PHYSICS
workshop

EXPERIMENTS

#7441

306 PCS

8^+

LEARN PHYSICS BY BUILDING MODELS & ASSEMBLE SIMPLE AND COMPOUND MACHINES

37 EXPERIMENTS INCLUDED

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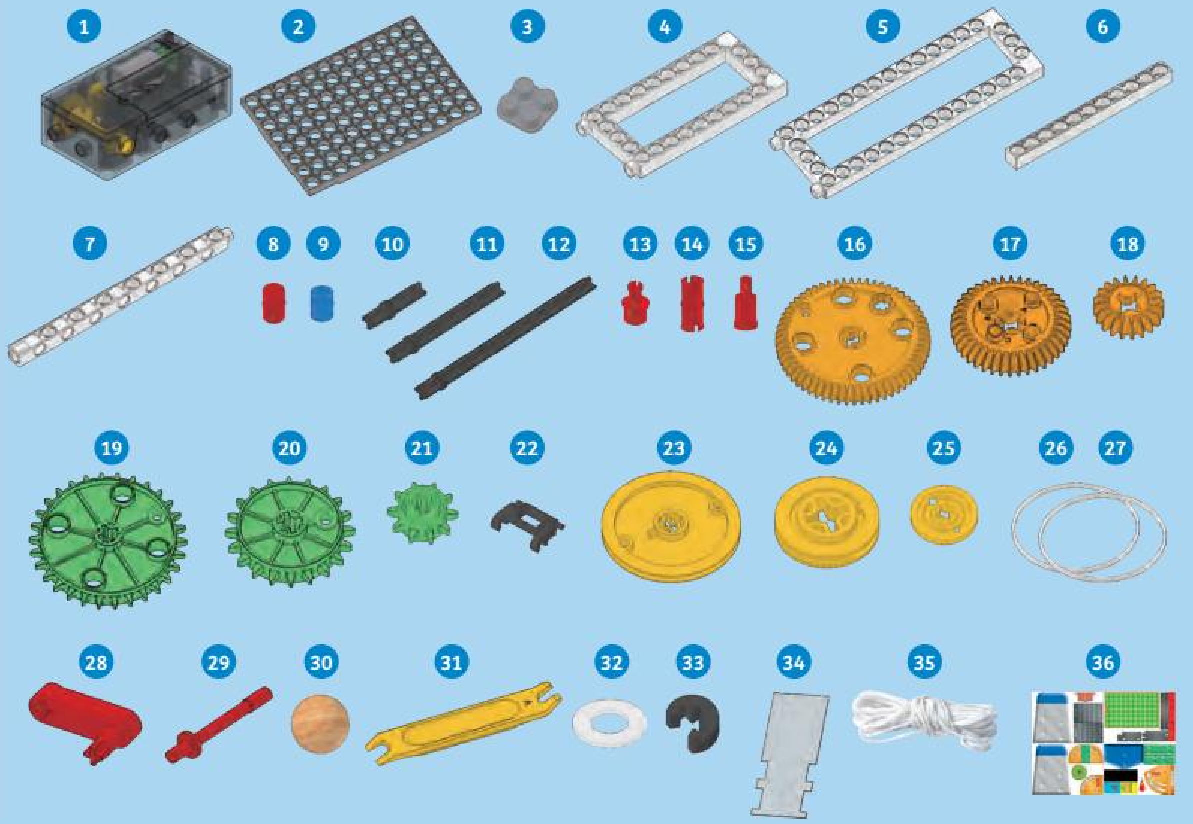
Kit Contents

What's inside your experiment kit:



Checklist: Find – Inspect – Check off

✔	No.	Description	Qty.	Item No.
○	1	C-28X MOTOR WITH SWITCH	1	7441-W85-A
○	2	C-BASE GRID	4	7125-W10-A1SK
○	3	C-BASE GRID CONNECTOR	6	7026-W10-I1SK
○	4	C-5X10 FRAME	2	7413-W10-I1SK
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○	6	C-11 HOLE ROD	4	7413-W10-P1SK
○	7	C-15 HOLE DUAL ROD	4	7413-W10-H1SK
○	8	C-LONG PEG	20	7061-W10-C1R
○	9	B-SHORT PEG	4	7344-W10-C2B
○	10	C-35mm AXLE II	4	7413-W10-O1D
○	11	C-60mm AXLE II	4	7413-W10-M1D
○	12	C-100mm AXLE II	4	7413-W10-L2D
○	13	C-AXLE	20	7026-W10-H1R
○	14	C-20mm AXLE CONNECTOR	10	7413-W10-T1R
○	15	C-CAM CONNECTOR	2	7413-W10-S1R
○	16	C-60T GEAR	4	7026-W10-W5O
○	17	C-40T GEAR	2	7346-W10-C1O
○	18	C-20T GEAR	8	7026-W10-D1O
○	19	C-30T CHAIN GEAR	3	3569-W10-C1G
○	20	C-20T CHAIN GEAR	3	3569-W10-D1G
○	21	C-10T CHAIN GEAR	3	3569-W10-D2G
○	22	C-CHAIN	140	3569-W10-B1D
○	23	C-OD53mm PULLEY	2	7344-W10-N1Y
○	24	C-OD33mm PULLEY	2	7344-W10-N2Y
○	25	C-OD23mm PULLEY	2	7344-W10-N3Y
○	26	C-70mm RUBBER BAND	2	R10-02
○	27	C-100mm RUBBER BAND	2	R10-05
○	28	C-CRANK	1	7063-W10-B3R
○	29	C-BAR	2	7026-W10-J2R
○	30	C-WOODEN BALL	8	R36#3620
○	31	B-PEG REMOVER	1	7061-W10-B1Y
○	32	C-WASHER	10	R12#3620
○	33	C-AXLE FIXING	10	3620-W10-A1D
○	34	P-DIE CUT PLASTIC SHEET	8	K41#3620
○	35	C-4000mm STRING	1	R39-W85-400
○	36	P-DIE CUT CARD	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


28X MOTOR WITH SWITCH


BASE GRID


BASE GRID CONNECTOR


5X10 FRAME


5X15 FRAME


11 HOLE ROD


15 HOLE DUAL ROD


SHORT PEG


LONG PEG


35mm/60mm/ 100mm AXLE

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. 28X MOTOR WITH SWITCH(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 GRID (x4)
You can easily attach many of the parts to the four gray base grids. You can also attach the grids to one another to create a larger base. Whether a grids underside is smooth or the holes go all the way through doesn't affect its function.

3. BASE GRID CONNECTOR (x6)
These can be used to connect two base grids together. They can be inserted into the top or bottom of a base grid.

4. 5X10 FRAME (5 holes by 10 holes) (x2)
You can do a lot of things with this sturdy support structure — insert it into a base grid, or attach a rod or another frame to it. All kinds of axles will fit through its holes.

5. 5X15 FRAME (5 holes by 15 holes) (x2)
The long frames form the foundations of most of the structures and machines in the experiments.

6. 11 HOLE 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 11 hole rod is also capable of providing more than mere passive support — at times its role can be truly pivotal.

7. 15 HOLE 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. LONG PEG(x20) and SHORT PEG(x4)
These are used for attaching rods and frames to one another. The blue short pegs 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 pegs into opposites sides of the same hole. Two of the pegs' sides are flattened, so you can use the peg remover tool to extract pegs from a hole during disassembly.

10-12. 35mm AXLE II (x4), 60mm AXLE II (x4), 100mm AXLE II (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.

AXLE



20mm AXLE CONNECTOR

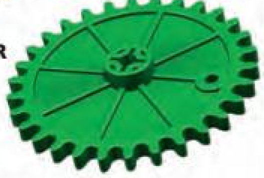
CAM CONNECTOR


60T GEAR



40T GEAR


20T GEAR

30T CHAIN GEAR



20T CHAIN GEAR


10T CHAIN GEAR


CHAIN

13. AXLE (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 axle is inserted in a hole, its thin rim will protrude a little, allowing it to be pried out with the part separator tool.

14. 20mm AXLE CONNECTOR (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 20mm axle connector lets you connect two components so that they can rotate or pivot relative to one another.

15. CAM CONNECTOR (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 cam connector is used to connect a wheel to a rod. If just the thinner end is inserted into a wheel's crank-hole, the cam connector can serve as a crank handle.

16. 60T GEAR (x4)
The kit's gears are orange. The 60T gear 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. The small hole near the edge of the wheel (or crank-hole) holds the cam connector 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. 40T GEAR (x2)
This gear has 40 teeth, but is otherwise similar to the 60T gear.

18. 20T GEAR (x8)
This one has just 20 teeth, is a little thinner than the others, and lacks a crank-hole for the cam connector.

19. 30T CHAIN GEAR (x3)
It is green and has 30 teeth. As with the other chain gears, a chain can go over the rim of teeth. It also has a crank-hole for the cam connector. Unlike the gears, both sides of the chain gears are the same. The nub in the center is thicker with all the chain gears.

20. 20T CHAIN GEAR (x3)
This chain gear has just 20 teeth, but is otherwise shaped just like the large one.

21. 10T CHAIN GEAR (x3)
It has just 10 teeth and is missing the hole for the cam connector, 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(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 chain gears 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.

OD53mm PULLEY

OD33mm PULLEY

OD23mm PULLEY

RUBBER BANDS

CRANK

BAR

WOODEN BALL

PEG REMOVER

WASHER

AXLE FIXING

23. OD53mm PULLEY (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 has a crank- hole for a cam connector.
Pulleys , like chain gears, are used to transmit forces or movements, in order to increase or reduce them. Instead of a fixed interlocking chain, the pulley 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. OD33mm PULLEY (x2)
Instead of the crank-hole, this wheel has a small hole for the end of the cord.

25. OD23mm PULLEY (x2)
This one also has a cord hole.

26-27. 70mm RUBBER BAND (x2) and 100mm RUBBER BAND (x2)
There are two different sizes of rubber bands: 70mm and 100mm. 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. BAR(x2)
This serves admirably as a crank handle.

30. WOODEN BALL(x8)
This is used for several experiments and games.

31. PEG REMOVER (Part Separator Tool) (x1)
This is a handy tool for extracting long pegs and axles from holes. The thicker end lifts out the long peg, the thinner end the axle. You can use the long axle to push out long pegs, axles, cam connectors, 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 FIXING (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.

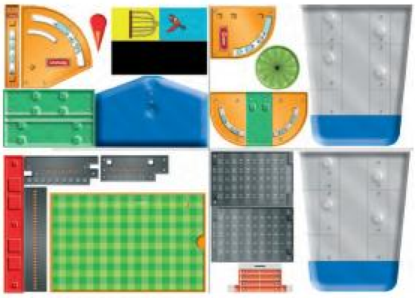
Axles fixings will keep wheels and axles from slipping.

34. DIE CUT PLASTIC SHEET(x8)
These flat plastic panels are inserted into the large gears to make a simple waterwheel.

35. 4000mm STRING (x1)
This is required for some of the models.

36. DIE CUT CARD (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.


4000mm STRING


DIE CUT CARD

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 13). 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 72) will be assembled from pieces from the die cut cards. 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 20T gear. Just insert one end of each axle into the gear from each side. To make it super-secure, you can strengthen the clamp by inserting a bit of tissue paper into the gear 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.

Earth Attracts Us

Who Falls Up?

How many times in your life have you taken a tumble? A dozen times? A hundred? On any one of those occasions, did you ever fall upwards? Or did you ever float around in the air like an astronaut? No, down you went, each time.

The time in your life when you fell most often was probably when you were just learning to walk. No doubt, you were impatient to get your head in the air and stand on your own two feet. You wanted to move along much faster than you could when crawling along on all fours. You trained for weeks, trying your hardest to learn how to keep your balance. It was a mighty struggle against a formidable foe, a foe that tries its hardest to pull everyone and everything down to the ground. Its name: **gravity**.

Gravity

We usually don't think much about gravity, but we always feel it. When we lift a pitcher of water, we feel it. When we pick up a pencil, we feel it, but less than with the pitcher of water. Earth's gravity exerts its force equally on all physical bodies. So gravity must have something to do with weight — as we will learn in more detail with our first experiment, the potato trap.

DID YOU KNOW?

Gravity builds muscles

In order to be able to walk upright, we grow sturdy bones and strong muscles. Our largest muscles are the ones that we use for walking — in our legs and rear end. If Earth's gravity were much greater, we would walk around like hulking muscle-bound brutes. If it were much weaker, we would have stick-thin legs and skinny little bottoms. Plants and animals would all look different too.

KEYWORD: GRAVITY

Gravity is the attraction of the mass of Earth, the moon, or a planet, toward bodies at or near its surface. On Earth, the gravity at the surface is a downwards force that causes an acceleration equal to about 9.8 meters per second per second (m/s/s or m/s^2).

WORKSHOP 1: POTATO TRAP

YOU WILL ALSO NEED

- *1 wooden match*

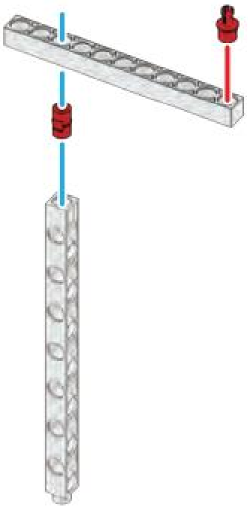
HERE'S HOW

Follow the assembly steps to construct the potato trap model. Be sure that the table on which the model is sitting is level and not tilted.

1

Remove the head from a wooden matchstick and insert it into the slit of a axle. This will be the stick on which your potato will be impaled.

2



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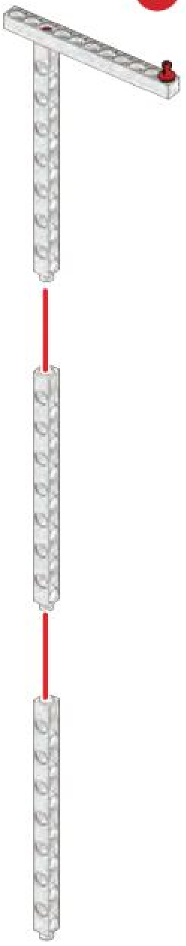

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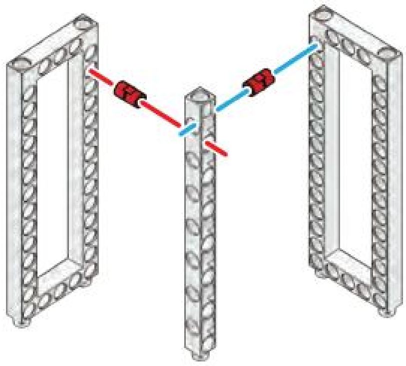

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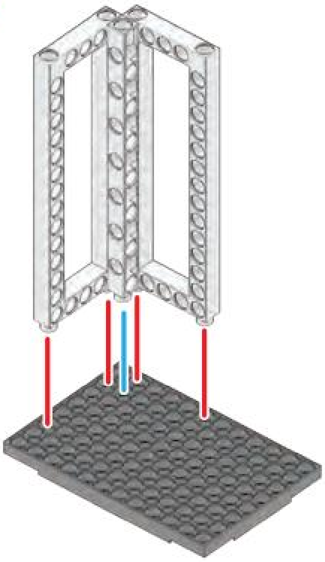

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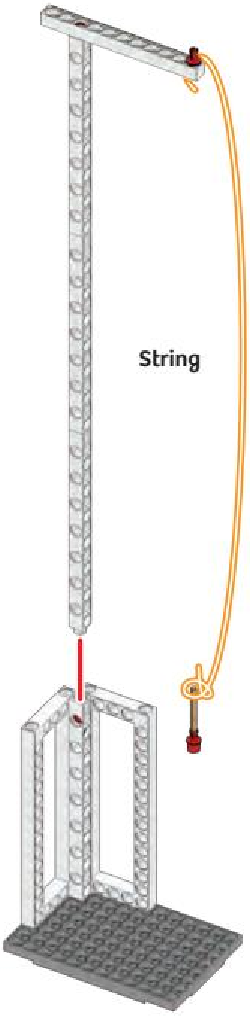

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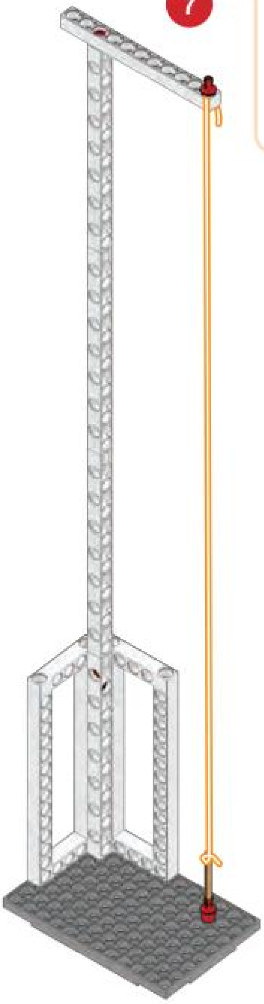


Determine the exact point where the potato, if dropped from the top rod, will hit the base grid.

Your axle-stick assembly will first serve as a plumb bob. A plumb bob always points downward, precisely toward the center of Earth.

Guide the string through the last hole of the 11 hole rod on the top of the tower and secure it with a axle.

Tie the end of the string to the free end of the match in your axle-stick assembly.

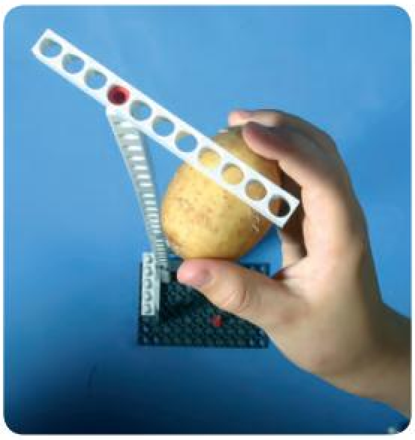
Wait until it stops swaying, then untie the axle-stick from the string and insert it into the hole in the base grid closest to the spot above which it came to rest. This is where the potato will land.

Now do Experiment 1.

Done!

Lower the string until the axle-stick almost touches the base grid.

Hold the string in place by inserting a second axle into the hole in the 11 hole rod. The axle-stick on the other end of the string should dangle just above the base grid.



EXPERIMENT 1: POTATO TRAP

You will also need: 1 wooden matchstick, 2 small raw potatoes (as round as possible, one about 3 cm (1 in) thick and other about 5 cm (2 in) thick)

First, hold the smaller potato between your thumb and forefinger beneath the last hole in the small rod at the top of the potato trap model, without it touching the assembly. If the potato is not perfectly round, turn its fat end to the bottom, so that it doesn't rotate too much as it falls. Let it go carefully, without jerking it! Did it hit the target stick? If not, try again. When you hit the stick, use the second matchstick to measure how deep of a hole you made in the potato. Make a mark on the matchstick with a sharp pencil to record the depth of the penetration of the match into the potato.

Now drop the larger potato. Measure the depth of penetration. Have you noticed something? Exactly: the fatter potato has the deeper hole.

GAME

Who has the best aim?

After the experiment, two or more players can drop their potatoes onto the spit five times each. Whoever gets the most hits, and whoever ends up with holes closest to one another, wins the game. The loser has to peel and cook the potatoes. The grand prize winner is the one whose potato is impaled two or more times in the same hole. The prize? You have to think that up for yourselves.

