EXPERIMENT MANUAL

THAMES & KOSMOS

PHYSICS workshop

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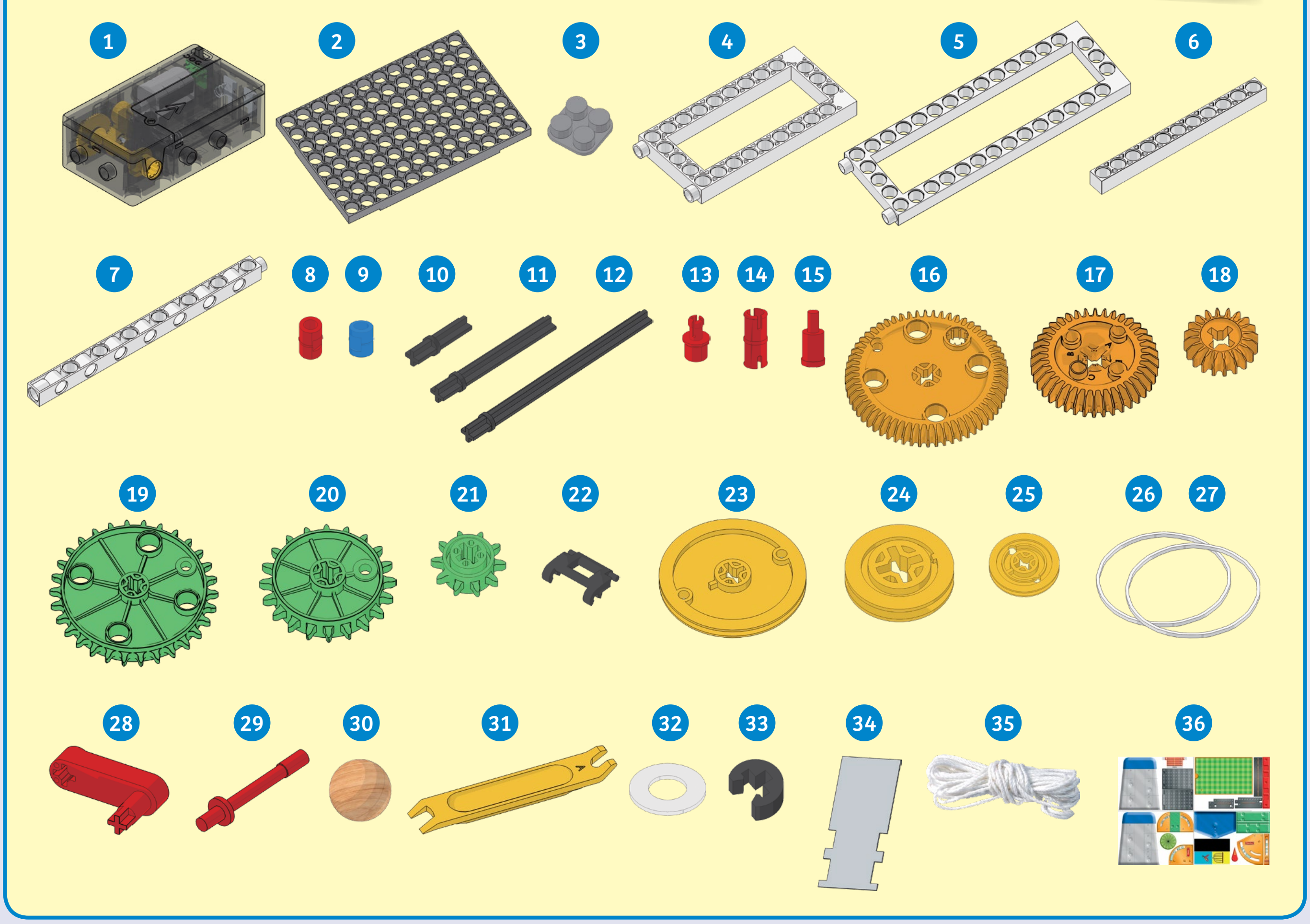
››› KIT CONTENTS

What's inside your experiment kit:

