cup. Now, there should be five inches of string between the two cups.

Hang the string from the wheel and position the left pulley cup at the bottom of the momentum trap track.

7. Adjust all the tracks and stunts so that, in your best estimation, a gumball will travel all the way from the dispenser down to the pulley cup. Place a gumball in the momentum trap and in the pulley cup on the right. The assembly is finished!

Now it's time to test the setup!

8. It's a good idea to put the gumball machine on a tray, in the lid of a box, or on a piece of fabric like a tablecloth when you are experimenting with it. The reason for this is that it is normal for gumballs to fall off the track or for a stunt to miss its target some of the time. You must carefully adjust the model to get the gumball to travel from the top to the bottom without falling off course. The tray, box lid, or tablecloth will help keep the gumballs from rolling all over the place when they fall out of the machine.

9. Hold the gumball machine steady with one hand. Turn the knob clockwise to dispense one gumball. If the knob gets stuck, turn it counterclockwise to release the jam. What happens?

10. Segment by segment, make adjustments to the model until the gumball makes it all the way to the cup at the end.

11. Rotate the globe and dispenser to the other side and try the second course.

12. Return the gumball to the globe each time by taking the pulley cup and dumping it into the globe funnel.

WHAT'S HAPPENING?

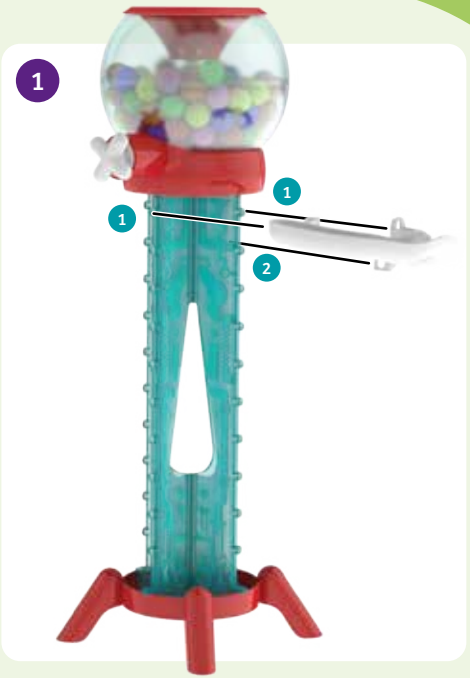
In a perfect run, the machine works like this: On the first side, the gumball drops out of the dispenser and onto the trampoline. It bounces into the centripetal force funnel, where it spirals around. It falls through the hole and into the variable-slope track. It rolls down and into the momentum trap. If a gumball is already in the momentum trap, the first gumball will knock the gumball that is already there down the track and into the pulley cup. Depending on how many gumballs are in each pulley cup, the pulley cup may move down or it may not. On the second side, the difference is that the gumball starts in the pendulum before it falls down into a track below. Where the gumball lands depends on the rotational speed of the pendulum. The pendulum might need a little push, because the gumball falls straight down into it from the dispenser.

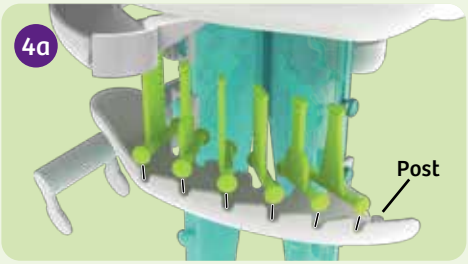
››› EXPERT SETUP 2

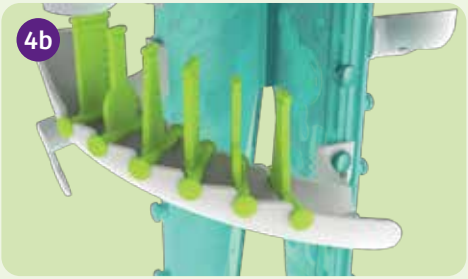
Now that you have built the first setup, try this setup. It is even more challenging.