Potatoes and Weight

The results of this first experiment probably make complete sense to you. After all, the fatter potato is heavier. Right. But what exactly do we mean by "heavy?" If you try to stab the matchstick into the potato with your hand, you will notice that you need to use some force. And because the matchstick embedded itself in the potato when it fell, there must have been force in the falling potato too.

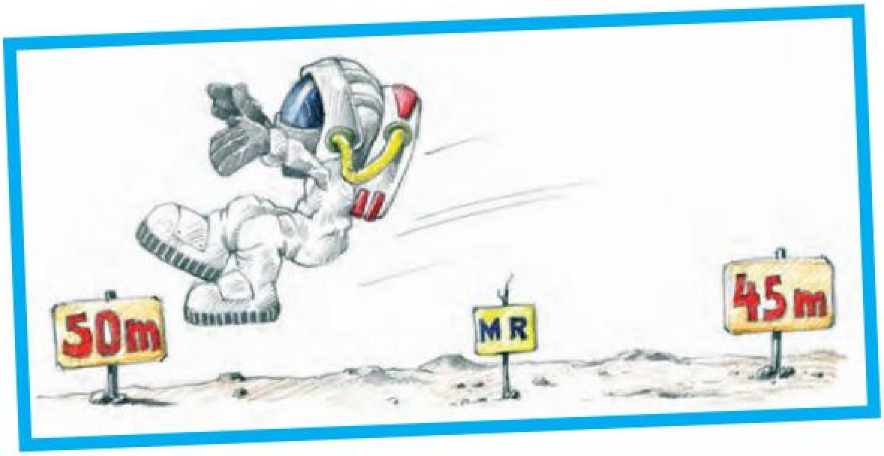
Another name for the force of gravity is **gravitational attraction**. Earth attracts or pulls on all objects with its great mass. It is this force of attraction that makes all objects "heavy," and that gives them their weight. When you hold a potato in your hand and feel its weight, you are feeling the gravitational force of Earth, which pulls the potato downward.

Mass Is Everything

Why does Earth attract things? First of all, there will always be a force of attraction between two bodies — that is a law of nature. The attraction exerted between two bodies is called **gravitation** (from Latin *gravis* = "heavy"). Earth is a powerfully large body and its force of attraction acts on all other bodies on or around it. It acts more weakly on those bodies we call "light," and more strongly on those we call "heavy." That is why the penetration hole was deeper in the larger potato than in the smaller one. The strength with which Earth attracts a body depends on its **mass**. But what exactly is meant by mass?

On the Moon

Let's touch down on the moon for a little while. We get out of the landing module and work up the courage to take our first step. As soon as we take it, we're carried along for several meters, hovering just over the surface before our foot lands. The reason: the moon has a mass one sixth that of Earth, and a gravity weaker than Earth's by that same factor. Thus, we weigh six times less on the moon than we do on Earth. But whether we are on Earth or the moon, our mass remains the same.



KEYWORD: GRAVITATION

Gravitation is a force manifested by acceleration toward each other of two free material particles or bodies.

KEYWORD: MASS

Mass is the property of a body that is a measure of its inertia and that is commonly taken as a measure of the amount of material it contains that causes it to have weight in a gravitational field.

An astronaut after the first moon landing in 1969. While the flag seems to be fluttering in the wind, in reality it is not, because there is no atmosphere on the moon and therefore no wind.

Now let's drop a hammer onto the moon's dusty surface. It falls a lot more slowly than it would on Earth — as does the dust that it kicks up when it lands. While the mass of an object remains the same on all moons and planets, its weight depends on the gravity of the celestial body it is on or near. So an object's mass makes it heavy, but to different degrees in different places.

Weightlessness

In empty space, far away from any sizeable celestial bodies, things are practically weightless. There, we would weigh almost nothing at all. The same thing would happen between two celestial bodies: Wherever their powers of attraction cancel each other out, the result is a state of weightlessness. When astronauts go there, their space ships provide them no solid ground beneath their feet, leaving them to float in mid-air. If they want to drink something, they have to suck it out of a bottle through a straw. Why? Because the liquid can't flow down into their mouths from a cup. It has no weight. But both the liquid and the astronaut drinking it have the same mass that they would have on Earth. The mass of a body is measured in **kilograms (kg)**.

Where Is it Pulling Us?

Where is Earth taking our experimental potatoes? In what direction is it pulling them? The answer: to its center. More precisely, it is pulling them towards its center of gravity or center of mass. Does Earth always pull with the same force? No, not quite. The farther we are from its center of mass, the weaker its gravitational attraction on us. Deep in a mine, its attraction is stronger than on Earth's surface, while we weigh more on Earth's surface than we do in a flying airplane. But even on the surface of Earth, there are differences. At the North or South Pole, an object is just a little bit heavier than it would be, say, at the Equator. Earth is a little flattened at the poles, and its surface there is thus a little closer to its center. These differences are so slight, however, that they "carry little weight." In any case, there is another reason why Earth's gravity is weaker at the Equator, which is that its rotation results in a greater centrifugal force there. To find out more about that, see p. 93.

Where Is the Center of Gravity?

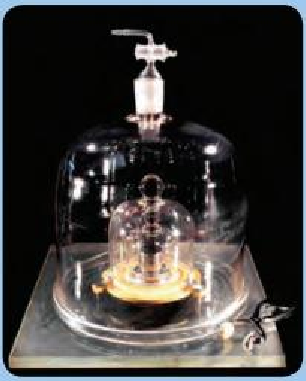
On two legs, you'll stand more safely than on one. On your hands and knees, you will be even more stable. Why? Just like Earth, any object has its **own center of gravity**, the location of which determines its equilibrium, how stable it stands, and how easily it tips. But how can you find an object's center of gravity? Let's build a center-of-gravity locator.

DID YOU KNOW?

The Kilogram Prototype

If you want to measure something, you have to have something else to compare it with, a so-called **unit of measure**. 5 kg, for example, corresponds to 5 times a 1 kg unit. The kilogram is the unit of measure for mass. In order for everyone in the entire world to be able to calibrate their scales exactly alike, they have to have a determination of a unit of 1 kg from a source that always stays the same. For over a century, that source has been the kilogram prototype kept in Paris since 1889: a cylinder made of heavy platinum-iridium metal, 39 mm high and 39 mm in diameter. For unknown reasons, however — perhaps as a result of cleaning — the prototype has lost a tiny bit of its mass.

Scientists have been looking for a different yardstick for mass, one that would be universally valid and would never change. At the moment, there are at least two candidates to replace the kilogram prototype in Paris. One possibility is to use a silicon crystal containing a precisely known quantity of atoms. Another suggestion is to use the electromagnetic force needed to balance a 1-kg object as a unit of measure. If either of these ideas is successfully developed, then perhaps the kilogram prototype can enjoy a well-deserved retirement in a museum.



A picture of the kilogram prototype kept at the Bureau International des Poids et Mesures, in Paris, France.

KEYWORD: CENTER OF GRAVITY

Center of gravity is the point at which the entire weight of a body may be considered as concentrated so that if supported at this point the body would remain in equilibrium in any position.

KEYWORD: WEIGHT

Weight is the force with which a body is attracted toward Earth or a celestial body by gravitation and which is equal to the product of the mass and the local gravitational acceleration.

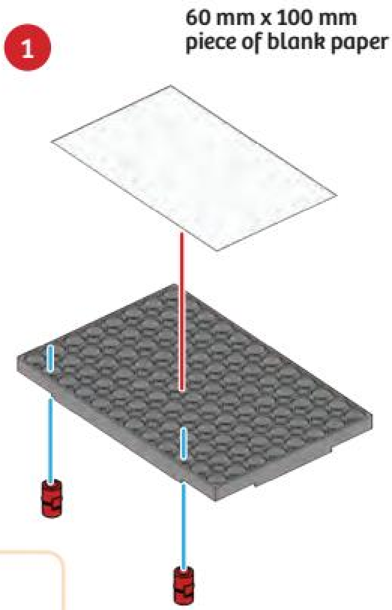
WORKSHOP 2 Center of Gravity Locator

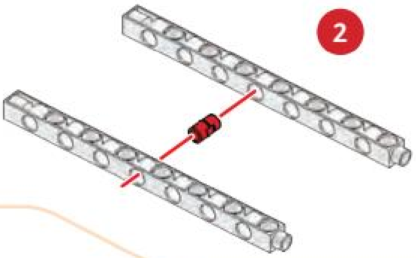
YOU WILL ALSO NEED

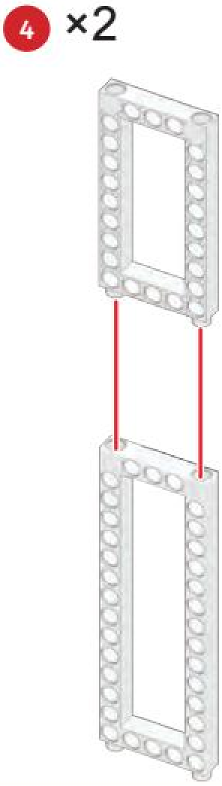
- *60 mm x 100 mm piece of blank paper*

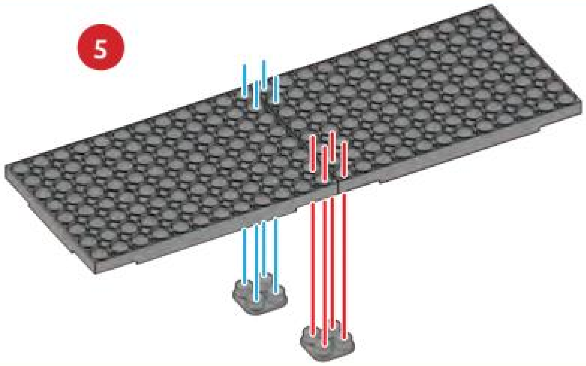
HERE'S HOW

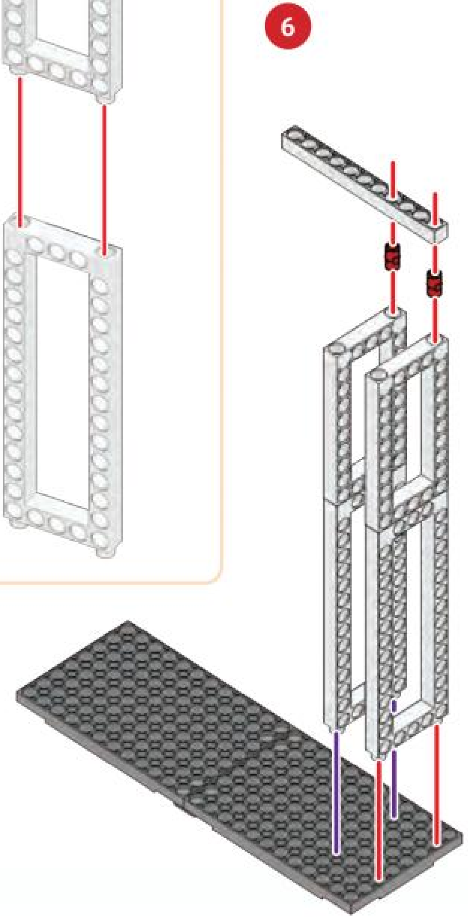
Follow the assembly steps to construct the model. Be sure that the table on which the model is sitting is level.

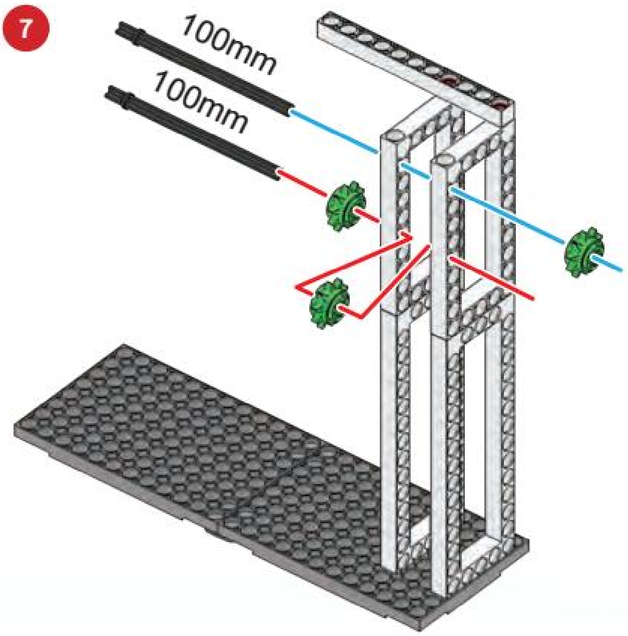












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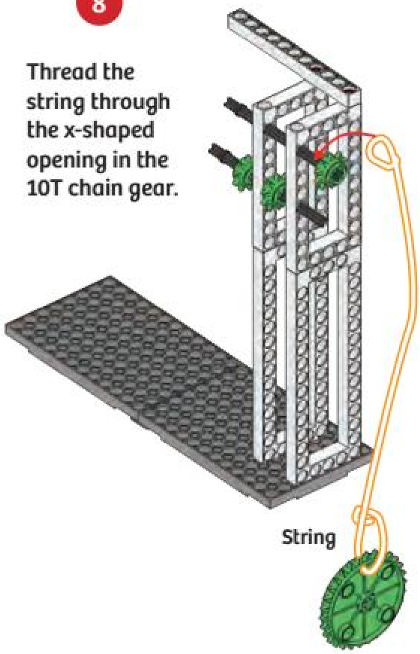
Thread the string through the x-shaped opening in the 10T chain gear.



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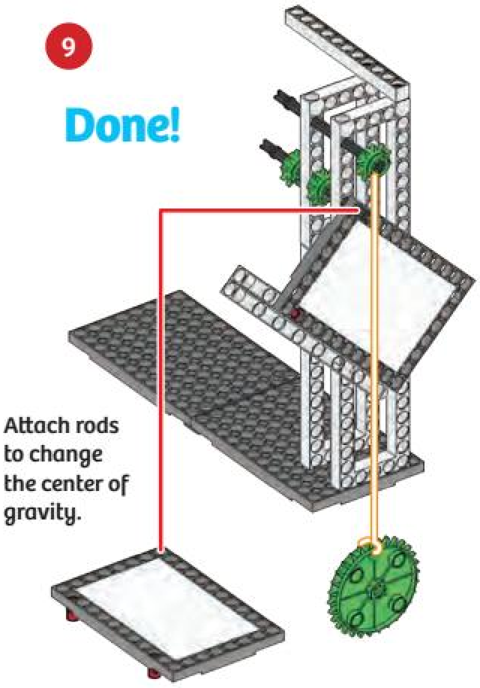
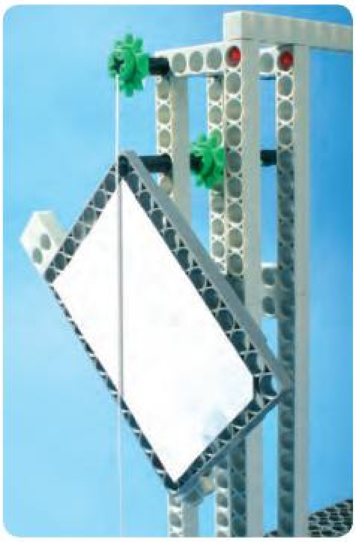
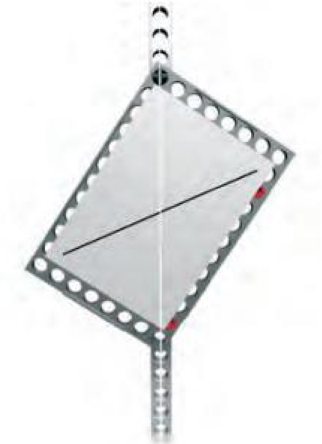
Done!

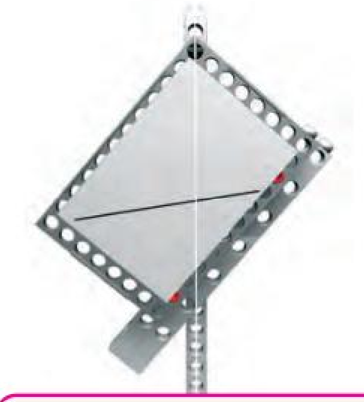


Attach rods to change the center of gravity.

The upper axle with the string may be moved forward or backward as needed. The center of gravity of the suspended base grid can be changed by attaching two long rods. See Experiment 2.







EXPERIMENT 2: FINDING YOUR CENTER

Step 1: We will use one of the base grids as the object of which we would like to determine the center of gravity. Tape a sheet of white paper to the front of the base grid. Suspend the base grid from the lower axle by one of its corner holes. It should hang freely without hitting anything. Wait until the grid stops moving and then push carefully on the axle until the grid almost touches the string. Gently press the string againstthe grid and use a felt-tip pen to mark two spots, one at the top and one lower down, where the string touches the paper taped onto the grid. Now remove the grid from its hanger, pull back the axle, and re-hang the grid from an adjacent corner hole (a different corner hole that is not the one diagonally across from the original corner hole). Repeat the procedure with the felt-tip pen. Remove the grid again and draw two lines, each connecting the pair of marks you made each time you suspended the grid. The point where the two lines cross is the grid's center of gravity.

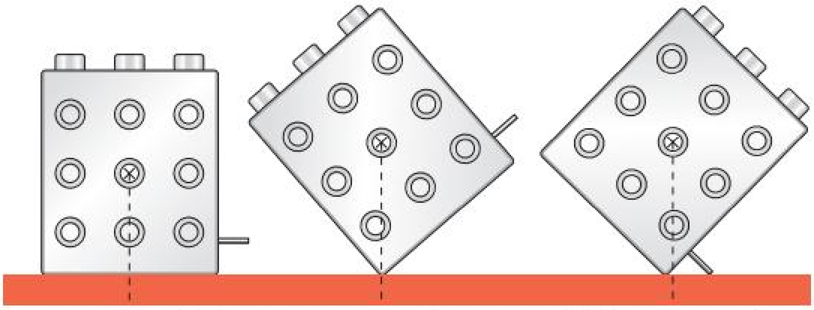
Tip: If the string gets pulled towards the grid, let it stick a little so both components can release their charge and the experimental results aren't skewed. The attraction is caused by a static electrical charge between insulating materials.

Step 2: Now let's change the object by attaching two long rods along the long edge of the grid. What do you notice? The center of gravity has moved towards the side where the two rods have been attached, or more specifically in the direction of the center of gravity of the rods themselves. Test the result by trying to balance the grid on your fingertip just at the spot where you have calculated its center of gravity to be.

KEYWORD: CENTER OF AREA

The center of area is the center of gravity projected onto the surface of an object.

In reality, what we have determined with our locator is the center of gravity on the object's surface — also known as **center of area**. In order to determine how deep the actual center of gravity lies within the three-dimensional object, we would need a more precise apparatus. In the case of the grid or the rods, this three-dimensional center would be about halfway through the object at the spot beneath its center of area.



The balance or equilibrium of the motor box (with the battery in it) is stable when it rests flat on its bottom; when it rests on its corner edge, it is unstable; and when it rests on its corner edge and shaft, it is stable again. What about when the battery is removed?

When Is a Body in Equilibrium?