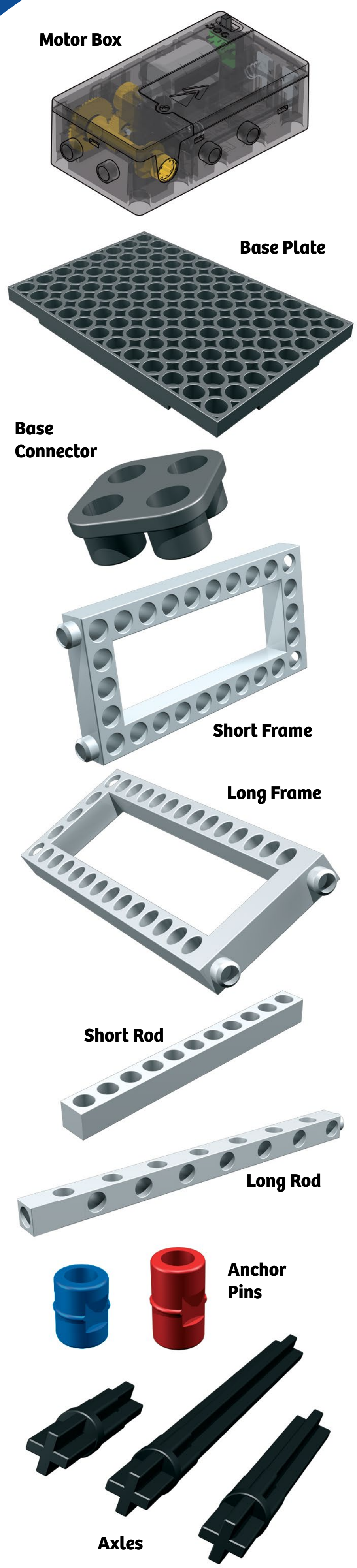


Checklist: Find – Inspect – Check off

✔	No.	Description	Qty.	Item No.
❍	1	Motor box	1	7441-W85-A
❍	2	Base plate	4	7125-W10-A1SK
❍	3	Base plate connector	6	7026-W10-I1SK
❍	4	Short frame (5x10)	2	7413-W10-I1SK
❍	5	Long frame (5x15)	2	7413-W10-J1SK
❍	6	Short rod (11-hole rod)	4	7413-W10-P1SK
❍	7	Long dual rod (15-hole dual rod)	4	7413-W10-H1SK
❍	8	Anchor pin (red)	20	7061-W10-C1R
❍	9	Short anchor pin (blue)	4	7344-W10-C2B
❍	10	35-mm axle	4	7413-W10-O1D
❍	11	60-mm axle	4	7413-W10-M1D
❍	12	100-mm axle	4	7413-W10-L2D
❍	13	Shaft plug	20	7026-W10-H1R
❍	14	Joint pin	10	1156-W10-A1R
❍	15	Shaft pin	2	7026-W10-J3R
❍	16	Large gear wheel (60 teeth)	4	7026-W10-W5O
❍	17	Medium gear wheel (40 teeth)	2	7346-W10-C1O
❍	18	Small gear wheel (20 teeth)	8	7026-W10-D1O
❍	19	Large sprocket wheel (30 teeth)	3	3569-W10-C1G
❍	20	Medium sprocket wheel (20 teeth)	3	3569-W10-D1G
❍	21	Small sprocket wheel (10 teeth)	3	3569-W10-D2G
❍	22	Chain link	140	3569-W10-B1D
❍	23	Large pulley wheel	2	7344-W10-N1Y
❍	24	Medium pulley wheel	2	7344-W10-N2Y
❍	25	Small pulley wheel	2	7344-W10-N3Y
❍	26	Short rubber band	2	R10-02
❍	27	Long rubber band	2	R10-05
❍	28	Crank	1	7063-W10-B1R
❍	29	Crankshaft	2	7026-W10-J2R
❍	30	Wooden ball	8	R36#3620
❍	31	Anchor pin lever	1	7061-W10-B1Y
❍	32	Washer	10	R12#3620
❍	33	Axle lock	10	3620-W10-A1D
❍	34	Waterwheel paddles	8	K41#3620
❍	35	Cotton string	1	R39-W85-400
❍	36	Die-cut paper sheets	1	K16#3620-US1

For the motor, you will need:
2 x AA batteries (1.5-volt, type AA/LR6)

For some experiments, you will also need:
Scissors, match stick, blank paper, large plastic bag, wooden skewer, tape, sewing needle, thread, tealight candle, plastic water bottle, paper clips, heavy book, wooden board, extra rubber bands, cup or mug, C batteries or similar-sized objects for weights, small cylindrical container with lid, wire cutter, pliers



In this kit, you will find a large number of colored plastic components. You will use these pieces to build all the structures, machines, and mechanical models used in the experiments. Screws, nuts, bolts, and glue are not included because all of the models are held together with plastic pieces.

1. Motor Box (x1)
This contains an electric motor, a compartment for two AA batteries (1.5-volt), a switch for forward, reverse, and off, two output holes for axles, and gears to reduce the motor's rotation speed and increase its torque. The engine box is your drive unit. The battery compartment has a sliding cover that you can remove when you want to install or replace the battery.

2. Base Plate (x4)
You can easily attach many of the parts to the four gray base plates. You can also attach the plates to one another to create a larger base. Whether a plate's underside is smooth or the holes go all the way through doesn't affect its function.

3. 4-Peg Base Plate Connector (x6)
These can be used to connect two base plates together. They can be inserted into the top or bottom of a base plate.

4. Short Frame (5 holes by 10 holes) (x2)
You can do a lot of things with this sturdy support structure — insert it into a base plate, or attach a rod or another frame to it. All kinds of axles will fit through its holes.

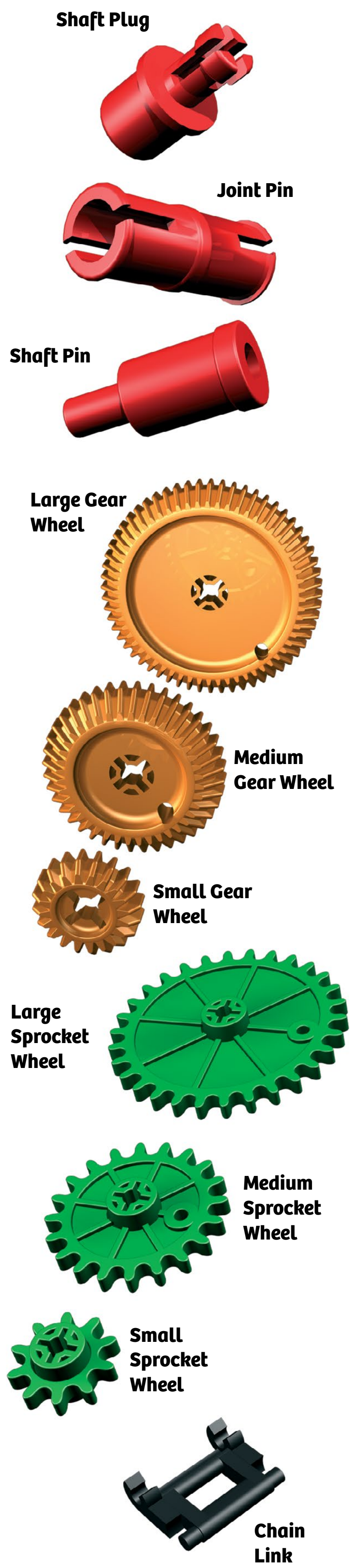
5. Long Frame (5 holes by 15 holes) (x2)
The long frames form the foundations of most of the structures and machines in the experiments.

6. Short Rod (11 holes) (x4)
This has a row of holes and is very useful. For example, it can be used to make a framework more stable, or to hold an axle. It also has two smooth sides, which will be important when we play our ball games. But the short rod is also capable of providing more than mere passive support — at times its role can be truly pivotal.