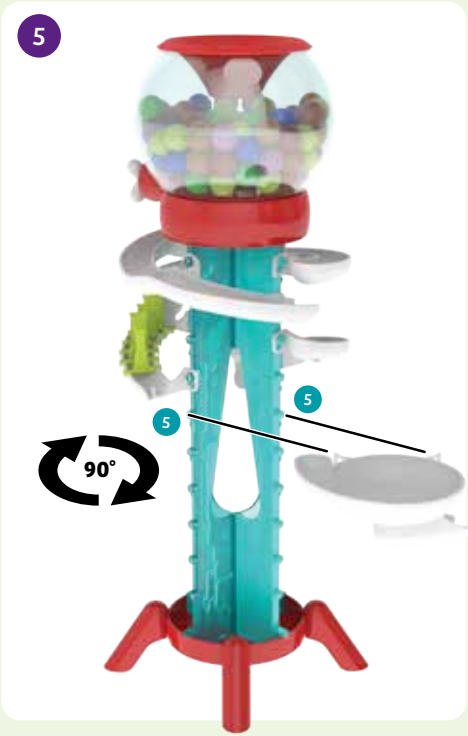
HERE'S HOW

1. Attach the momentum trap track to the tower. Attach its left side to peg 1 on the side of the tower under the knob. Attach the middle to peg 1 on the next side of the tower to the right, and its right side to peg 2 on the side of the tower opposite the knob.
2. Rotate the model 180 degrees so the knob is facing backward. Attach the 180-degree straight track to pegs 1, 1, and 2 on the side of the tower opposite the momentum trap track.
3. Attach the pinball launcher to pegs 3 and 4 on the sides under the 180-degree straight track, as shown.









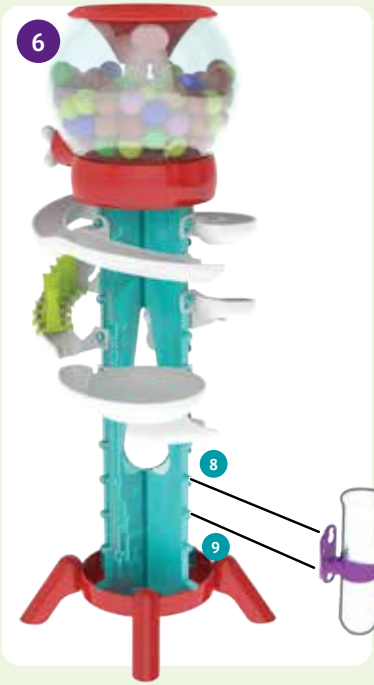
4 Rotate the model 180 degrees. Attach the domino track to the tower. Attach its left side to peg 3 on the side of the tower under the knob. Attach its right side to peg 4 on the side of the tower to the right of the knob. Then attach the domino track stop onto the side of the tower at the end of the 180-degree track, just above peg 3, as shown.

4a Insert the six dominos and the domino track post into the domino track. The flat side of each domino should be facing the higher end of the domino track.

4b Make sure all the dominos are standing straight up. They will probably fall over during assembly. Just set them back up again before each gumball run.

5 Rotate the model 90 degrees. Attach the centripetal force funnel to the tower. Attach its left side to peg 5 and its right side to peg 5 as shown.

››› EXPERT SETUP 2



Done!

6 Attach the tip-over tube with the angled pivot post to pegs 8 and 9 as shown. Make sure the tip-over tube is held high up in the clamp, so that a gumball coming out of the funnel will fall into the tube.

7 Hang the collection cup on the edge of the base, under the tip-over tube.

8 Adjust all the tracks and stunts so that, in your best estimation, a gumball will travel all the way from the dispenser down to the collection cup. Place a gumball in the momentum trap, one on the post in the domino track, and two in the tip-over tube. The assembly is finished!

Now it's time to test the setup!

9 Follow steps 8 through 11 on page 14 like you did for the first setup.

12 When the gumball falls into the pinball track, you have to launch it back out by pulling the trigger back and releasing it. After a run, return the gumball to the globe each time by taking the collection cup and dumping it into the globe funnel.

WHAT'S HAPPENING?

In a perfect run, the machine works like this: On the first side, the gumball drops out of the dispenser into the momentum trap track. The gumball from the trap drops into the pinball launcher, where you fire it back out and it falls into the tip-over tube. On the second side, the gumball rolls from the 180-degree smooth track and knocks over the dominos, then flies out of the machine because of how fast it is moving. The dominos knock the gumball from the domino track into the centripetal force funnel. Then it rolls into the tip-over tube, which tips over and empties into the cup or the base of the machine. You might need to tap the tip-over tube to get it to tip over.