It's a tricky business to try to keep your balance while sitting on top of a large ball. But it's not a problem sitting on top of a large box. There are three ways a body can be in **equilibrium**. Its state of equilibrium at any given moment depends on what would happen if it were moved. If its center of gravity were to rise, then its equilibrium is **stable**, if it were to drop, then it is **unstable** (wobbly). If its center of gravity remains at the same level when the object is moved, then its state of equilibrium is said to be **indifferent**.

When Is a Body Stable?

A body is stable if its center of gravity is located vertically above its base of support. Then, it is in a state of stable equilibrium.

If its center of gravity lies vertically above its tipping line (the edge of the base), then it will wobble or tilt. The slightest movement will make it tip over. But its steadiness will also depend on the force needed to push it off balance, as well as on the base on which it supports itself. In the case of a car, the four wheels resting onthe pavement form a rectangle. That is its base of support.

Tipping Force and Center of Gravity

An object's stability is greater if...

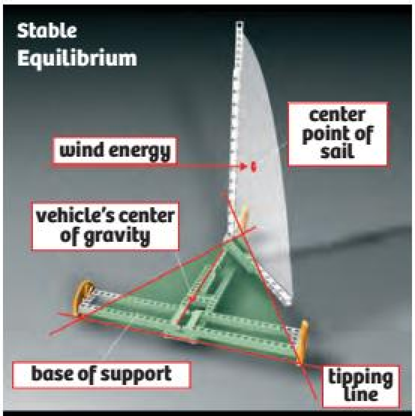
...its weight is greater.
...its base is larger.
...the force tipping it is weaker.
...its center of gravity is lower.

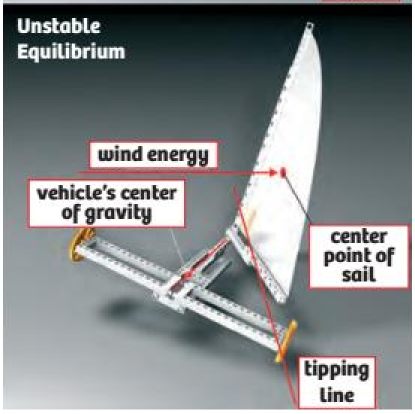
A car will be most stable as it steers through a sharp curve when its center of gravity is as low as possible and its wheels are as wide apart as possible. Then the tipping force — that is, the force trying to throw the car from the curve (the centrifugal force, see page 93) — has little chance to get the upper hand.

The four-part rule for stability also applies to other vehicles, including the sail car that you will be building yourself (instructions on page 13). In the case of a sail vehicle, the tipping force is the wind, which exerts itself against the center of the sail and tries to push the car past its tipping point.

The weight of the sail car, making its impact at the vehicle's center of gravity (located "in the air"), lies vertically above the triangular base of support and keeps the sail car on the ground — its equilibrium is stable (upper picture).

If the wind is strong, the vehicle rises up on one of its rear wheels, the base of support shrinks toward the tipping line (lower picture), and the equilibrium becomes unstable. A really strong wind will tip the vehicle over. Modern sail cars reach speeds of up to 160 km/h. But what exactly is meant by **speed**?





KEYWORD: EQUILIBRIUM

Equilibrium is the state of a body or physical system at rest or in unaccelerated motion in which the resultant of all forces acting on it is zero and the sum of all torques about any axis is zero.

Sail Car WORKSHOP 3

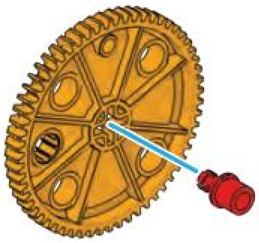
YOU WILL ALSO NEED

- *sheet of plastic (such as from a thick trash bag) for the sail, at least 330 x 240 mm*
- *wooden skewers or sticks*
- *tape*
- *sewing needle and thread*

HERE'S HOW

Follow the assembly steps to construct the model.

1 ×3



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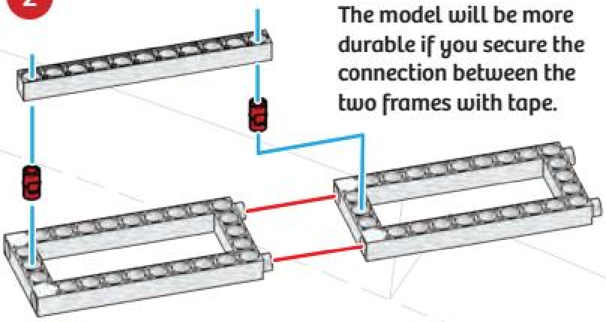
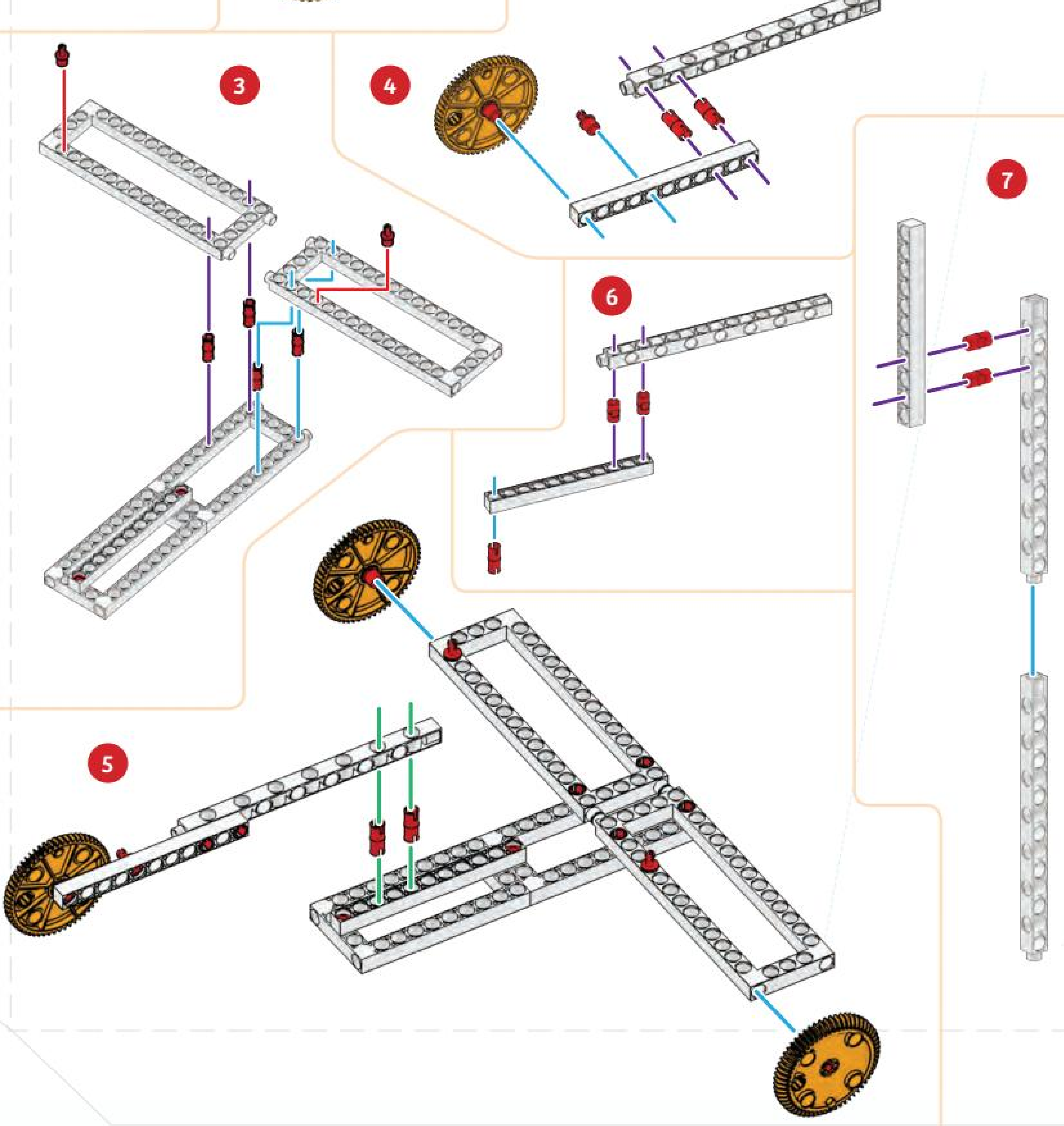


The model will be more durable if you secure the connection between the two frames with tape.



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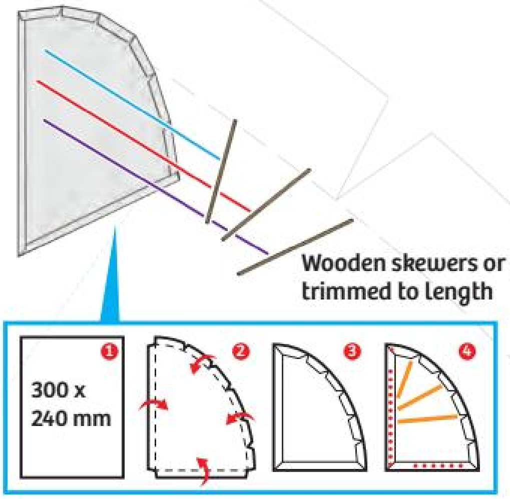


Wooden skewers or sticks, trimmed to length

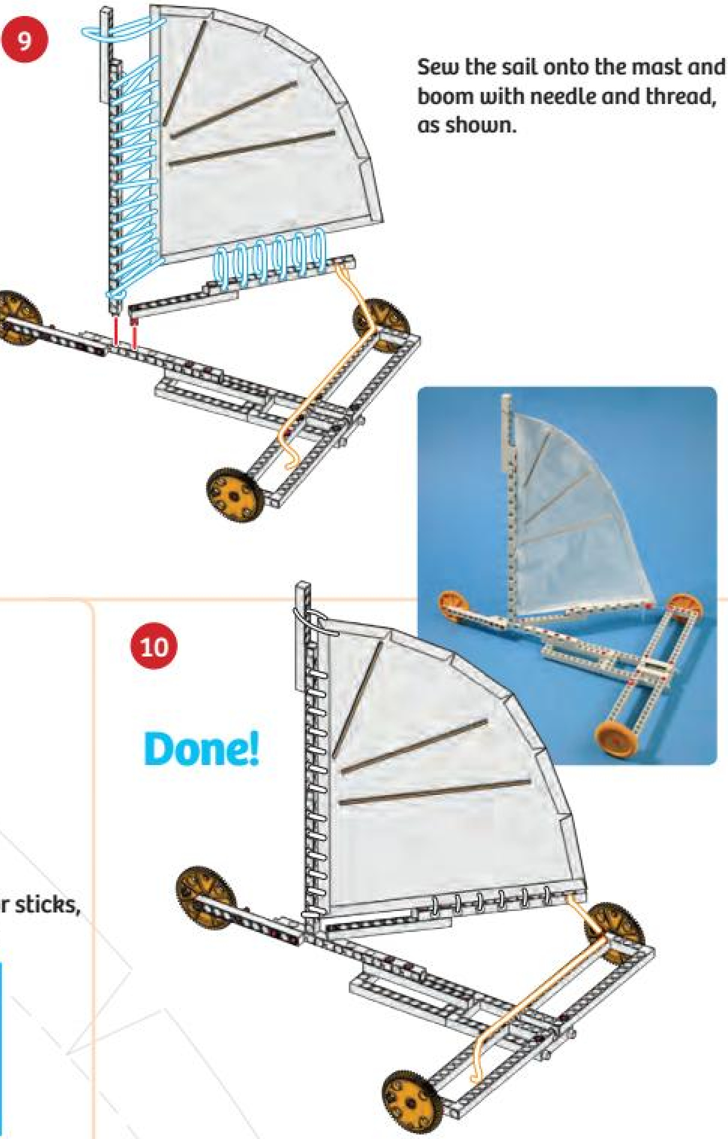
On these two pages, you can see the pattern for the sail. The solid lines indicate where to cut with scissors, the dashed lines indicate where to fold, and the blue lines show where to position the sail struts.

1. Trace the sail template onto a sheet of plastic (such as from a thick trash bag) and cut it out.

2. Fold back the plastic at the edges of the sail.

3. Secure the hems with tape.

4. Tape pre-cut sections of wooden skewers to the sail to provide it with a supporting framework.



9

Sew the sail onto the mast and boom with needle and thread, as shown.

10

Done!

Speed Is No Mystery

Remember how the potatoes fell very quickly from their starting point onto the spit in the potato experiment? How quickly did they fall? What do we mean by words like slowly and quickly, anyway? A snail creeps along at a snail's pace, while a racecar whizzes by at Indy 500 speed. What does **speed** mean? It is an indication of the number of meters an object covers in a second. We could also say it specifies distance traveled over a period of time. So it's just a matter of dividing the distance traveled by time.

What about Velocity?

Velocity is similar to speed, but it also takes into account the direction of movement, not just the rate of movement.

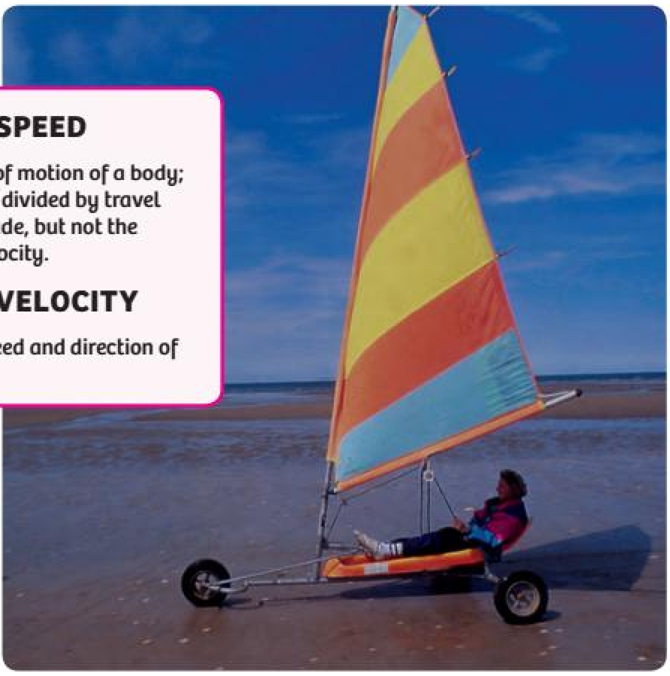
Speed = meters (m) per seconds (s) = m/s
Speed = kilometers (km) per hours (h) = km/h
Speed = miles (mi) per hour (h) = mi/h

KEYWORD: SPEED

Speed is the rate of motion of a body; distance traveled divided by travel time; the magnitude, but not the direction, of a velocity.

KEYWORD: VELOCITY

Velocity is the speed and direction of a body.



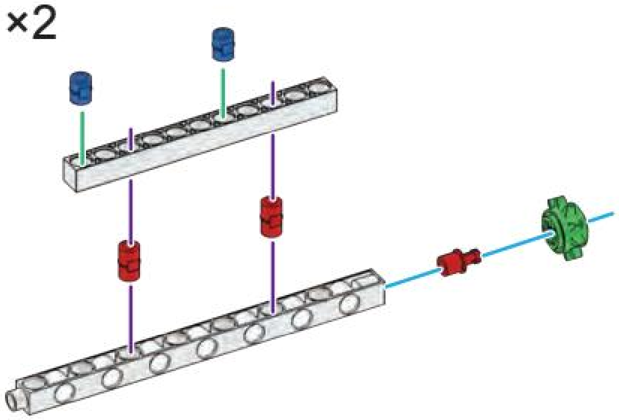
DID YOU KNOW?

The historic sail vehicle

The ancient Egyptians used vehicles that sailed on land. Three thousand seven hundred years ago, the Qigong people drove sail-powered transport wagons 20,000 kilometers across the Chinese steppe. Around 1600, the Dutch inventor Simon Stevin's sailing chariot "Wonder of the Hague" reached a speed of 33.5 km/h. The first steam locomotives were already running when, in 1853, the Windwagon Transport Company of Kansas City hoisted sails onto train cars. Up until the sixties, a sail car called "Aunt Anne" provided public transportation in Germany. Today, sail vehicles are mostly used for sport and entertainment.

WORKSHOP 4: ALL-TERRAIN VEHICLE WITH TREADS

1 ×2



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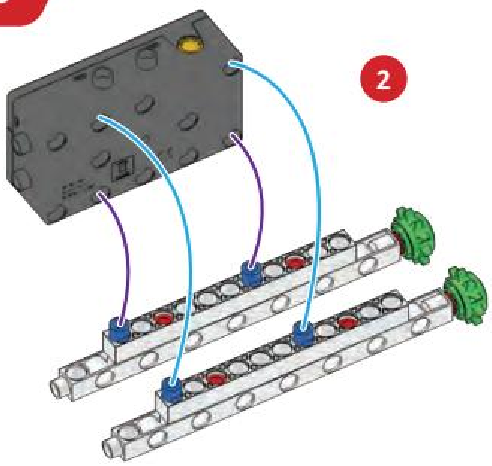

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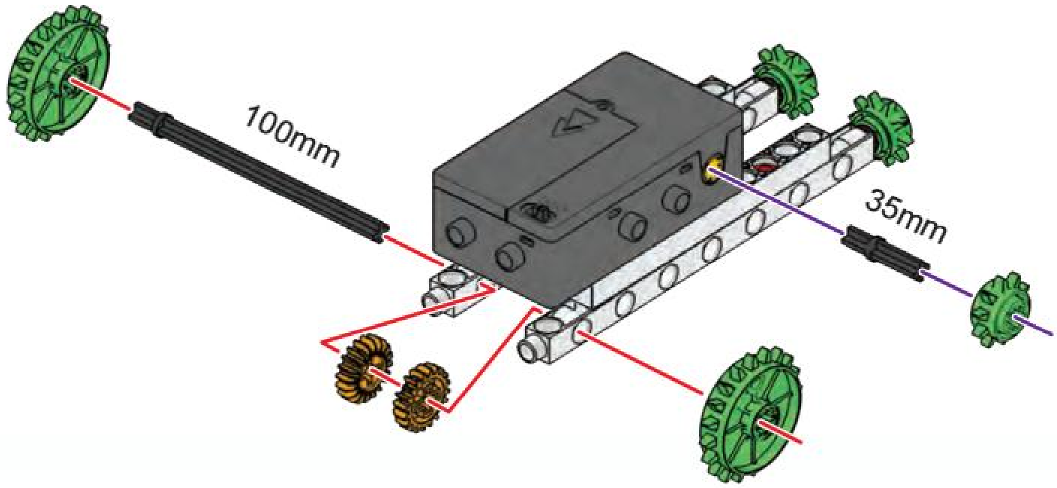