7. Long Dual Rod (7 holes per side) (x4)
This rod has two rows of holes capable of holding any of the axles in the kit. It is also useful for stabilizing frameworks. The main differences between this and the first rod are that this one has no smooth sides and the spacing between the holes is twice as long. Its main advantage is that it can be used at the corner of a structure, to attach pieces going in two directions. And the design of its ends lets you insert it anywhere and lengthen it whenever you need to.

8-9. Anchor Pins: Regular (x20) and Short (x4)
These are used for attaching rods and frames to one another. The blue anchor pins are shorter than the red ones. Thus, they don't stick as far into holes as the red ones do, so they offer weaker connections, but also the ability to insert two pins into opposites sides of the same hole. Two of the anchor pins' sides are flattened, so you can use the pin remover tool to extract pins from a hole during disassembly.

10-12. Axles: 35-mm (x4), 60-mm (x4), 100-mm (x4)
The black axles come in different lengths. They have plus-sign-shaped cross sections, so that gears and wheels inserted onto them turn with the axles. You will be using them mostly as drive axles. They have two different ends. At one end of each axle you will see a ring, which ensures that the axle does not push through the hole of a frame or rod while at the same time leaving enough room to insert a wheel onto it. You will also notice that the axle is thicker on the inside of the ring— small enough to rest inside a hole, but too large to push a wheel onto.



13. Shaft Plug (x20)
This red-colored piece will hold fast when its thick end is inserted into a hole. If you press a wheel into its other end, the prongs will hold the wheel securely while still letting it rotate freely. You can also use this piece to attach cardboard and other pieces to frames or rods. When the shaft plug is inserted in a hole, its thin rim will protrude a little, allowing it to be pried out with the part separator tool.

14. Joint Pin (x10)
This red-colored piece is split at both ends. Either end can be inserted into the hole of a rod or frame, where it will rest securely while still being able to rotate. Its other end can then be inserted into another rod or frame hole. The joint pin lets you connect two components so that they can rotate or pivot relative to one another.

15. Shaft Pin (x2)
This red piece will fit into a hole of one of the rods, with the thick section able to rotate in the hole. Its rim keeps it from slipping out of the hole. The thinner end, meanwhile, fits nicely into the crank-hole of a wheel. So the shaft pin is used to connect a wheel to a rod. If just the thinner end is inserted into a wheel's crank-hole, the shaft pin can serve as a crank handle.

16. Large Gear Wheel (x4)
The kit's gear wheels are orange. The large wheel has 60 teeth around its periphery. Like all the gear wheels, this one has slanted teeth on one side, and on the other side it is flat. The hole in the middle lets you mount it on an axle or a shaft plug. The small hole near the edge of the wheel (or crank-hole) holds the shaft pin so you can crank it. A gear wheel lets you transfer force and motion onto another wheel (or another gear shaft). In that process, you can increase the force while decreasing the rotations, or increase the rotations while decreasing the force.

17. Medium Gear Wheel (x2)
This gear has 40 teeth, but is otherwise similar to the large gear wheel.

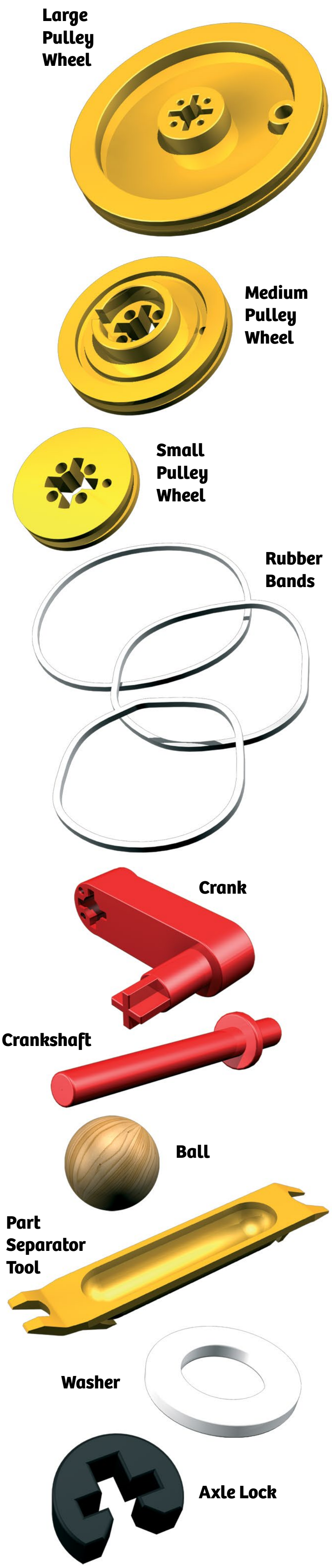
18. Small Gear Wheel (x8)
This one has just 20 teeth, is a little thinner than the others, and lacks a crank-hole for the shaft pin.

19. Large Sprocket Wheel (x3)
It is green and has 30 teeth. As with the other sprocket wheels, a chain can go over the rim of teeth. It also has a crank-hole for the shaft pin. Unlike the gear wheels, both sides of the sprocket wheels are the same. The nub in the center is thicker with all the sprocket wheels.

20. Medium Sprocket Wheel (x3)
This sprocket wheel has just 20 teeth, but is otherwise shaped just like the large one.

21. Small Sprocket Wheel (x3)
It has just 10 teeth and is missing the hole for the shaft pin, but is otherwise like the other two. Now and then, we will be using it on an axle to keep other pieces securely in place.

22. Chain Link (x140)
This is black and can be connected to other links to create a chain. The longest chain has 140 pieces. The inside of the chain is smooth, the outside rough. If you turn the rough outer side inward, the chain grinds on the wheels and can get caught. Chains and sprocket wheels are good for carrying large forces over long distances. They are "forgiving," because they are a little loose and compensate for imperfections. Chains can also be used as conveyor belts or as treads or drive chains for land vehicles.