››› EXPERT SETUP 3

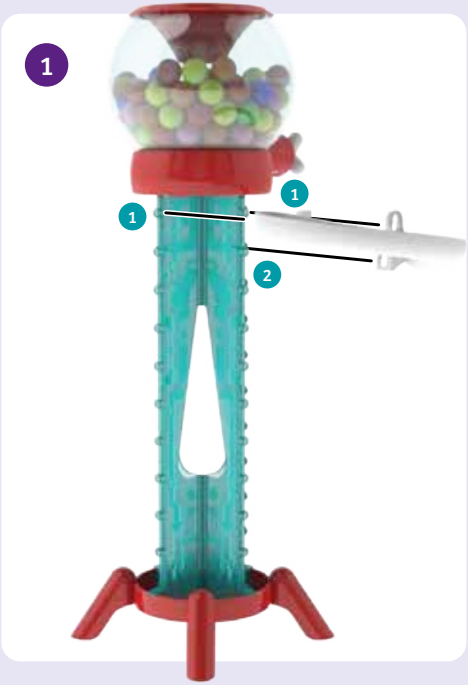
Now that you have built the first two setups, try this setup. It is the most challenging.

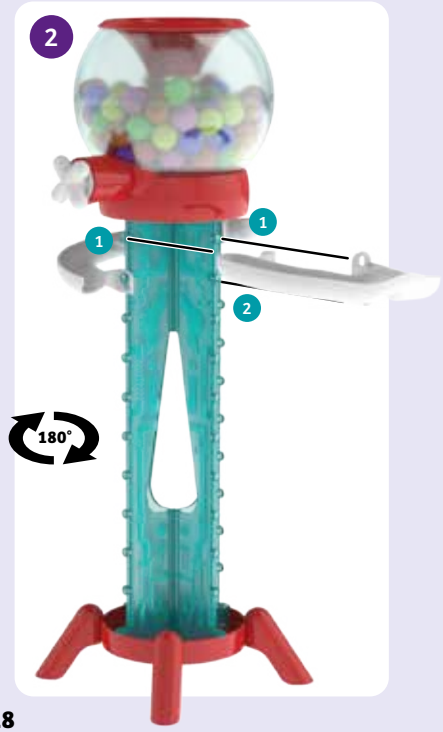
HERE'S HOW

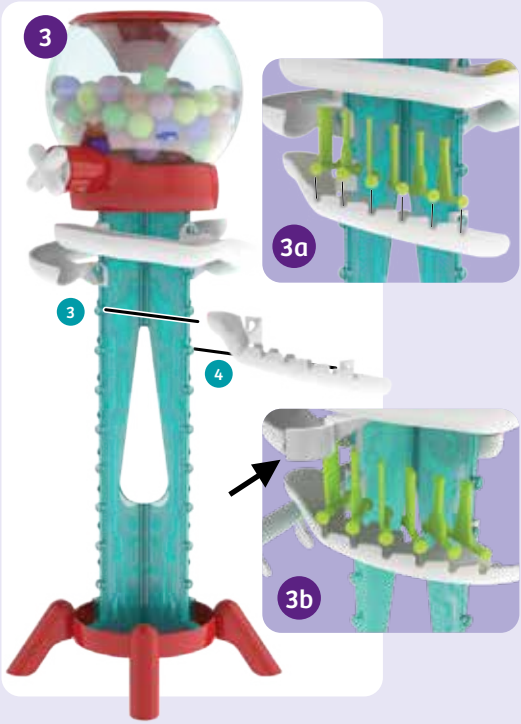
1. Attach the 180-degree straight track to pegs 1, 1, and 2 on the sides of the tower as shown. Pay attention to the knob location.
2. Rotate the model 180 degrees so the knob is facing forward. Attach the momentum trap track to the tower to pegs 1, 1, and 2 on the sides of the tower as shown.
3. Attach the domino track to pegs 3 and 4 on the sides under the momentum trap track, as shown.

3a Insert the six dominos and the domino track post into the domino track.

3b Attach the domino track stop onto the side of the tower at the end of the 180-degree track, which leads into the domino track.