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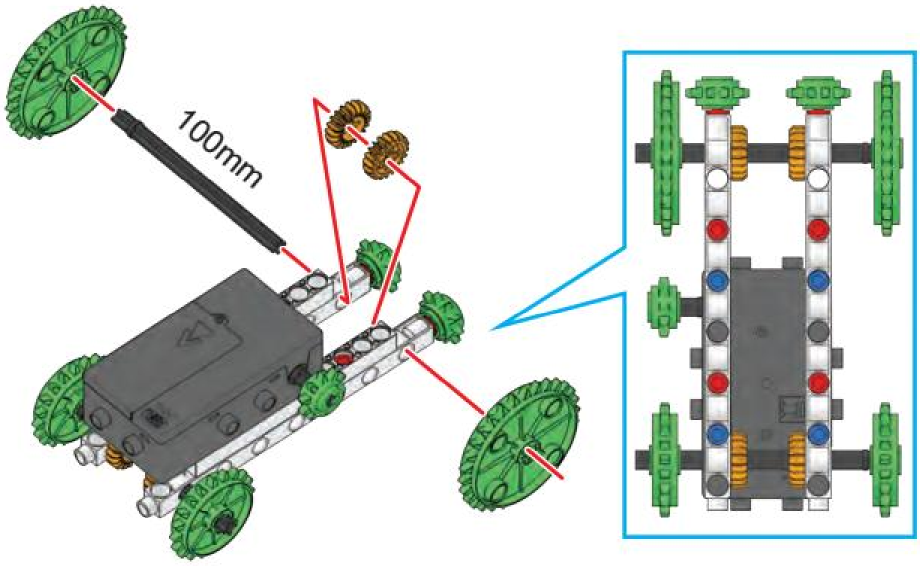

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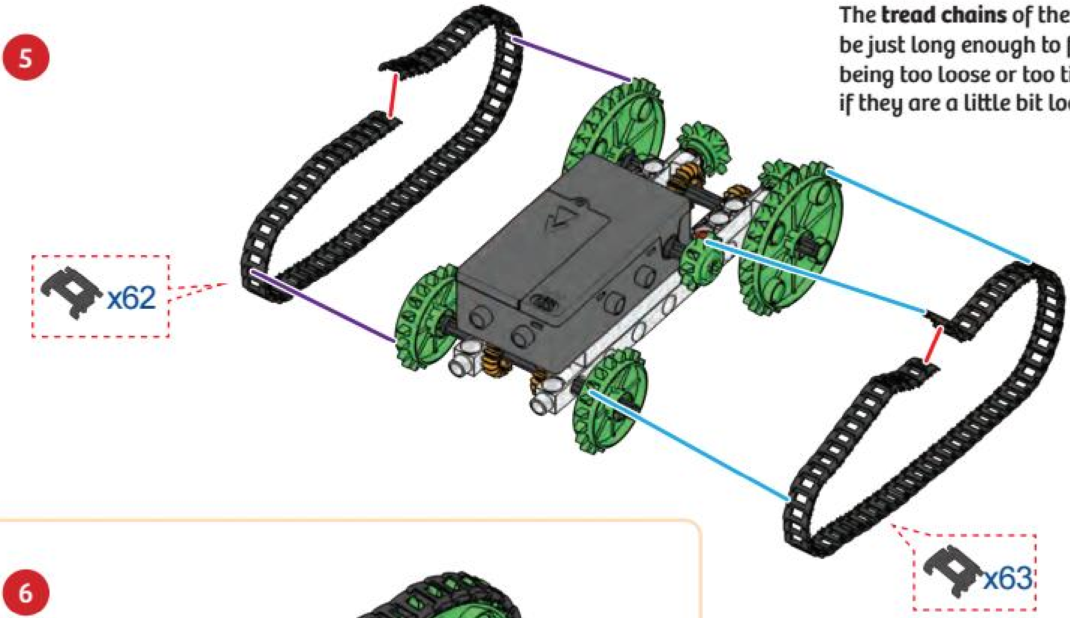
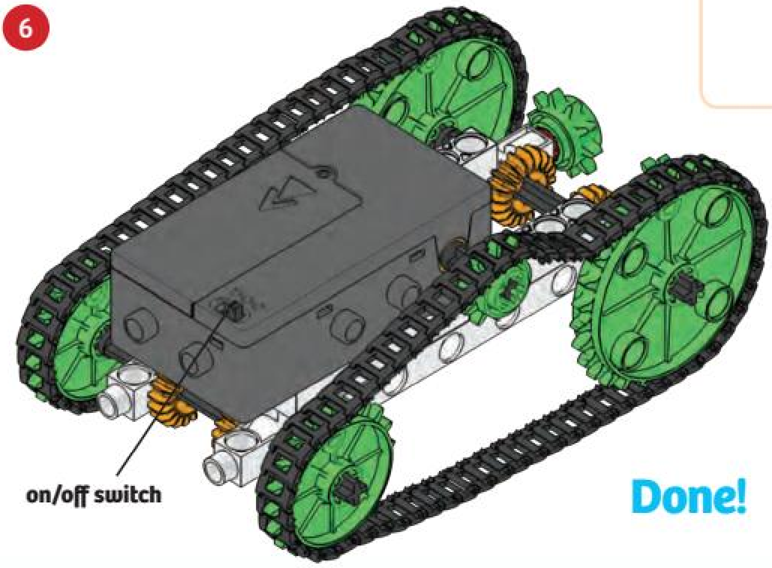


The **tread chains** of the vehicle should be just long enough to fit without being too loose or too tight. It is okay if they are a little bit loose.

6



The on/off switch lets you run the vehicle forward or in reverse.

Done!

Now try Experiment 3.

DID YOU KNOW?

What goes the fastest?

Pedestrian:	5 km/h
Bicyclist:	20 km/h
Skydiver w/ Parachute:	20 km/h
Blue whale:	27 km/h
Common Swift (a Swallow-like bird):	160 km/h
Amtrak Acela train:	250 km/h
Formula One racecar, top speed:	362 km/h
High-speed French TGV train:	300 km/h
Passenger jet:	900 km/h
Sound:	1,195 km/h
Jet car on land, top speed:	1,227 km/h
Saturn V space rocket on the way to the moon:	40,000 km/h
Earth on its orbit around the Sun:	107,208 km/h

EXPERIMENT 3: ALL-TERRAIN VEHICLE TIME TEST

Now we will find out how fast our **all-terrain vehicle** goes. Find a room with a long stretch of open floor. Place a pencil on the floor at one end as your starting line. Have a second pencil ready for the finish line. Get a watch with a second hand, switch the motor to the forward mode, wait until the second hand is just before 12, and then set down the vehicle so its "headlights" are even with the starting line. Follow it as it drives along, keeping one eye on the watch. As soon as it has driven for 10 seconds, lay down your second pencil to mark the spot it has reached. Then measure the distance with a tape measure or ruler, and write it down.

If your vehicle goes, say, a distance of 6 meters (m) in 10 seconds (s), then in 1 second it goes exactly 6 meters divided by 10 seconds = 0.6 m/s (or 60 cm/s). Now for the speed in terms of hours: One hour equals 3,600 s. So in one hour the vehicle goes 3,600 x 0.6 m = 2.16 km. Its speed is therefore 2.16 km/h. That may not seem very fast, since a person can walk about 5 km in an hour. But your model, which is just 18 cm long, moves three times its own length each second! If a real vehicle 4 meters in length were to do that, it would have to go 13 m/s, or (multiplying x 3,600) 36 km/h. That's about 22 miles per hour. For a treaded vehicle, that's quite a brisk pace!

How Fast Does the Chain Gear Fall?

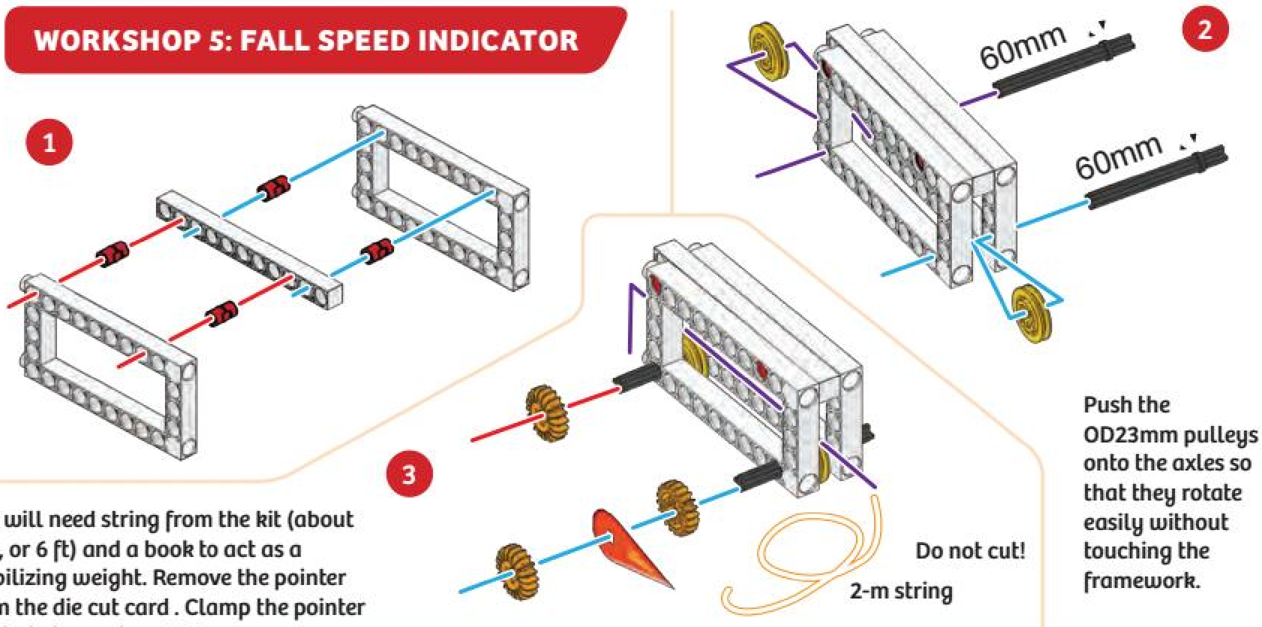
When something falls, it falls towards Earth's center. But how fast does an object fall? Always at the same speed, right? That's what we will investigate right now.

EXPERIMENT 4: FALL TIME

Take one of the 30T chain gear and drop it onto the ground. The drop may last about 0.5 seconds. Not much of an experiment, was it? Read on ...

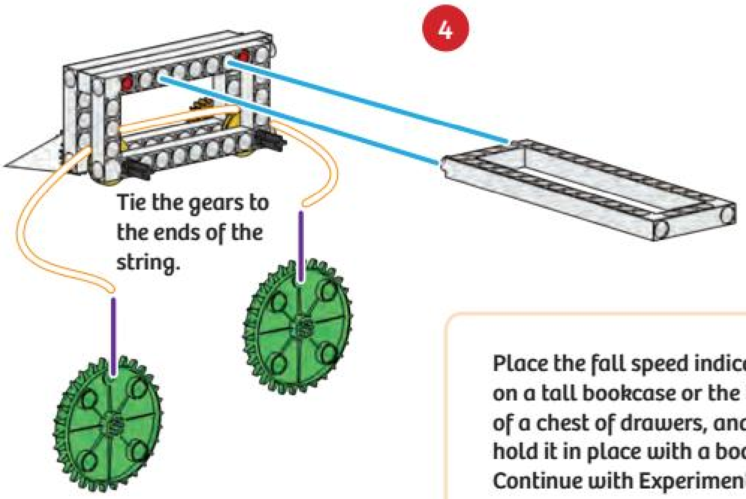
Half a second passes too quickly for us to be able to observe the drop very precisely. We need more time. For that purpose, we will construct a **fall speed indicator** that can slow down the chain gear's descent. The indicator has a string that runs over two rollers. We will suspend weights from the two ends of the string. Of course, under normal circumstances nothing falls to the ground over rollers. But apart from friction on the rollers (you will read more about friction starting on page 42), the weight of the object is not altered, just turned around. Something that normally falls will be pulled upward in the next two experiments.

WORKSHOP 5: FALL SPEED INDICATOR



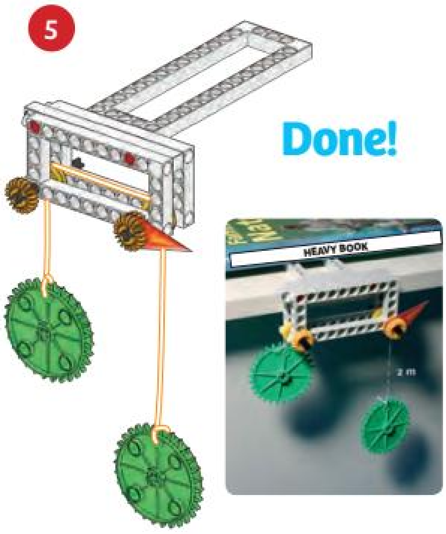
You will need string from the kit (about 2 m, or 6 ft) and a book to act as a stabilizing weight. Remove the pointer from the die cut card . Clamp the pointer firmly between two 20T gears.

Push the OD23mm pulleys onto the axles so that they rotate easily without touching the framework.



Tie the gears to the ends of the string.

Place the fall speed indicator on a tall bookcase or the top of a chest of drawers, and hold it in place with a book. Continue with Experiment 5.



Done!

EXPERIMENT 5: WEIGHT = GRAVITATIONAL FORCE

Tie a 30T chain gear to one end of the string on your fall speed indicator. This will serve as our falling body. Thread the other end of the string over the **pulley** and pull the gear up until it touches the fall speed indicator assembly. Tie another **30T chain gear** to the other end of the string, and let it rest on the ground. (Do not cut off the excess string, you will still need it. Untie the knots after the experiments.) This second wheel will act as a counterweight, canceling out the weight of the first wheel.
Now let both wheels hang at whatever height you like.

Nothing happens. Once they have stopped swaying, both wheels just hang in place. It makes no difference if one hangs higher or lower than the other. They both stay still.

EXPERIMENT 6: GRAVITATIONAL FORCE INCREASES FALL SPEED

Now we will tie an additional **20T chain gear** to the second wheel. This extra wheel will play the role of gravitational force, since the "actual" gravitational force has been cancelled out by the counterweight. We have chosen a much smaller "artificial gravity" than the natural one, so that it pulls more slowly and we have the time to see what happens.
Raise the chain gear with the extra gravity wheel up until it's just under its pulley, and then let it go. If it won't move by its own force, help it along a little in order to overcome inertia and friction (see pages 21 and 42). The pulleys will first turn slowly under the string, then faster. And along with the pulleys, the pointer will turn faster and faster until it's just a blur. The single wheel playing the role of the falling body is likewise pulled up with increasing speed, since the string holding the two weights is of course also pulled faster and faster over the pulleys. And that happens despite the fact that the weights remain the same.

We have observed that a body moves faster and faster as it falls, in other words with increasing speed. It **accelerates**. When a body (uniformly) accelerates, then the distance it travels per second (its speed) becomes greater every second. Mathematically, one writes acceleration with units of m/s/s or m/s^2.

What we demonstrated with our apparatus is the acceleration of falling or the acceleration of gravity. In our experiment, the body accelerated slowly. For a 2 m drop, it needed about 7 s. Without the pulleys and counterweight, and with normal gravitational force, it would have shot through that drop in about 0.7 s—

A parachute falls to Earth at about 20 km/h.

DID YOU KNOW?

Speedy Raindrops

If a raindrop were to fall through airless space from a cloud 200 m above ground, it would take about 6.5 seconds to hit Earth and land with a speed of 62 m/s, or 225 km/h. Its average speed of descent would come to 31 m/s, or 112.5 km/h, and a rain shower would quickly tear an umbrella to shreds. Because of air friction, however, which slows down the drops, the rain only falls with a harmless average speed of 25 km/h.

in other words, just one tenth of the time. Any body attracted by gravity falls with accelerating speed. On the moon, acceleration amounts to just 1.62 m/s^2.

Earth's gravitational acceleration or increase in speed, by contrast, amounts to 9.81 m/s every second that it falls. Expressed differently: the distance a body falls per second increases by 9.81 m every second. That means that after one second the speed a body falls is 9.81 m/s, and after two seconds its speed is an extra 9.81 m/s, or 19.62 m/s. After three seconds, you add another 9.81 m/s to get 29.43 m/s. Earth's gravitational acceleration is the same for all bodies, regardless of how heavy they are. This acceleration formula applied to your potatoes from Experiment 1. However, the acceleration formula does not take into consideration air resistance, so it only really applies in airless space. Air does, in fact, slow down an object's fall.

How Do You Measure Force?

We now know what mass is and how to measure it. We learned a little about weight and the way it is elicited by the gravitational force of Earth. And in our fall speed experiment we learned what acceleration is. So we have learned about all the pieces that make up the definition of the unit of **force**. That unit is called the **newton**, abbreviated "N."

One newton is the force required to accelerate a mass of 1 kilogram (1 kg) to a speed of 1 meter per second (1 m/s) in a second. Expressed differently: 1 N is the force that gives the mass of 1 kg the acceleration of 1 m/s^2. We can measure this force with our Force Scale. First, we will assemble one for larger forces.

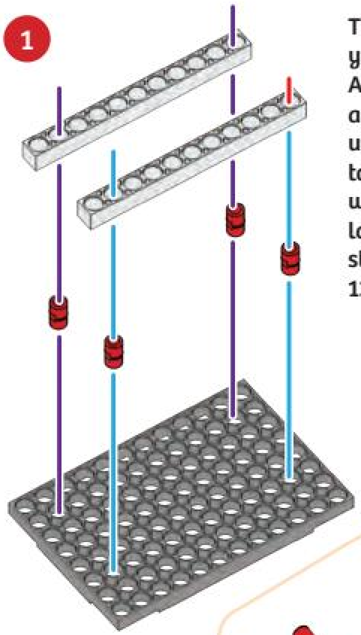
KEYWORD: FORCE

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

$$1\,\mathrm{N} = 1\,\mathrm{kg} \times 1\,\mathrm{m} / 1\,\mathrm{s} / 1\,\mathrm{s} = 1\,\mathrm{kg} \cdot \mathrm{m}/\mathrm{s}^2$$

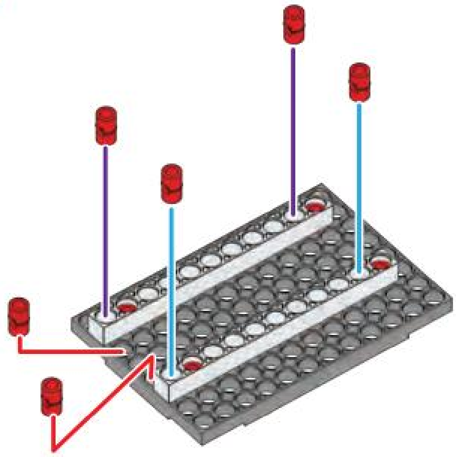
WORKSHOP 6: FORCE SCALE, 0 TO 7.5 NEWTONS

1



This model allows you to measure forces. Assemble the device as shown. You will use this force scale to take measurements in workshops that appear later on in this manual, starting with Workshop 13 on page 36.