23. Large Pulley Wheel (x2)
Like the two other sizes of pulley wheels, this one is yellow. A rubber band or cord can go along the groove around its rim. On its inner side, you will see a ring with an opening. If you push the inner sides of two equal-sized pulley wheels together and then slide them onto an axle, it creates a drum with room for the knot and an exit hole for the cord. Near its edge, the pulley wheel has a crank-hole for a shaft pin.
Pulley wheels, like sprocket wheels, are used to transmit forces or movements, in order to increase or reduce them. Instead of a fixed interlocking chain, the pulley wheel uses a drive belt made of rubber, leather, or cloth, which can slip and still turn in the groove with fluctuations of force or overloads. Drive belts therefore afford a soft and elastic means of transmission.

24. Medium Pulley Wheel (x2)
Instead of the crank-hole, this wheel has a small hole for the end of the cord.

25. Small Pulley Wheel (x2)
This one also has a cord hole.

26-27. Rubber Bands: Short (x2) and Long (x2)
There are two different sizes of rubber bands: short and long. They do the work of drive belts, springs, and energy stores.

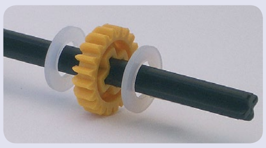
28. Crank (x1)
You will use the crank to turn axles by hand and also to convert rotating motion into back-and-forth motion.

29. Crankshaft (x2)
This serves admirably as a crank handle.

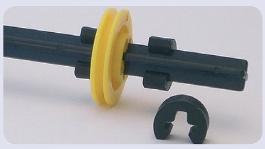
30. Wooden Ball (x8)
This is used for several experiments and games.

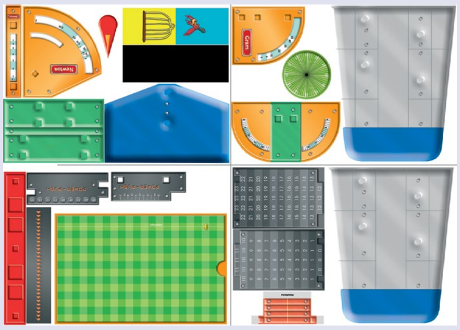
31. Anchor Pin Lever (Part Separator Tool) (x1)
This is a handy tool for extracting anchor pins and shaft plugs from holes. The thicker end lifts out the anchor pin, the thinner end the shaft plug. You can use the long axle to push out anchor pins, shaft plugs, shaft pins, and base connectors.

32. Washer (x10)
We use this piece to reduce friction — for example, to keep vehicle's wheels from rubbing against its chassis or rod — but also to increase the distance or space between parts, or to press one part against another. The washers be used whenever you find that wheels or gears are rubbing against other components. In particular, they will come in handy when you use several gears in the assembly of a vehicle or machine that might otherwise have the freedom of their rotation hindered, with a resulting slowing of the mechanism's performance. These washers may not show up in the photograph of a particular workshop project, but feel free to make use of them whenever you think it makes sense to do so. A good engineer improvises to improve performance.


Plastic washers can be used to separate gears.

33. Axle Lock (x10)
These are designed to prevent a wheel from wandering along the axle, or slipping. They are easy to install without having to remove the wheel or the axle.


Axles locks will keep wheels and axles from slipping.

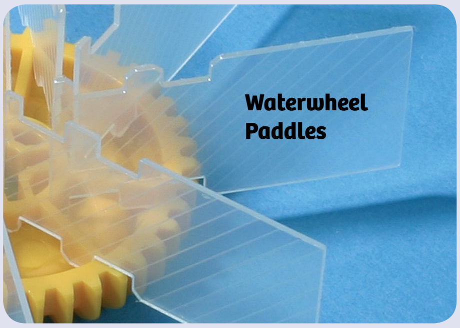


The Die-Cut Paper Sheets

34. Die-Cut Paper Sheets (x1)
Remove each individual piece as you need it for its experiment. If any bits of paper remain attached to one of the pieces, just remove them carefully with a pair of scissors.

35. Waterwheel Paddles (x8)
These flat plastic panels are inserted into the large gears to make a simple waterwheel.

36. Length of String (x1)
This is required for some of the models.



String

Tips and Additionally Required Materials

You will need **two AA batteries** (1.5-volt) which are not included in the kit due to their limited shelf life.

You will find the larger kit components packed in the compartments of the box. All of the smaller pieces are packed in plastic pouches. Please be careful not to lose any of the small pieces when you open the pouches!

For a few of the experiments, you will need to provide additional **common household items** (matches, skewers, tealight candles in aluminum containers, paper napkins, transparent adhesive tape, permanent marking pen, quart-sized plastic drinking bottle, freezer bag or plastic shopping bag, etc.).

You will see a pattern for the **sail** of the sail car (see the Workshop on page 14). Trace the lines with a permanent marking pen onto a freezer bag or a sheet of plastic from a good-quality plastic shopping bag, and cut the sail out with scissors.

The rotor blades for the **wind-power plant** (page 73) will be assembled from pieces from the die-cut sheets. If you want to leave the wind power generator outside for a long time, you will need to cut the blades and tailpiece out of plastic. Just get a couple of thick flexible plastic presentation folders from a stationery store — they come in a variety of colors and thicknesses. If you have plastic folders that are too thin, you can make the blades and tailpiece out of two layers held together with tape. To get the size and shape of the plastic pieces right, trace around the die-cut paper pieces with a waterproof marker.

In a few of the models, the axles will also have to be **lengthened**. The best way to do that is to connect two axle shafts with a small gear wheel. Just insert one end of each axle into the gear wheel from each side. To make it super-secure, you can strengthen the clamp by inserting a bit of tissue paper into the gear wheel hole before inserting the axles.

This diagram shows how you lengthen an axle.

cm vs. in

Throughout this kit, the Metric System of units is used instead of the Imperial System of units. Although you may be more comfortable with units from the Imperial System such as inches and feet, scientists around the world use the Metric System in order to be able to clearly communicate with each other without the need for conversion. Thus, since this is a science kit, we will use the Metric System as well. For your reference, 1 inch equals 2.54 centimeters. There is a ruler printed at the back of the book.