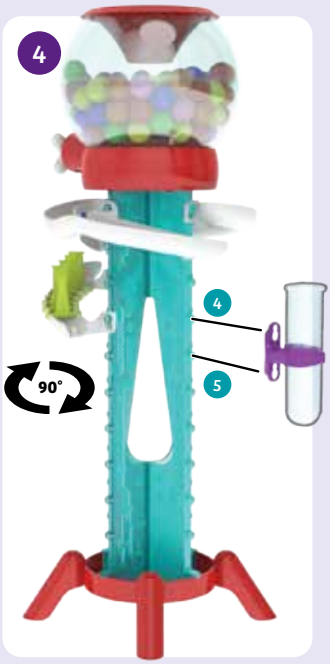
››› EXPERT SETUP 3

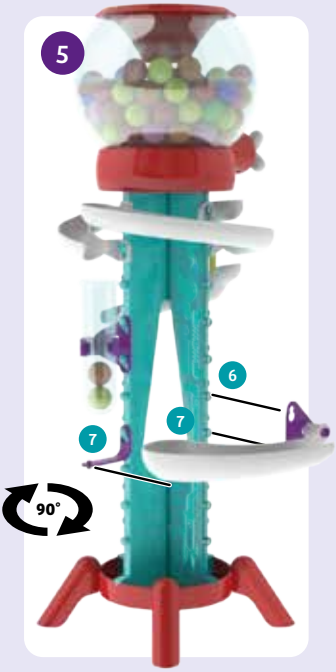
4. Rotate the model 90 degrees. Attach the tip-over tube with the angled pivot post to pegs 4 and 5 as shown.

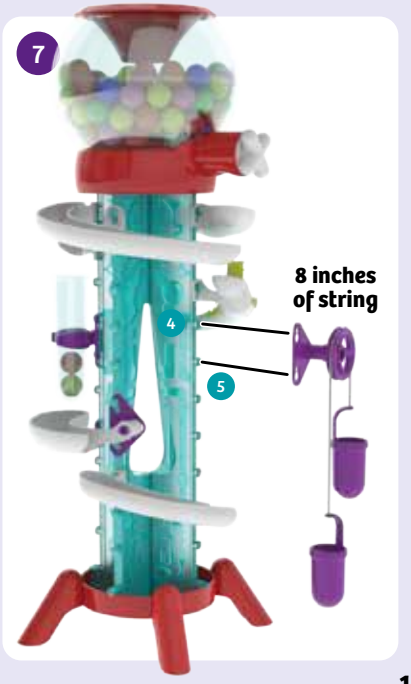
5. Rotate the model 90 degrees. Attach the variable-slope track with the straight pivot post and the holder to pegs 7, 6, and 7 as shown.

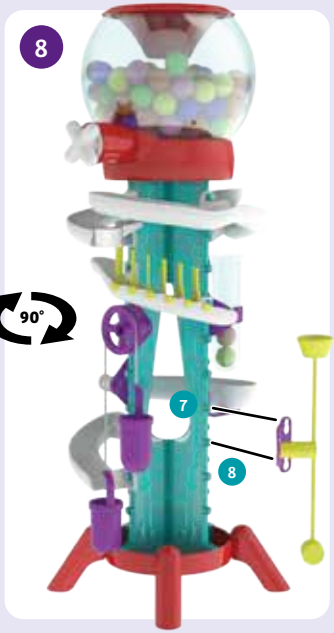
6. Rotate the model 90 degrees. Attach the friction track to pegs 8 and 9 as shown.

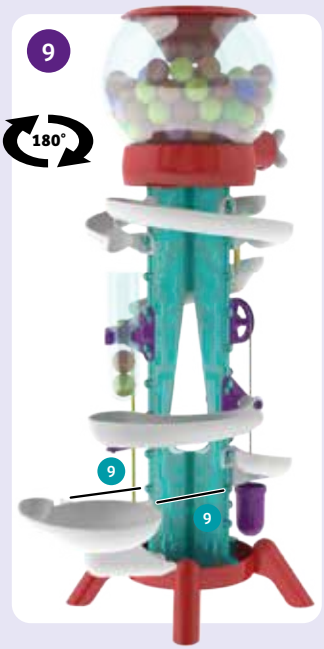
7. Attach the pulley wheel and cups to pegs 4 and 5 as shown. The string between the pulley cups should be 8 inches long.