2



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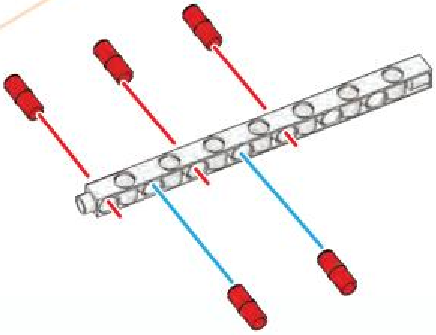
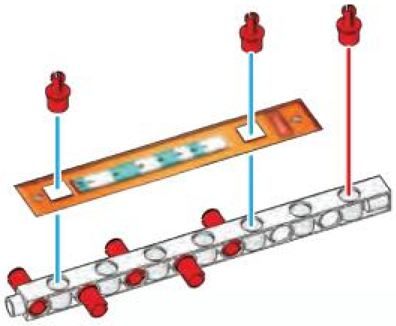
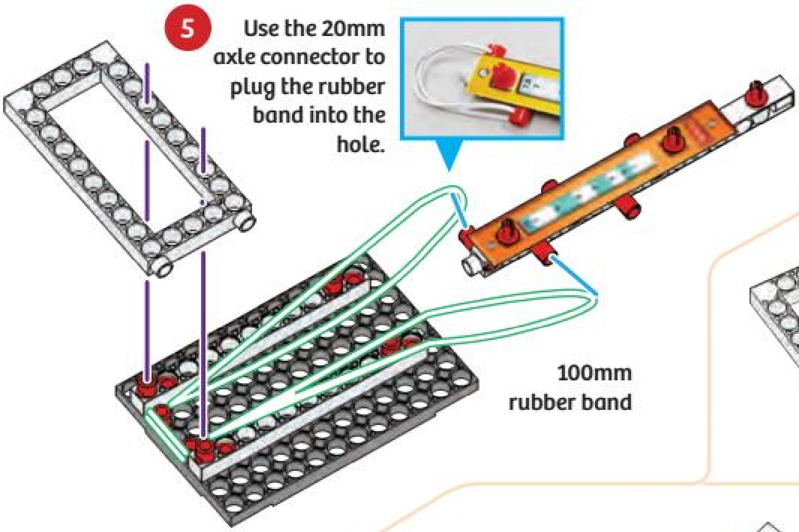


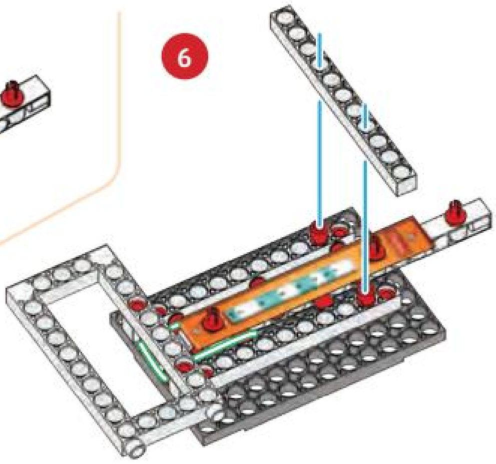
4

You will find the newton scale on the die cut card .

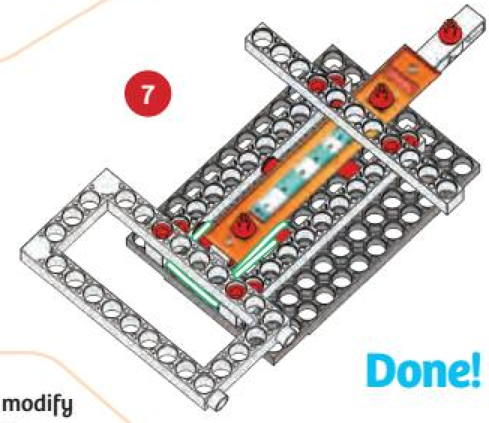




Use the 20mm axle connector to plug the rubber band into the hole.

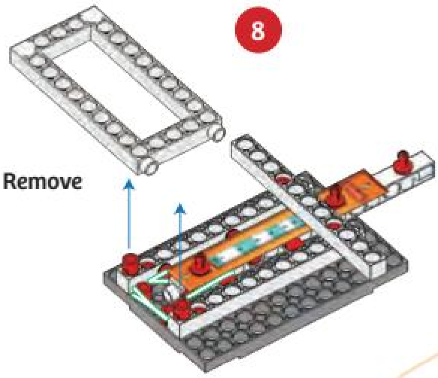


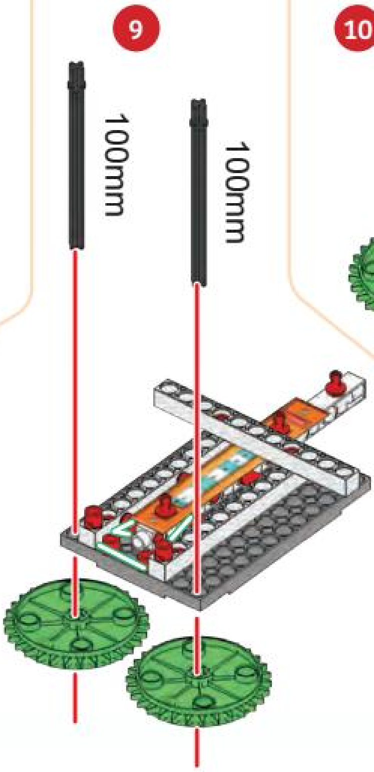
Be sure that the measuring rod moves freely centered between the guide **rods**. Do not tilt the measuring **rod** when you take your readings.

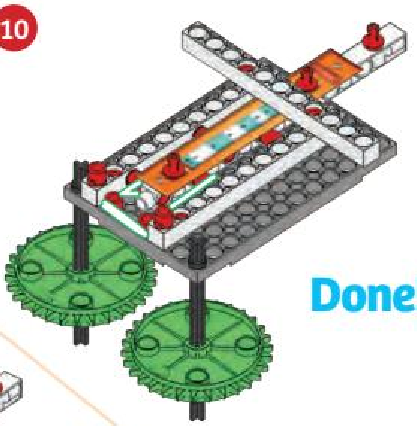


Done!

Steps 8–10 show you how to modify the force scale so that you can clamp it to the edge of a table using the 30T chain gear.





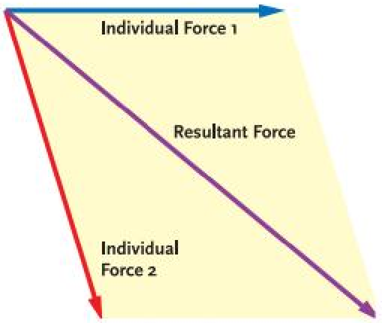


Done!

Adding Up Forces

As you know, gravity is directed toward the center of Earth. When you push open a door, your force is directed forward against the door. A force has a **magnitude** (size), but also always has a **direction** in which it acts. But if two forces of different magnitude act on the same body from different directions, what happens? The result is called the **resulting force** (or **resultant force**). It amounts to something like a compromise.

Forces of different magnitudes can be added geometrically if they are represented as arrows. The length of the arrow indicates the magnitude of the force, and the arrow's direction indicates the force's line of action. From two separate forces, a third force arises, which is the resulting force. If they act on the same location, one can add them by a parallelogram method. For each line of force, one draws a parallel line through the tip of the arrow of the other force. Where the parallel lines cross is the point where the resulting force's arrow ends.



Forces can be added with the parallelogram method.

Inert Mass and Gimbal

If left to themselves, all objects would, in fact, prefer to remain in place wherever they already are. And when they did move, they would prefer to just keep going at the same pace and in the same direction. Pretty stubborn, don't you think? These facts, which have to do with a tendency of matter called **inertia**, were described by Isaac Newton (1643-1727) in his First Law of Motion. Newton was an English natural scientist who studied forces and movement in great depth. The unit of force is named after him. In physics, a body in a state of rest is understood in terms of a state of movement. If a body's state of movement is to change, a force must be applied to it. Thus, force is the cause of any change in a state of movement. In brief: Without force, nothing changes. You can sense that yourself when you pull yourself out of a deep sleep early in the morning and have to get up, even though you still feel sluggish and totally without the energy to do so.

The next experiment will demonstrate the inertia of a body. In the experiment, a tealight candle is suspended in such a way that it moves freely on two axes. This so-called gimbal is a mounting system that is used for compasses and lanterns on boats, so that they don't sway and tip over during a sea voyage.

The English physicist, mathematician, and astronomer Sir Isaac Newton (1643-1727).

WORKSHOP 7: SHIP'S LANTERN

YOU WILL ALSO NEED

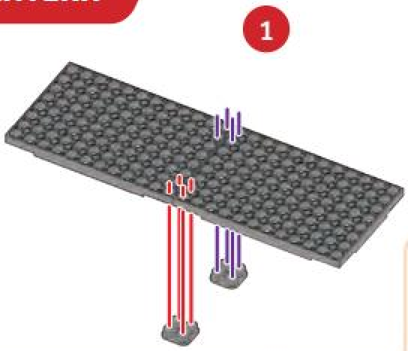
- *1 tealight votive candle*

Caution! Under no circumstances should you light the tealight — the plastic could melt!

HERE'S HOW

Follow the assembly steps to construct the model.

1



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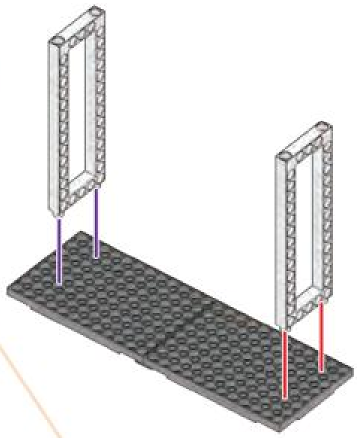

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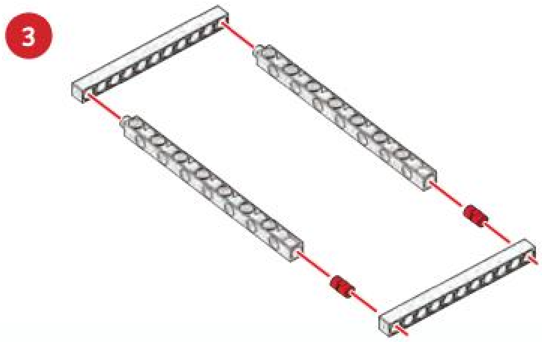

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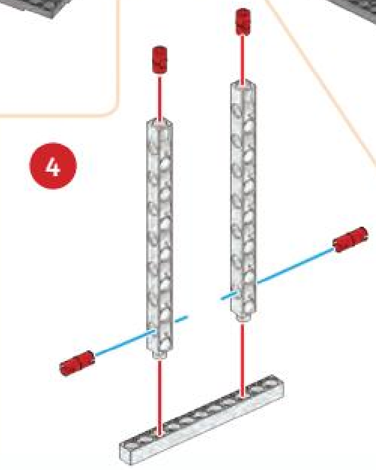

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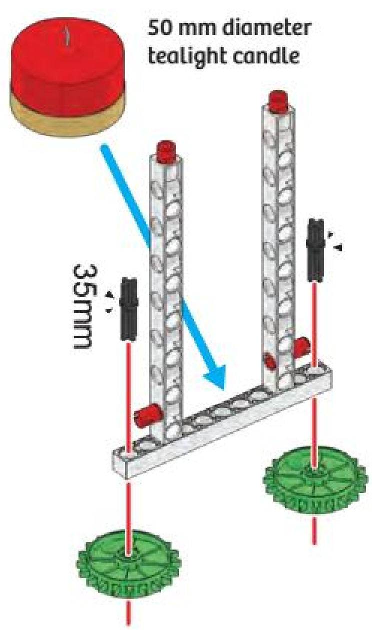
50 mm diameter tealight candle



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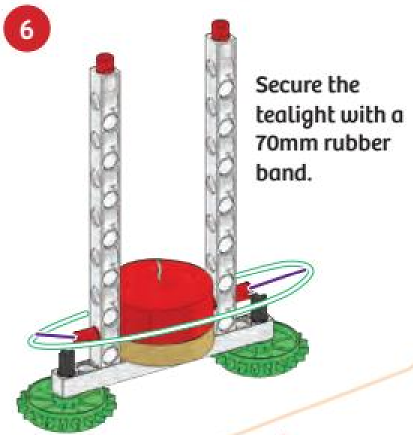
Secure the tealight with a 70mm rubber band.



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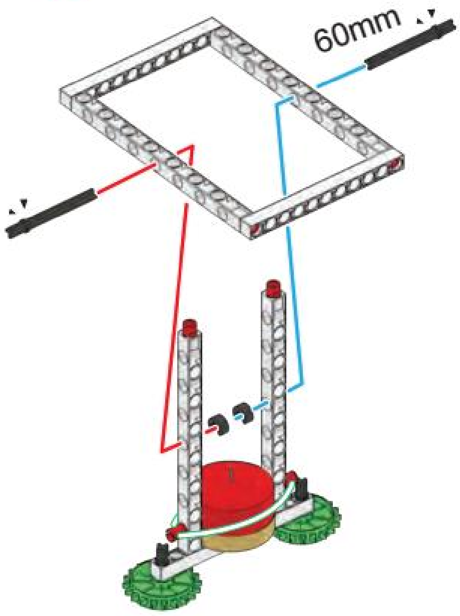

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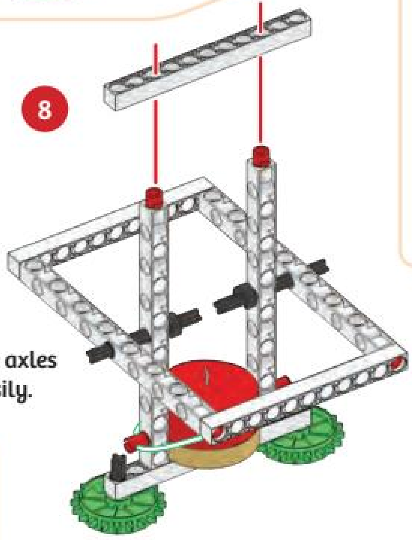
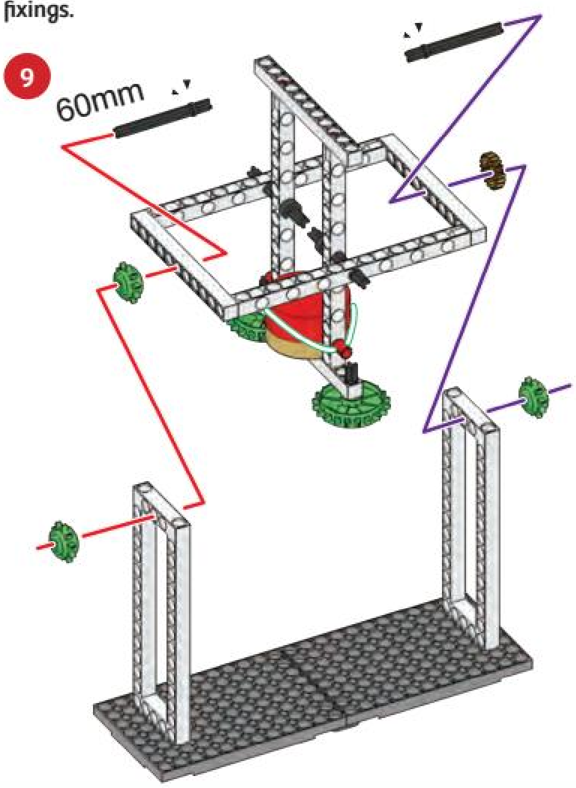


Make sure the axles can rotate easily.

Mount the lamp holder structure in such a way that the structure is positioned in the center and can rotate freely. Secure it with axle fixings.

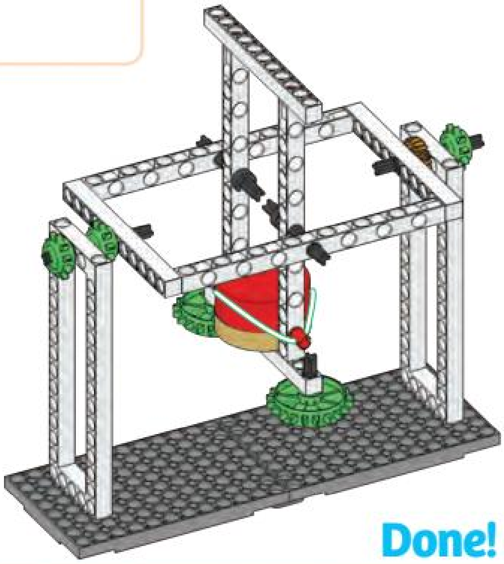
9



10

When you move the base grid, as if it were a ship riding the waves, you can easily see how stable the tealight is.

Now try Experiment 7.



Done!

KEYWORD: INERTIA

Inertia is a property of matter by which matter remains at rest or in uniform motion in the same straight line unless acted upon by some external force.

KEYWORD: GIMBAL

A gimbal is a pivoted ring mounted at right angles to one or two others to ensure that something (such as a ship's compass) always remains horizontal.

KEYWORD SUMMARY

You should not confuse these terms:

Mass is the capacity of a body to be heavy. A body's mass is the same on any celestial body and anywhere in space. Mass is indicated in kilograms (kg).

Force is the cause of a change in a body's state of movement. It is indicated in newtons (N).

Gravity is Earth's force of attraction. It applies to all objects. On celestial bodies with a greater mass than that of Earth, the force of attraction is greater, and on smaller ones it is smaller. Gravity is indicated in newtons (N).

Weight is what mass, i.e. a body, acquires when attracted by gravity. It changes when gravity changes. Weight is also indicated in newtons (N).

Speed is the distance covered in a certain amount of time. Speed is the magnitude of velocity. It is indicated in meters/second (m/s) or in kilometers/hour (km/h).

Velocity is speed plus direction. The magnitude of a body's velocity is its speed. It is also indicated in meters/second (m/s) or in kilometers/hour (km/h).

Acceleration means getting faster, in other words it refers to increasing velocity. It is indicated in meters/second/second (m/s^2).

EXPERIMENT 7: THE STEADY TEALIGHT

First, hold the apparatus so that the tealight (don't light it!) hangs in the center, where the two base grids meet. Now tilt it to one side and then to the other, then backwards and forwards and then both at once. Aside from tiny movements, the tealight stays upright. Your manipulations never really reach the candle. They just revolve around it. The tiny movements that the lantern does make are actually due to friction at the axles. This transfers a little of the force from your hands to the tealight holder.

The tealight, pulled by the force of gravity, moves into an upright position at the spot where it can be closest to the center of Earth. The lower the center of gravity of the light and its holder and the heavier the light, the more stable its equilibrium is. The tealight just stays and "hangs out" in this position. It can't be moved very easily from its resting spot. It is even pretty much held in place if you jerk its support surface out from under it.

EXPERIMENT 8: FORCES OF INERTIA

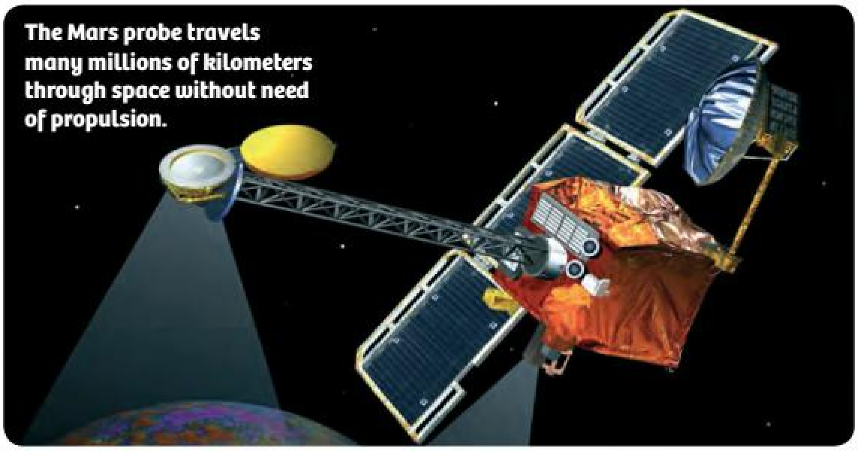
Remove the tealight from the gimbal apparatus and set it on a sheet of paper (don't light it!) on a table surface. Jerk the paper away quickly to the side. The tealight stays in place, practically undisturbed. Its force of inertia is stronger than the horizontally applied force that is transferred from your hand to the sliding paper.