EXPERIMENT 9: THE TRAJECTORY PARABOLA

On your shot put device, measure the height of the point where the ball leaves the slot, relative to the surface on which the shot put device stands. Position the lower table of the target board so that its "0" line is it that same height, and then mount the upper table above it. Now, the target board is "zeroed" by height. Next, place the end of a measuring tape or stick beneath the point where the wooden ball will be shot from the device you constructed. Make sure that the measuring tape extends in the direction in which you will be shooting. Attach it to the table surface with tape. This will establish the zero point for distance.

Now position the target board so that its front edge is 10 cm away from the zero point. Set your shot put machine to a 46° angle, shoot a ball at the board with a drive power of 3, and observe exactly which height line the wooden ball hits. In other words, at how many centimeters above the height of the slot out of which the ball is shot does the ball hit the target? Plot the height measurement at the corresponding distance on the graph printed on the inside back cover of this manual. Then repeat the procedure at distances of 20 cm, 30 cm, 40 cm, and so on, up to 80 cm.

For each distance, plot the height the ball reaches on the graph just as you did with your first shot, and try to link the points into a continuous curve with a pencil line. If one of the points is totally out of line with the rest of the curve, repeat the corresponding shot.

The ball flies farthest when it is thrown at an angle of 45°.

You will get a curve that bends only a little bit at first and then more strongly. But what accounts for the curve? It's simple. The physical trajectory is due to two individual forces: the force with which the ball is shot and the force of gravity. The force with which the object is shot gives it an initial speed and a direction. The initial upward-angled velocity of the object "fights" with the acceleration of its fall. What is the outcome of the fight? Both forces come together in a smooth curve, with no bumps or bruises. The flight path from the takeoff point to ground impact is called a trajectory parabola. The path forms a high arch with a steep shooting angle and a flat arch with a low shooting angle. In addition, the path is flatter and more elongated the greater the initial force is. Because the force is only applied initially, it can only give the ball an initial velocity, and cannot accelerate it. Earth's gravity, on the other hand, acts on the ball during its entire flight — causing the speed of the ball's fall to the table surface to increase by the gravitational acceleration of 9.81 m/s^2.

EXPERIMENT 10: HOW STEEP AND HOW FAR?

Using the shot put device, shoot a ball at an angle of 33° and a drive power of 3 over an empty table surface. Take note of where the ball hits, and measure the distance between that point and the shooting device. Repeat the procedure with the same drive power, but this time at an angle of 75° and again at an angle of 46°.

At what angle did the ball travel the farthest? At 46°, assuming that you worked the shot rod consistently and always used the same drive power setting. Wouldn't you think that a ball shot at a flat angle would fly farther? In fact, though, any object — regardless of whether it is a ball, a rock, or a piece of iron — flies farthest when it is shot or thrown at an upward angle of 45°.

Here is one more thing that will probably interest you: how long does the ball rise, and how long does it fall? You would think that the time falling would be shorter, wouldn't you? In fact, ascent time and descent time are the same. At least, that is true assuming that the takeoff point and the landing point are at the same height. In our experiment, that height is the number board's 0 line. The time equivalence is explained by the fact that the ascent is, from the perspective of physics, simply a descent in reverse.

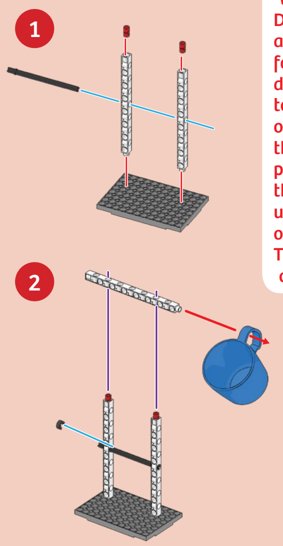
GAME

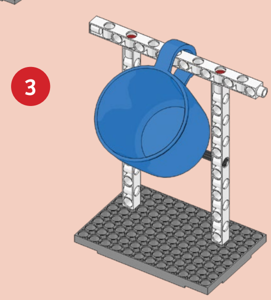
Dunkin' shot put

Now that you know about angles, drive power settings, and flight paths, you are ready for a little target practice. This game works best with two or more players.

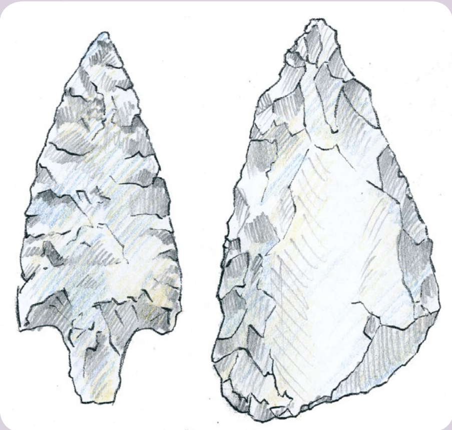
Hang a mug in a holder as shown below, and off you go! You can make up your own rules. Suggestions: each player shoots 10 times in one turn. Shoot at the mug from 30 cm away at first, then 60, and finally 80. A successful hit gets a point total corresponding to the distance: 10, 20, and 50.

Warning! Do not aim at eyes or face. The device is able to discharge objects other than the ball provided with the toy. Do not use with any other objects. There is a risk of injury.

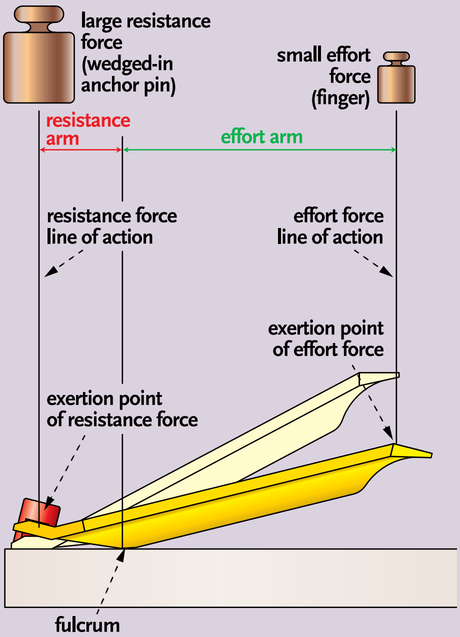




Simple Machines



The spears and hand-axes of stone-age humans are simple machines.



effort force x effort arm = resistance force x resistance arm

A pair of scissors consists of two levers. Their cutting force increases as you get closer to their shared pivot point.