Done!

8 Rotate the model 90 degrees. Attach the pendulum with the angled pivot post to pegs 7 and 8 as shown.

9 Rotate the model 180 degrees. Attach the centripetal force funnel to pegs 9 and 9.

10 Hang the collection cup on the edge of the base, under the centripetal force funnel. Adjust all the tracks and stunts so that, in your best estimation, a gumball will travel all the way from the dispenser down to the collection cup. Place a gumball in the momentum trap. It is optional to start with a gumball or two in the tip-over tube. The assembly is finished!

Now it's time to test the setup!

11 Follow steps 8 through 11 on page 14 like you did for the first setup. You will need to adjust the angle of the variable-slope track to get the gumballs to roll out of it.

12 After a run, return the gumball to the globe each time by taking the collection cup and dumping it into the globe funnel.

WHAT'S HAPPENING?

In a perfect run, the machine works like this: The tracks and stunts function similar to how they did in the previous setups. The new elements in this setup are the friction track and the pendulum. The friction track slows the gumball down. You might notice the gumball makes more sound when it goes down the friction track. The pendulum swings over and drops a gumball into the centripetal force funnel. As in the previous setup, the tip-over tube might need a little nudge to tip over. On its lowest setting, the gumballs don't roll out of the variable-slope track after being dumped there from the tip-over tube. Try increasing the slope of the track and observing what happens.

Design your own! Now that you know how all the parts of the gumball machine system work, you can design, build, and test your own configurations.

As a challenge, can you make a gumball machine in which the gumballs make it to the bottom every single time they are dispensed?

Glossary of Physics Terms

Acceleration: Acceleration is the measure of the change in speed (or more accurately, velocity) over a certain amount of time.

Body: A body is a physics term for a physical thing or object; something with mass.

Center of mass: Center of mass is a point on a body representing the mean (or middle) position of the mass of the body — mass on all sides of this point balances out.

Centripetal force: Centripetal force is a force that makes a body follow a curved path.

Elastic collision: An elastic collision is an interaction between two bodies in which the total kinetic energy of the two bodies remains the same. For example, they bounce off each other perfectly.

Energy: Energy is the capacity of a body to do work.

Equilibrium: Equilibrium is the state of a body at rest or in unaccelerated motion in which the result of all forces acting on it is zero.

Force: A force is the cause of a change in a body's state of movement.

Friction: Friction is the force resisting the motion of objects sliding past each other.

Gravity: Gravity is Earth's force of attraction on mass.

Inclined plane: An inclined plane is a flat surface tilted at an angle with one end higher than the other, also called a ramp.

Inelastic collision: An inelastic collision is a collision in which kinetic energy is not conserved due to the action of internal friction. For example, the bodies deform and the collision releases heat and sound energy.

Inertia: Inertia is tendency of a body to remain at rest or in motion.

Kinetic energy: Kinetic energy is the energy of motion.

Mass: Mass is the quantity of matter in an object or a body.

Matter: Matter is any physical substance that occupies space.

Momentum: Momentum is the combined effect of the mass and velocity of a body.

Pendulum: A pendulum is a weight suspended from a pivot that can swing freely.

Potential energy: Potential energy is stored energy.

Projectile: A projectile is a body upon which only the force of gravity is acting.

Pulley: A pulley is a simple machine consisting of a wheel on an axle with a rope or chain running over it that changes the direction of the force used for lifting a load.

Rotational inertia: Rotational inertia is the tendency of a body to remain in motion along a circular path around an axis and to resist slowing down.

Slope: Slope is the degree of steepness; it is the ratio of the difference in the vertical position to the difference in the horizontal position of two points on a line.

Speed: Speed is the distance traveled by a body in a certain amount of time.

Spring: A spring is an elastic object that stores mechanical energy.

Stable equilibrium: Stable equilibrium is the state of a body when its center of mass is located vertically above its base of support and it won't tip over.

Velocity: Velocity is the speed and direction of motion of a body.

Weight: Weight is a measure of the force that gravity exerts on mass.

Work: Work is force exerted over a distance.

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