Propulsion-free through Space and Time

On Earth, there are all kinds of obstacles and forms of resistance to the straight and steady forward movement of an object. The most important of these obstacles are **friction** (see p. 42) and **gravity**. Force must be continuously applied if the object's speed and direction are to be maintained. A space ship, on the other hand, projected into weightless space and brought to a certain velocity by a single initial application of force, maintains its velocity and its initially determined direction. If force is continuously applied to the vehicle, for example by a rocket engine, it moves faster and faster. If the force is increased, then its acceleration increases proportionately.

Weight Is Indicated in Newtons Too

Because weight is determined by the force of gravity, it is also a force and is indicated in newtons. What was a newton again? Gravity accelerates any given body by 9.81 m/s every second. Now, if the force of 1 newton accelerates a mass of 1 kilogram at 1 meter per second, while Earth's gravity accelerates a body by 9.81 meters a second, then the weight of one kilogram must add up to 9.81 times that — in other words, 9.81 newtons. We can therefore also use our force scale as a weight scale. If we want to measure the weight of an object in kilograms, we just have to divide the weight indicated in newtons (N) by about 10 (or more precisely by 9.81).



The Mars probe travels many millions of kilometers through space without need of propulsion.

WORKSHOP 8 Shot Put Device

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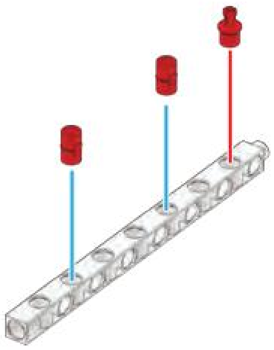

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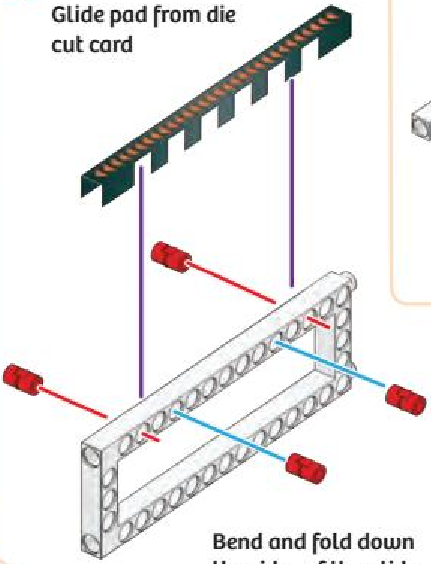
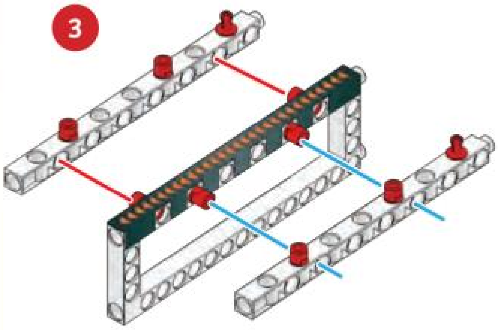
Glide pad from die cut card



Bend and fold down the sides of the glide pad and mount it as shown.

3



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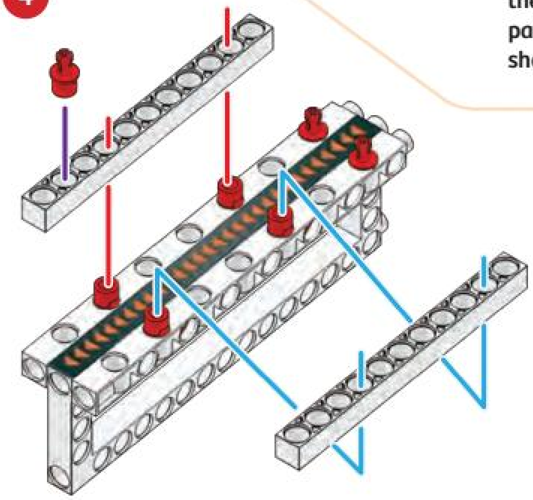

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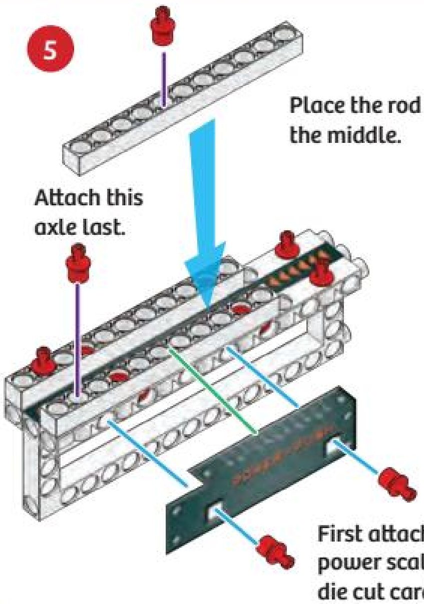


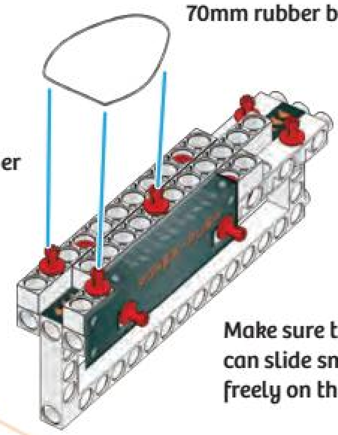
Place the rod in the middle.

Attach this axle last.

First attach the power scale from die cut card.

6

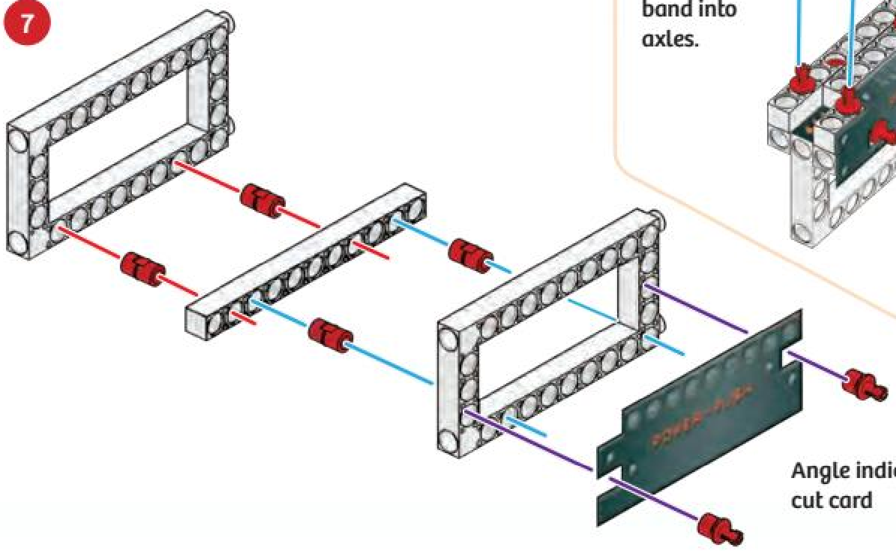
70mm rubber band



Insert rubber band into axles.

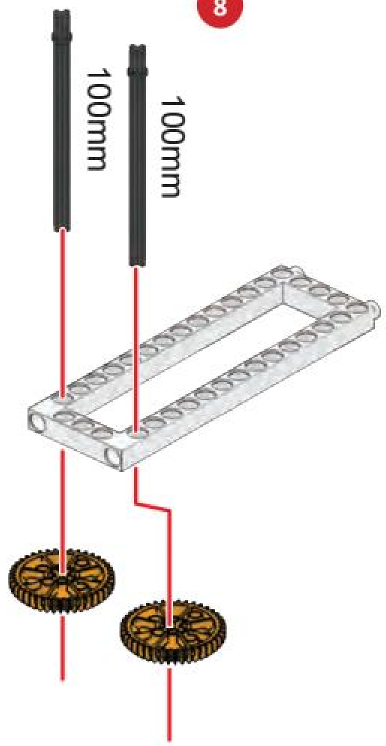
Make sure the 11 hole rod can slide smoothly and freely on the glide pad.

7



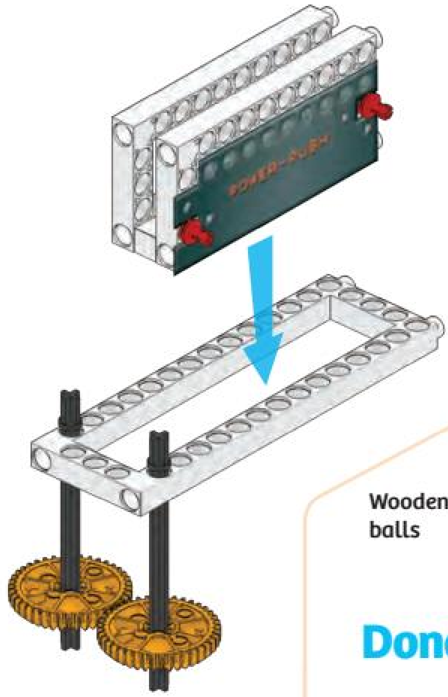
Angle indicator from die cut card

8



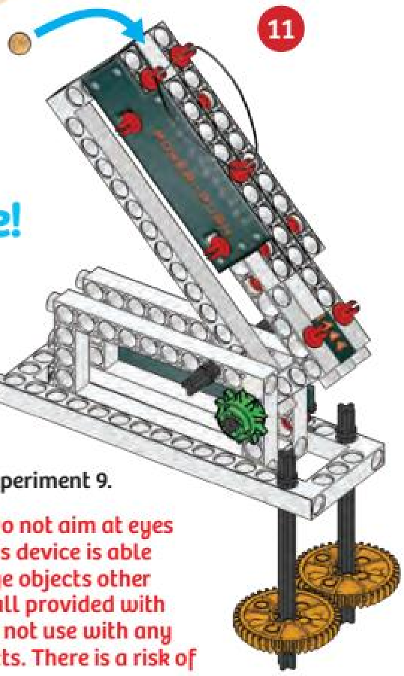
9

Place this assembly in the center of the frame.



Secure the model to a tabletop with the gears.

11

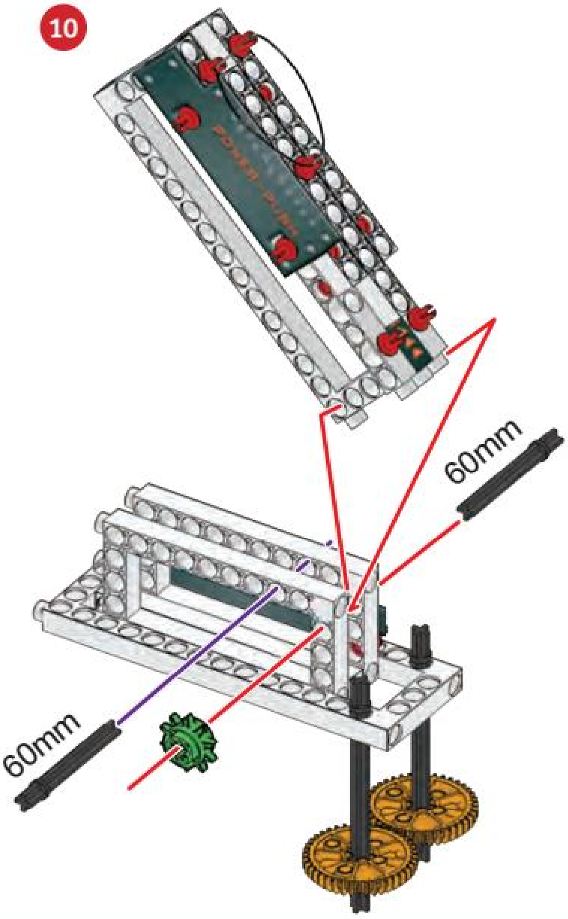


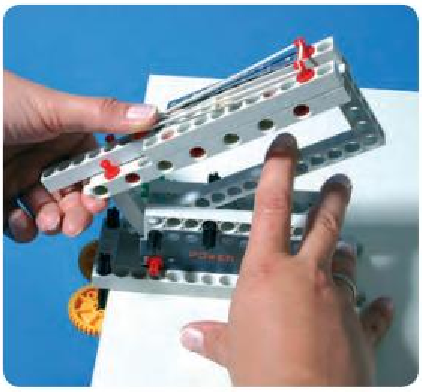
Done!

Now try Experiment 9.

Warning! Do not aim at eyes or face. This 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.

10





Instructions for shooting: Set the shooting angle by pulling up on the upper framework and inserting an axle through the hole directly above the desired degree marker. Use the power scale to determine the drive power of the shot rod when you shoot the ball. Pull the shot rod back with your thumb against the axle, until the rod's front end is at the number for the desired drive power. Drop a ball into the slot and let it roll back against the rod. As you hold the shot rod with the thumb of one hand, use your other hand to hold the framework steady. Finally, release your thumb quickly and cleanly. Check every once in a while to be sure that the slot's side rods are still firmly attached.

This crossbow designed by the Renaissance genius Leonardo da Vinci (1452-1519) worked on the same principle as our shot put machine. Deciding factors when making a shot are angle and tension.

Who Can Shoot Farthest?

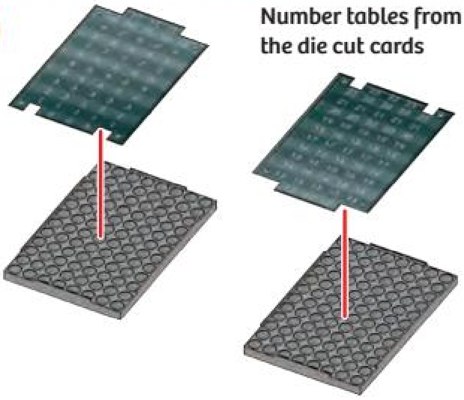
We will let you in on a little secret known by the world champion shot putters and javelin throwers: whatever you throw into the air in a high arch will inevitably fall back down again. Even the best training will not change that fact. As you know, gravity is the culprit here. And you also know that the harder you hurl a ball or stone the farther it will fly. The force with which the object leaves your hand plays an important role. If there were no gravity or air friction, your ball would fly off into space never to be seen again.

From playing ball games, you have also learned how to throw the ball in the right direction and with the right force in order for it to reach its target — your teammate or the goal, for example. Somehow, you just have an automatic feel for the ball's flight path. But how exactly? To figure it out, we will use a shot put device to shoot some balls at a numbered target board. The assembly instructions for the shot put device are on the previous page. The instructions for the target board are below.

Once your shot put device is assembled, you can practice a few shots at flat and steep angles, and with weak and strong force. If someone else is doing the shooting, you might be able to follow the flight path of the ball. After that, it's time to take some measurements with the target board.

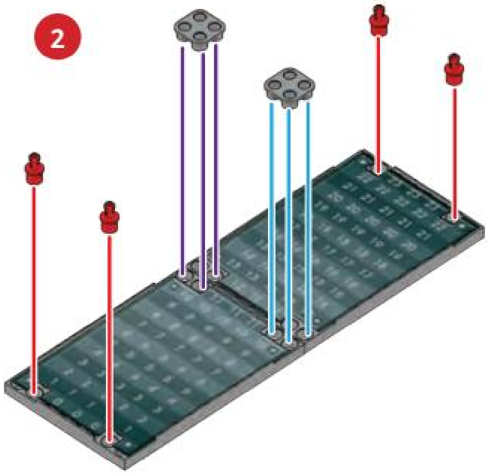
WORKSHOP 9: NUMBERED TARGET BOARD

1



Number tables from the die cut cards

2



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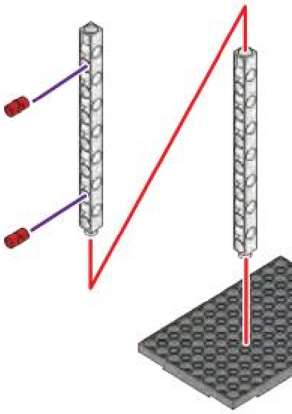

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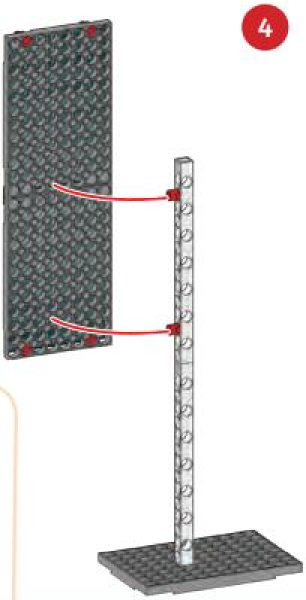

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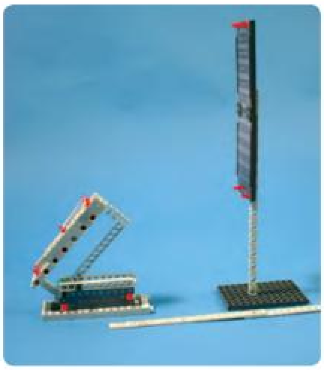


Position the shot put device so that it is aimed at the target board.

Done!

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.

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.

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

GAME

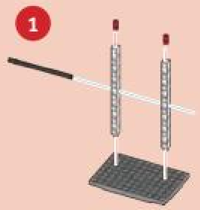
Dunkin' shot put

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.

1



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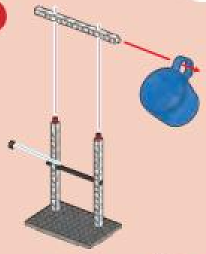

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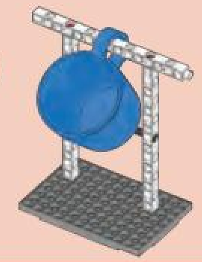


Simple Machines

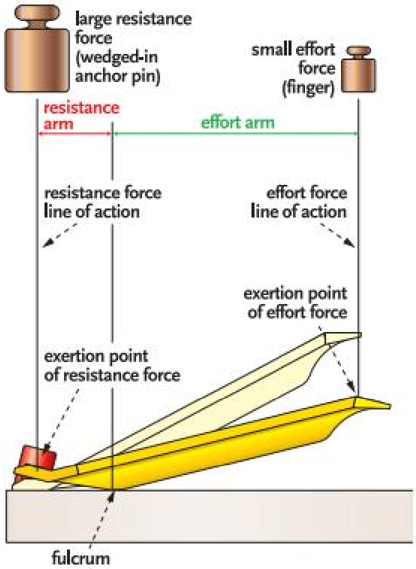
The spears and hand-axes of stone-age humans are simple machines.

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.**



effort force x effort arm = resistance force x resistance arm

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 **long pegs** and **axles** 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 long peg, 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.

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

Resistance Arm and Effort Arm

At the moment when you press on the handle with enough effort force for the long peg 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

Force Scale and Type One Lever WORKSHOP 10

❶

Tie a 200 mm piece of string to the axle.

❷

Tie the string to the other axle as shown.