Prehistoric Machines

The thing that separates us humans from other animals is that we have intelligence and know how to use tools and other resources to make work easier for us. Even our stone-age ancestors were no dummies. They were, in fact, the first people who figured out how to build machines. Machines? Can you really call hand-axes, spear points, and harpoons — whittled and carved out of stone, wood, and bone — machines? Yes, they are indeed **simple machines**. Machines are any tools and utensils that make our work easier. They are things that alter the magnitude and/or direction of the force that is needed to do specific kinds of work. We will learn exactly what we mean by "work" later in this manual. When machines make work easier, do they make it less? Not really. As the "golden rule" of mechanics states:

Force that is saved must be made up for in distance.

Or, in other words: the less force you need, the more distance you need. You can test the truth of this rule in the following experiments, with the help of seven simple machines: **lever, pulley, combined pulley, inclined plane, wedge, screw, and wheel.**

The Lever

By now, you will certainly have gotten some use out of the **part separator tool** that came with this kit. It's a tool that lets you lift out **anchor pins** and **shaft plugs** with ease even if they have gotten stuck in a hole. It's a lot more difficult to try to pull them out using nothing but your thumb and forefinger! Why is that? The part separator tool has two short, bent arms with a claw and a longer arm to grip with. Its claw grips under the anchor pin, with its longer arm tilting up. When you push down on the arm, the arm with the claw simultaneously moves up. But there is one spot on the bottom where almost nothing moves, namely the spot where the part separator tool supports itself against the assembly piece. That point is where the **fulcrum**, or pivot point, of the lever is. The two arms of the lever pivot around that point. So the tool has a short and a long arm as well as a fulcrum or pivot point.

One-Armed and Two-Armed Levers

But what is it about the part separator tool that makes it a lever? A lever is an inflexible object that can be rotated about an axis. Exactly what shape it has — angled, round, straight, bent, thick, or thin — has nothing to do with the way it saves energy. Every lever must have a pivot point. Every lever must also have two other points: one where the load or resistance is, and another where the effort force is exerted. If the pivot point lies between these two other points, then the lever is "two-armed" or two-sided, a type called a **first-class** or **type one** lever. If the pivot point is at the end of the lever, then it is "one-armed" or one-sided — or, as it is called, a **second-class** or **type two** lever. Your part separator tool is a type one lever.

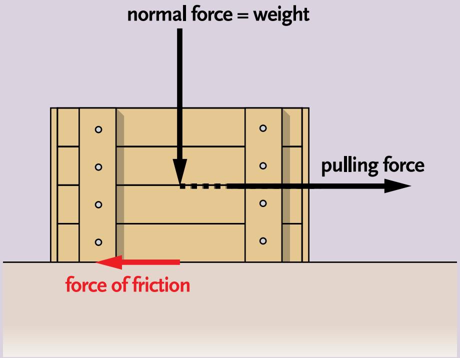
Resistance Arm and Effort Arm

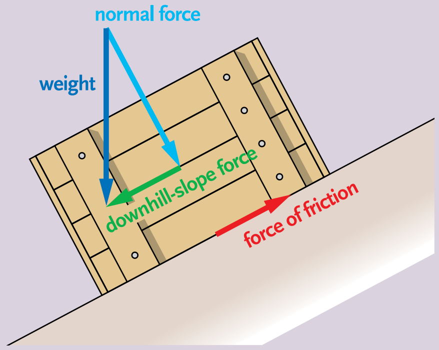
At the moment when you press on the handle with enough effort force for the anchor pin to come out of its hole, the part separator tool is in a state of balance or equilibrium in its work. But how can a small amount of effort force balance a large resistance force? Because the arm of the lever on the effort side is longer in precise proportion to the degree that the effort force is smaller. The opposite happens on the resistance side: the resistance arm is shorter in precise proportion to the degree that the resistance force is greater. If the effort arm is twice as long as the resistance arm, then there is a balance when the effort force is half as great as the resistance force. One says: effort force (kg) times the distance on the effort arm from the exertion point of the effort force to the fulcrum (m) is equal to resistance force (kg) times the distance from the resistance force to the fulcrum on the resistance arm (m). Written a little differently, this is how the equation goes:

effort force x effort arm length = resistance force x resistance arm length

body rolls on a surface, and is considerably less than kinetic friction. If you move the crate forward on two rolling broomsticks, it's easier than just shoving it along the floor. That's why it's easier to move furniture if you use a furniture dolly, a platform with wheels beneath it.

You can convince yourself of the advantage of rolling friction with the help of an inclined plane that you convert from a slide into a runway with a flick of a lever. It goes with a vehicle that has a runner tucked away unobtrusively between its wheels. The perplexed spectator will wonder how on earth the lever can release the vehicle's brakes. Only you will know the answer: as you move the lever, it pushes a roadway under the vehicle's wheels and simultaneously lifts the vehicle off the runner.