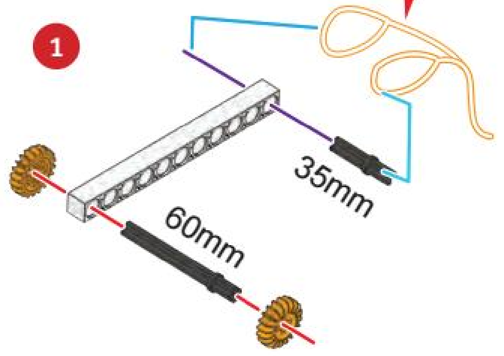
❸

Cut off the extra string.

❹

Tie a 700 mm string to the center of the loop.

1



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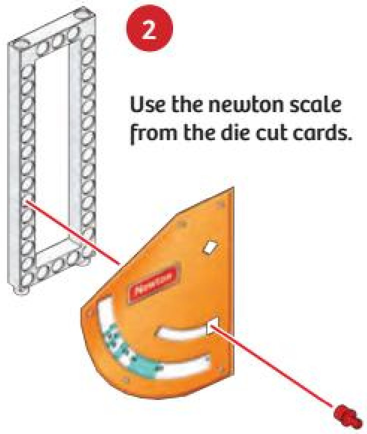
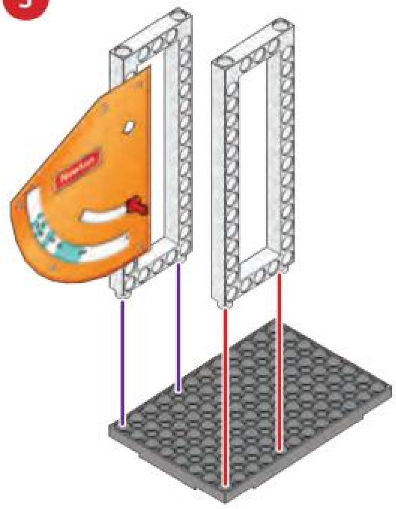


Use the newton scale from the die cut cards.

3



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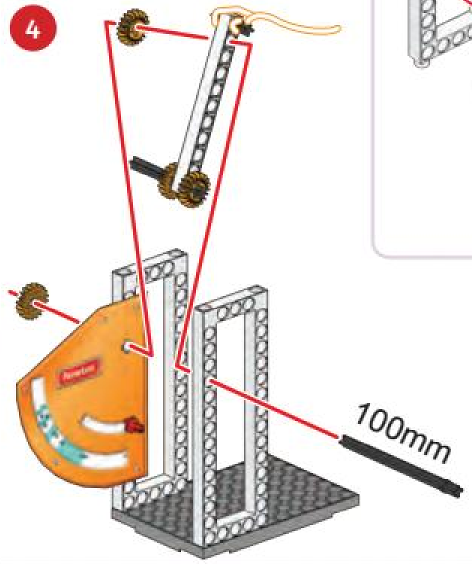

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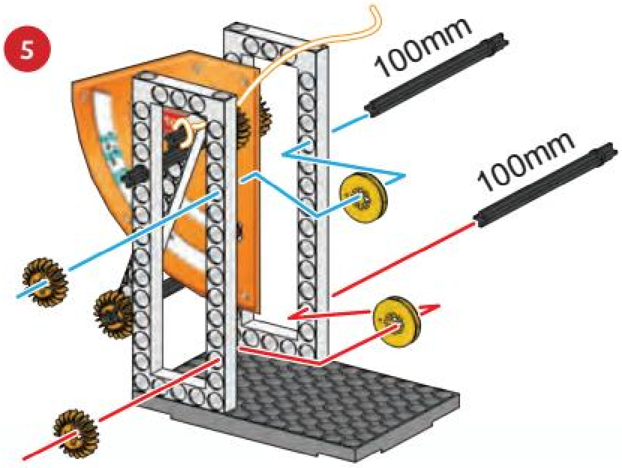

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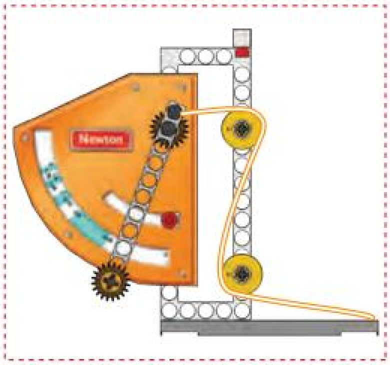

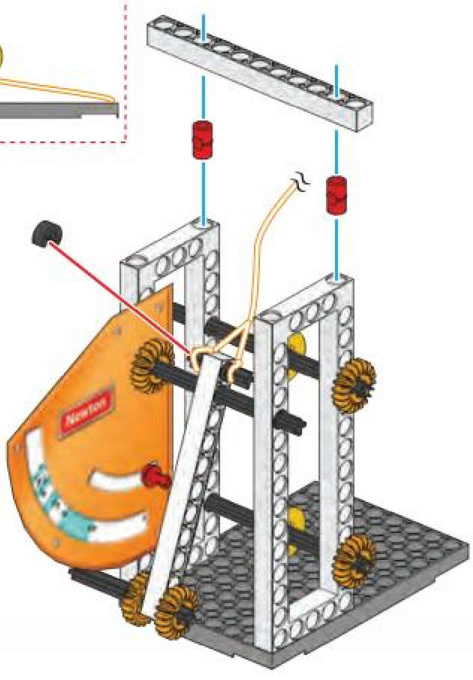

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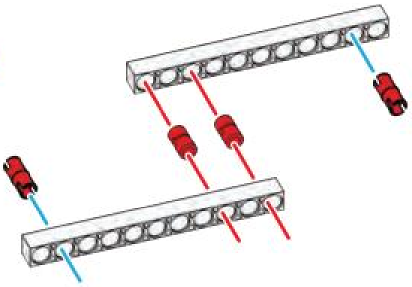

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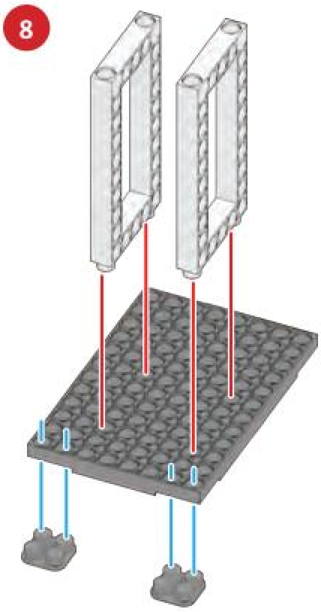

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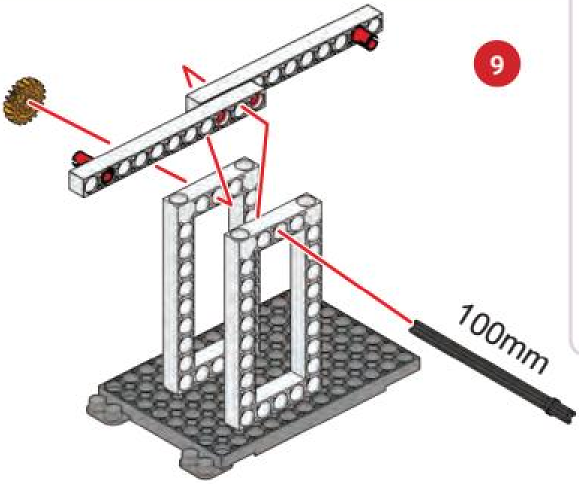
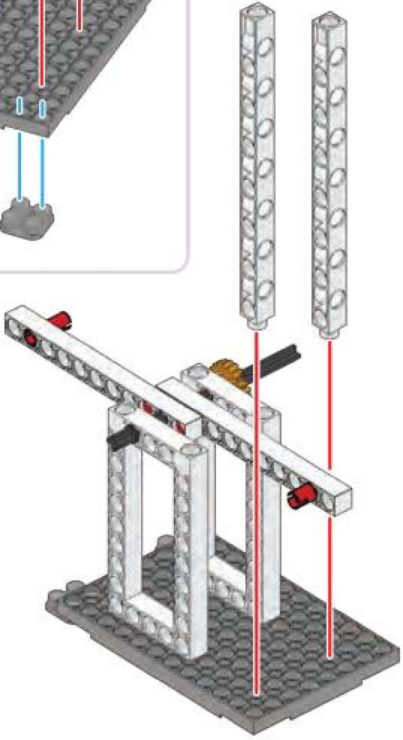
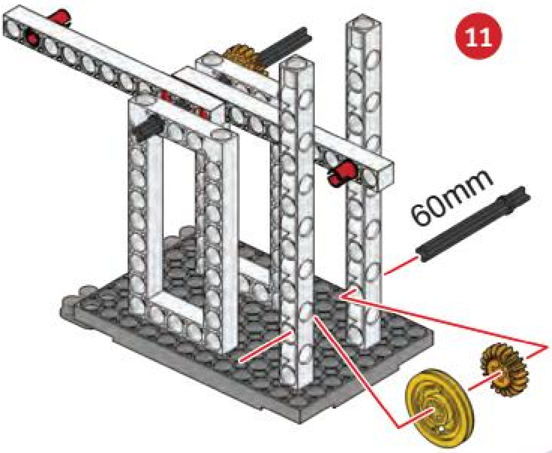

100mm

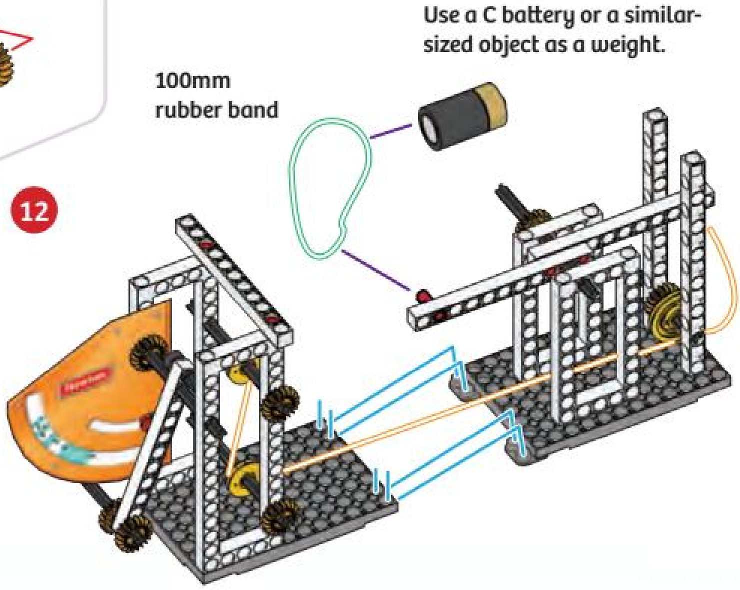
10

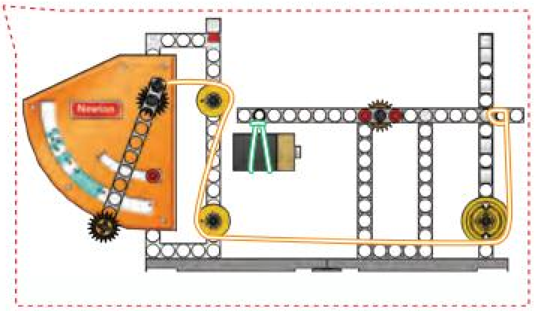


11

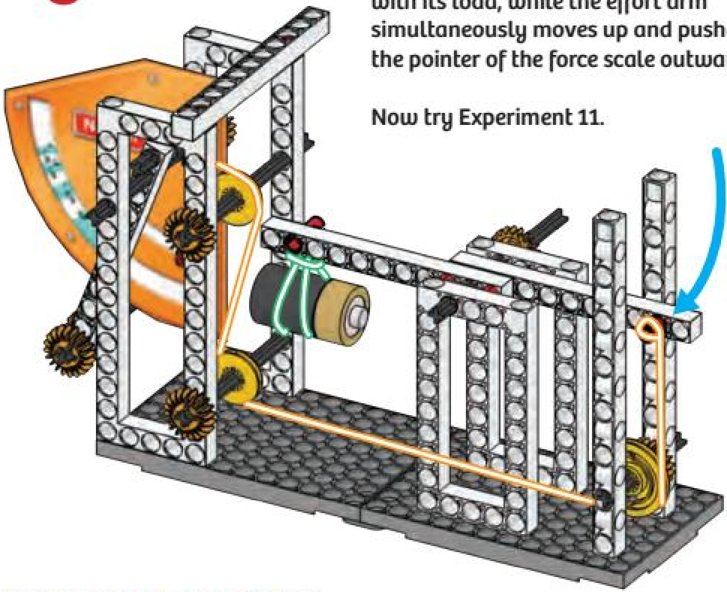

60mm

12


Use a C battery or a similar-sized object as a weight.
100mm rubber band

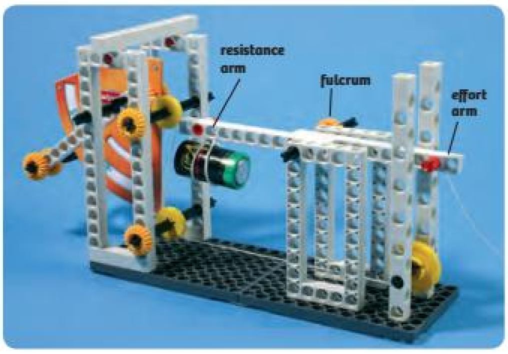

Newton

13



Because the lever pivots in the middle, the resistance arm moves downward with its load, while the effort arm simultaneously moves up and pushes the pointer of the force scale outward.

Now try Experiment 11.



Secure the end of the string with a 20mm axle connector.

Force on the Lever: Torque

Each of the two sides of the lever equation represents what is called **torque.** Torque is the product (that is, the result of a multiplication equation) of a force and the (vertical) distance of its line of action from the fulcrum. The product is expressed in newtons times meters or newton meters (Nm).

We will now measure how a lever works. First, build the force scale and a two-armed lever according to the workshop.

EXPERIMENT 11: MEASURING FORCES ON A LEVER

Insert a **20mm axle connector** into the next-to-last hole (the eighth hole from the fulcrum) on the left arm of the lever and use the **70mm rubber band** to hang the motor box **battery** from the arm to serve as the resistance load. On the opposite side, thread the end of the string through the next-to-last (eighth) hole and then insert a **20mm axle connector** here as well. Then pull the string through the hole until the lever is horizontal. The pulling force (weight) of the force scale acts on the string and counterbalances the resistance load. When the pointer of the force scale has been pushed out, balance has been achieved. The force scale can be a little sluggish, however; give the pointer a little nudge upwards and tap with your finger a few times on the base grid. Now look through the third hole of the pointer and read the value on the scale. What does it say? Depending on the kind of battery you have, it should read about 0.5 or 0.75 N. You can also use your force scale to read the corresponding weight in grams: 50 or 75 g.

The exertion points of the effort force and the resistance force are equally far from the fulcrum, namely eight holes or 8 cm. So the effort force has to equal the resistance force, since the effort arm length and resistance arm length are equal. The number you're reading off the force scale in grams is the weight of the battery.

Second experiment: Hang the battery from the fourth hole, cutting the distance from resistance force to fulcrum in half. Because that doubles the effort arm distance relative to the resistance arm, we must have saved energy. And what does the force scale show? Right! It now shows half the previous amount, about 25 or 37 N.

Calculation for "Measuring forces on a lever" experiment assuming a battery weight of 50 g.

We will use the following conversions:

centimeters to meters: 1 cm = 0.01 m

grams to kilograms: 1 g = 0.001 kg

kilogram-force to newtons: 1 kg = 9.81 N

(Here we will round up: 1 kg = 10 N)

1st Experiment:

effort side		resistance side
0.08 m x 0.5 N	=	0.08 m x 0.5 N
or 0.040 Nm	=	0.040 Nm

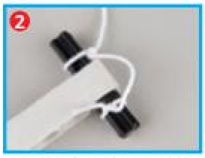
2nd Experiment:

effort side		resistance side
0.08 m x 0.25 N	=	0.04 m x 0.5 N
or 0.020 Nm	=	0.020 Nm

The torque (Nm) is the same, then, on either side of the fulcrum.

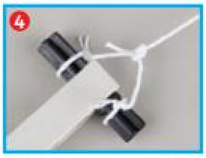
WORKSHOP 11 Force Scale and Type Two Lever

Tie a 200-mm piece of string to the axle.



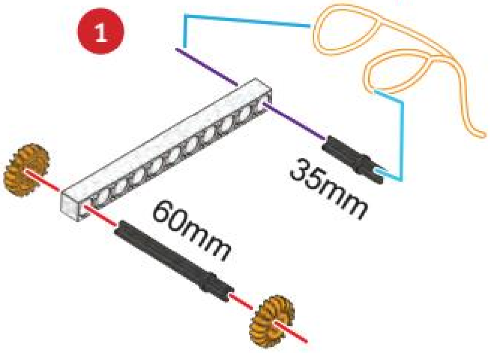
Tie the string to the other axle as shown.

Cut off the extra string.



Tie a 700-mm string to the center of the loop.

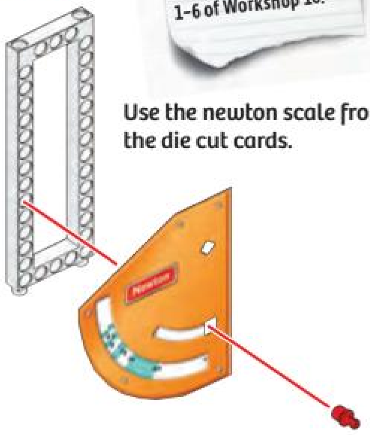
1



NOTE

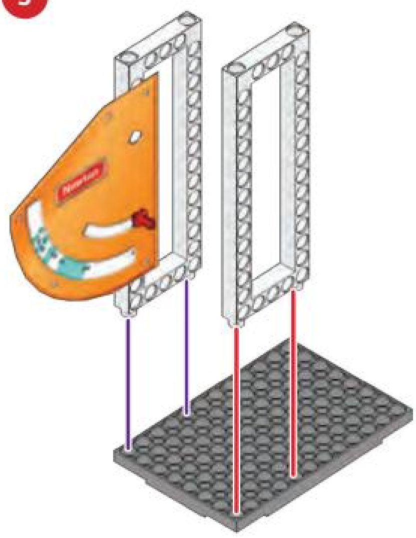
Steps 1–6 of Workshop 11 are the same as steps 1–6 of Workshop 10.

2



Use the newton scale from the die cut cards.