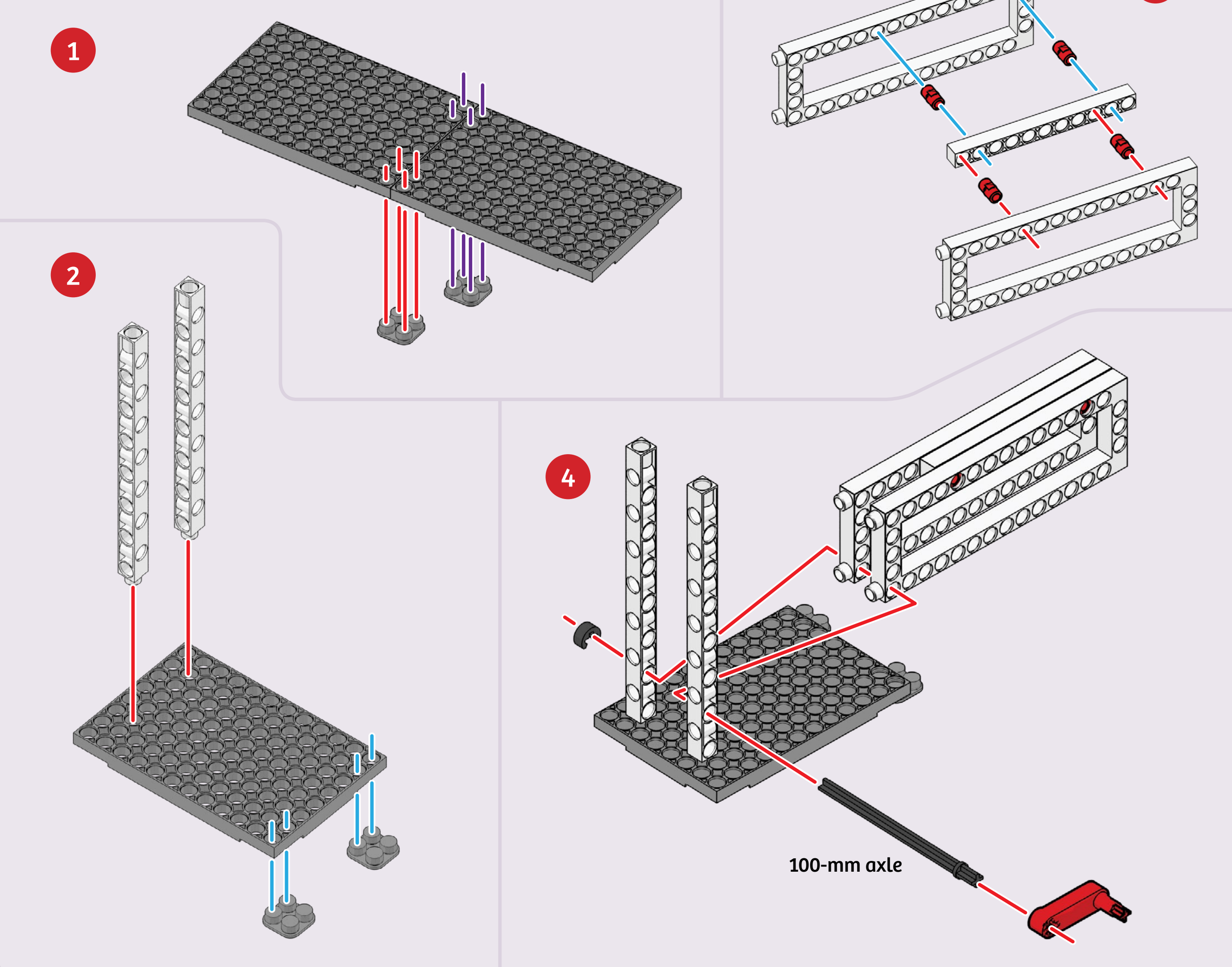




Top illustration: The force of friction works against the pulling force. During movement, it is always smaller than the pulling force.

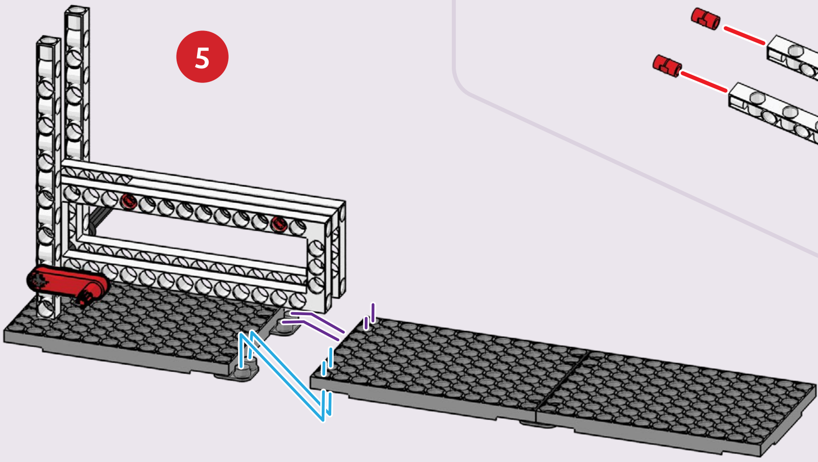
Bottom illustration: If a surface is gradually inclined to the point that the body will start to slide on it, the force of friction and the force of the downhill slope are equally great at this point.

WORKSHOP 16: WHEELED SLED, RUNWAY, AND SLIDE

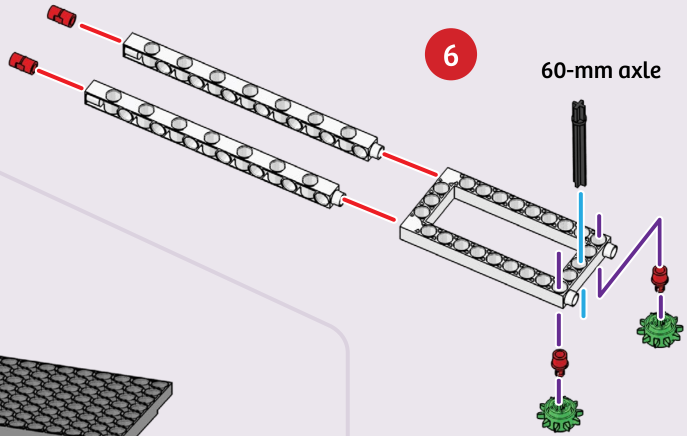


WORKSHOP 16: WHEELED SLED, RUNWAY, AND SLIDE

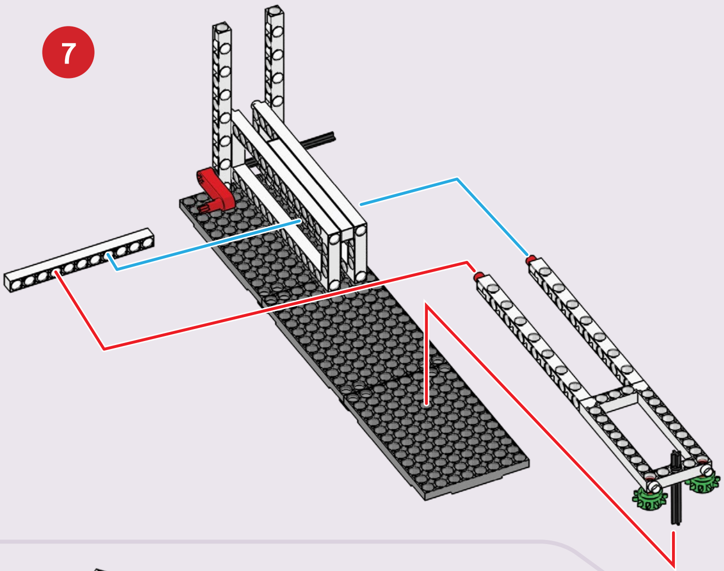
5



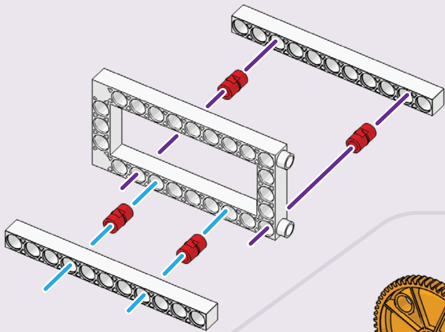
6



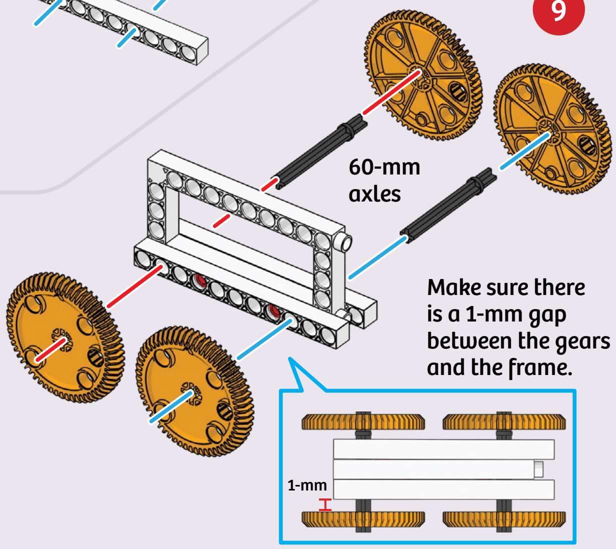
7



8



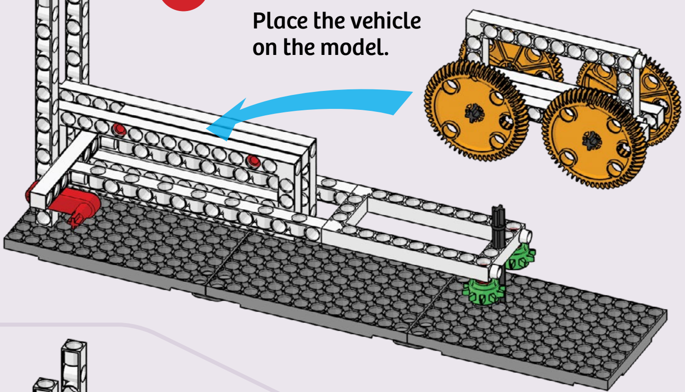
9

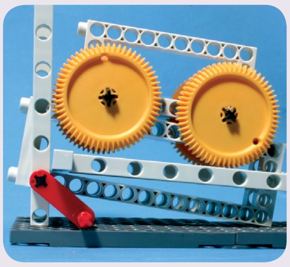


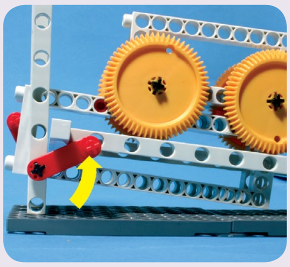
Make sure there is a 1-mm gap between the gears and the frame.

10

Place the vehicle on the model.

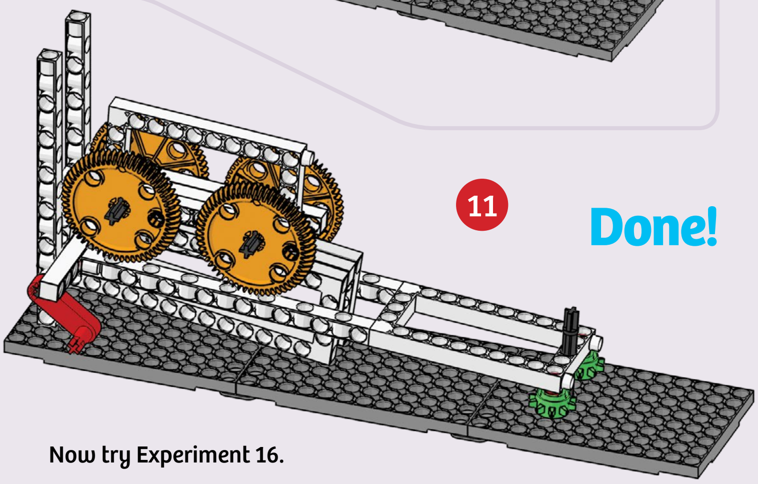




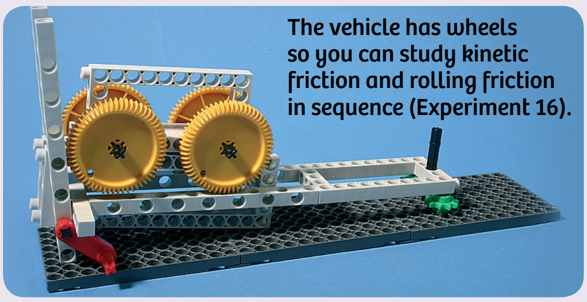


11

Done!



Now try Experiment 16.



The vehicle has wheels so you can study kinetic friction and rolling friction in sequence (Experiment 16).