3



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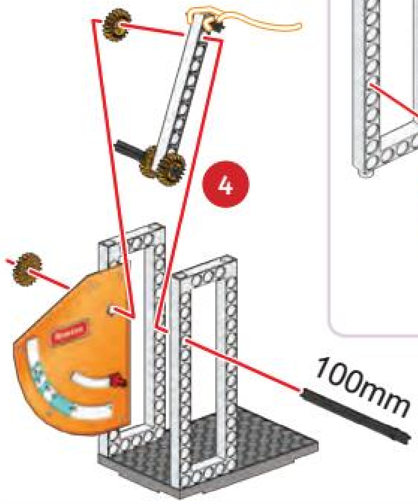

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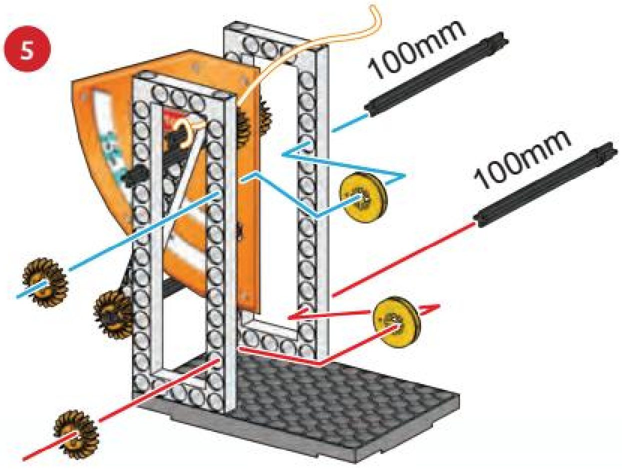

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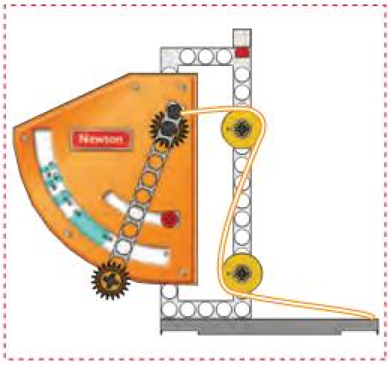

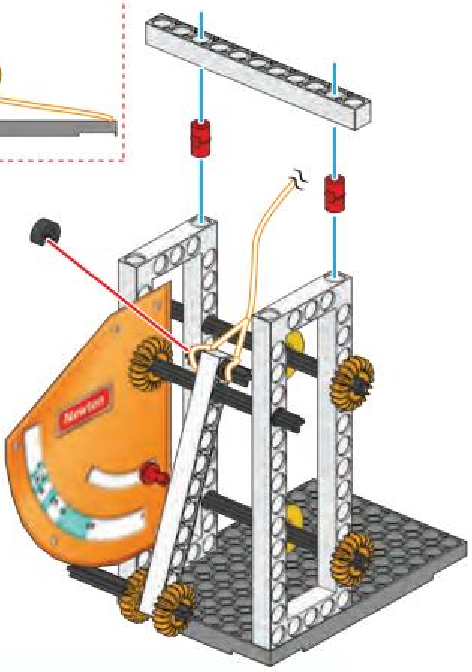

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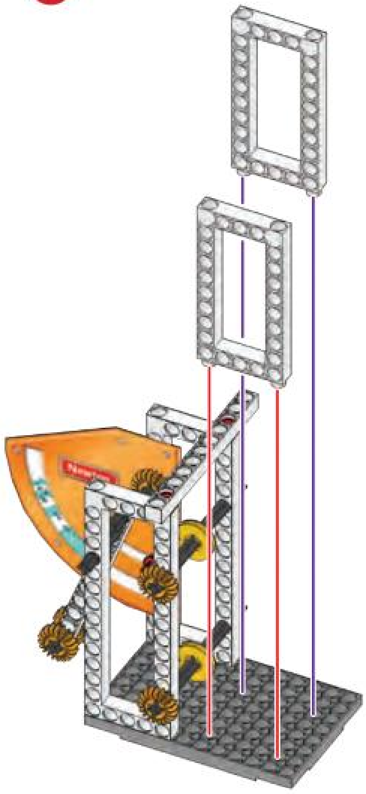

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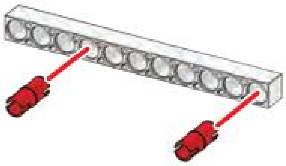

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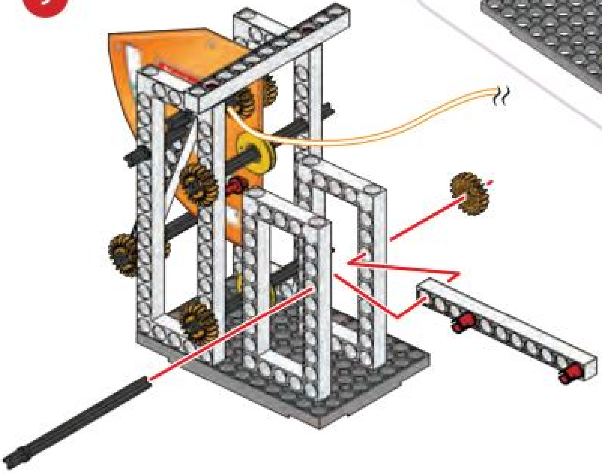

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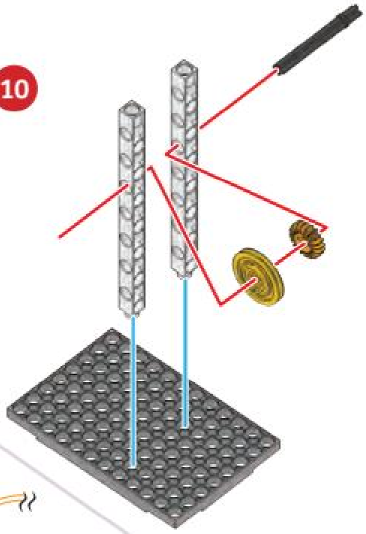

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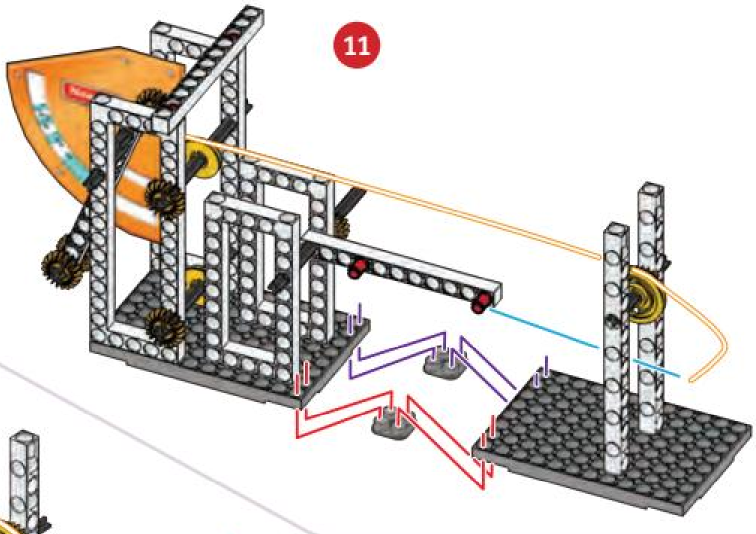

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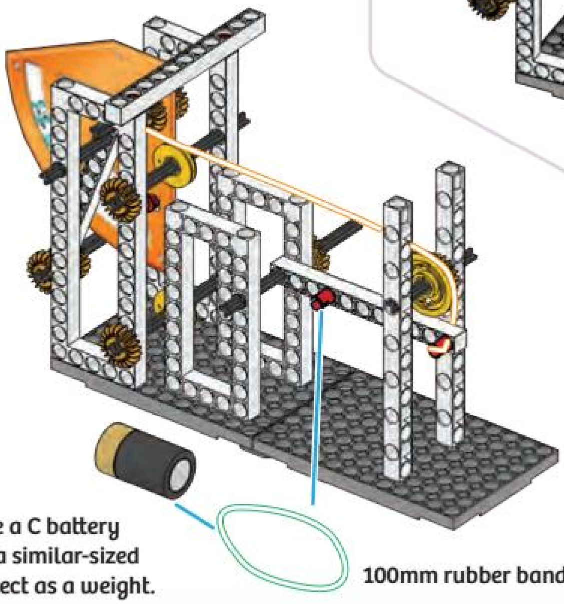
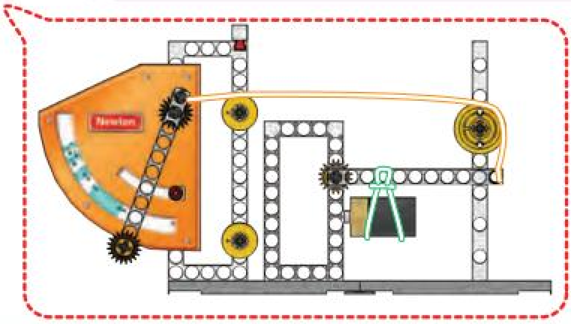


Use a C battery
or a similar-sized
object as a weight.

100mm rubber band



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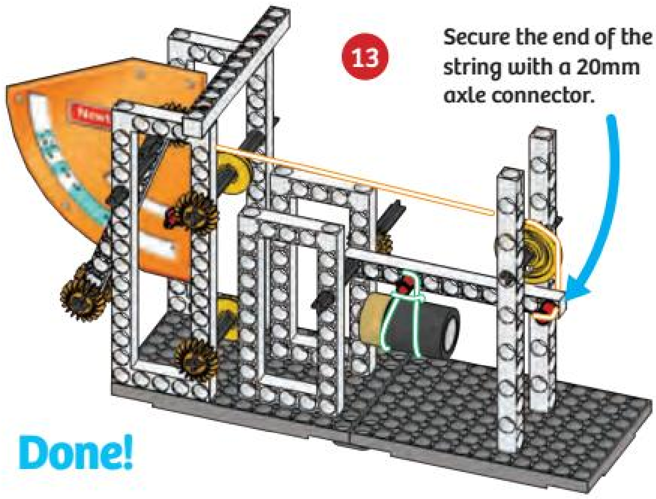
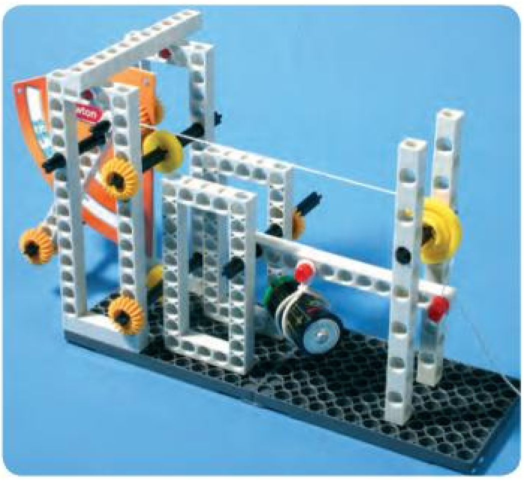


Secure the end of the string with a 20mm axle connector.

Done!



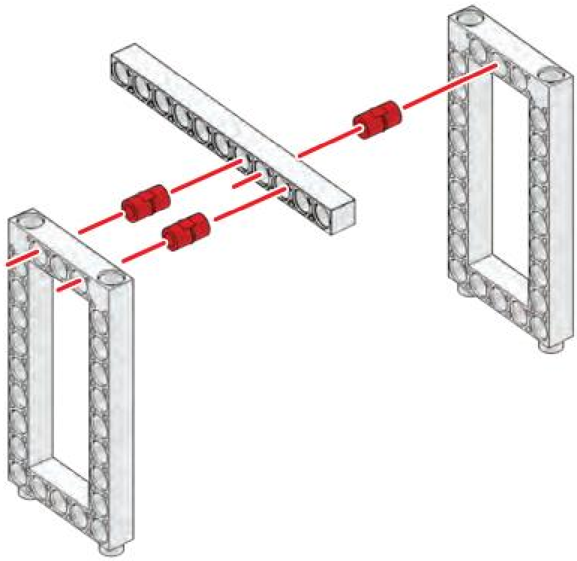
A bottle opener is a type two lever.

If you want to prove that with a one-sided lever the two torques are equal in the state of equilibrium, and that it is therefore also possible with that kind of lever to save force, you will have to alter the experimental setup a little.

Levers are all around us every day. Whether it's a door handle at home, a hand brake in the car, a wrench in the workshop, or a crowbar at a construction site, levers make work easier by reducing the effort we need to perform it. Our fingers, arms, hands, and legs obey the law of levers no less than does the seesaw on the playground. Levers are also found in places where a balance needs to be obtained, for example in postal scales. You can assemble a postal scale of your own with the workshop below. It will measure weights of up to 50 g.

WORKSHOP 12: LEVER POSTAL SCALE

1



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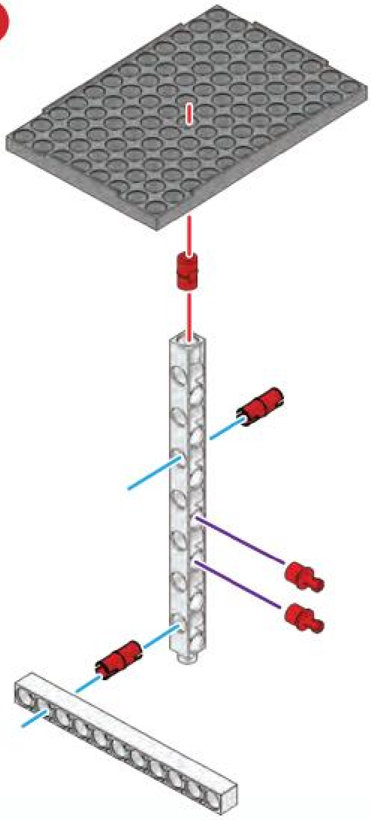
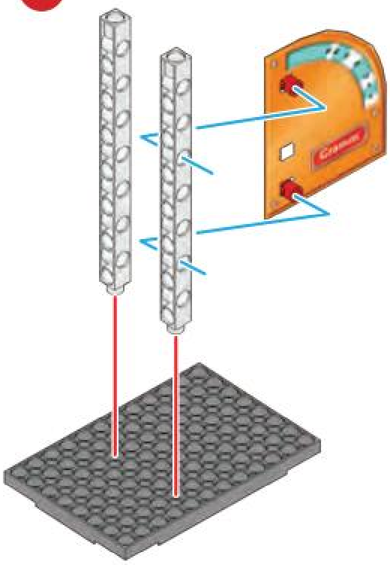


3

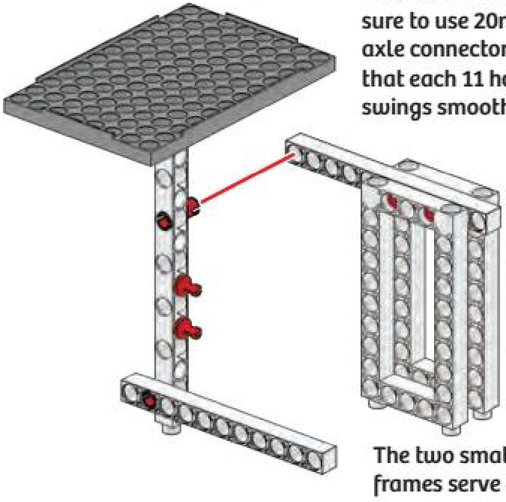
Postal scale dial from the die-cut sheets

4



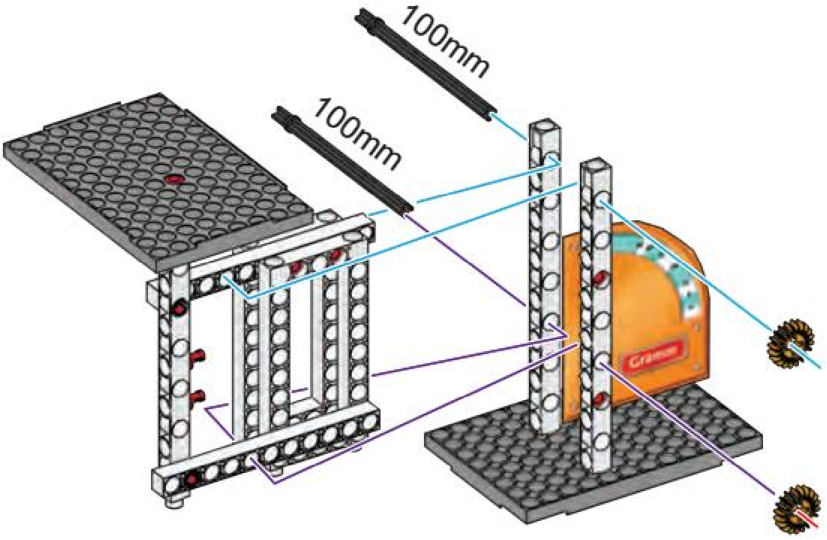
5

When attaching both 11 hole rods to the 15 hole dual rod make sure to use 20mm axle connectors so that each 11 hole rod swings smoothly.



The two small frames serve as counterweights.

6



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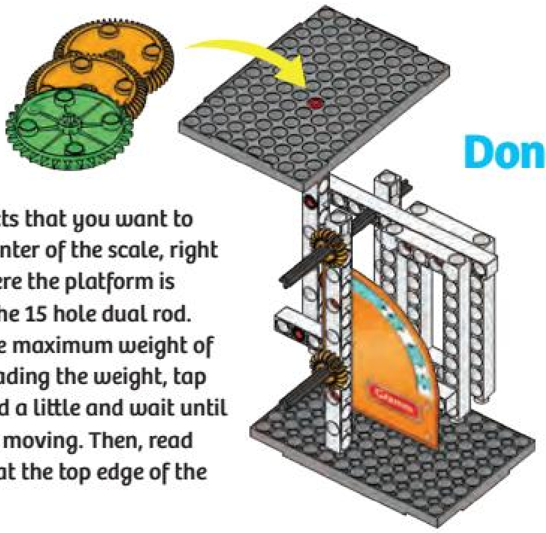


Place the objects that you want to weigh in the center of the scale, right in the spot where the platform is supported by the 15 hole dual rod. Don't forget the maximum weight of 50 g! Before reading the weight, tap on the base grid a little and wait until the scale stops moving. Then, read off the weight at the top edge of the pointer rod.

Done!

A postal scale like this one is not just useful for weighing things, it also offers you a very nice way to learn about how levers work. The load on the scale platform makes the counterweight rise. In the process, the center of gravity moves outward, with the rod holding the platform and load sinking and moving closer to the fulcrum. So the effort arm gets longer and the resistance arm gets shorter — and the heavier the object, the more this happens. The pointer rod, meanwhile, rises accordingly on the dial.

Changing the Direction of Force — the Fixed Pulley

Pulleys can be found in all sorts of places — sailboats, cranes, elevators, and construction sites, just to name a few.

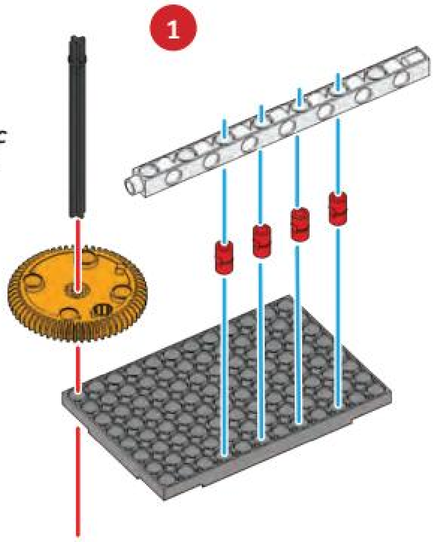
The simplest kind of pulley is the fixed pulley, which is a circular disk with an axle in the middle and a groove along the outer edge. A cord, rope, or chain runs through the groove. The pulley is attached to a fixed point by its axle mounting. The fixed pulley does not allow you to save energy, but it can still make your work easier. It helps to redirect force in a more convenient direction and location. Before we construct a fixed pulley, let's assemble the 0 to 7.5-newton force scale from page 19, so that we can measure the forces operating on it. The force scale is also usable as a spring scale for weights up to 0.75 kg (divide N values by 10). In the following experiment, we will measure the balance of forces on a fixed pulley.

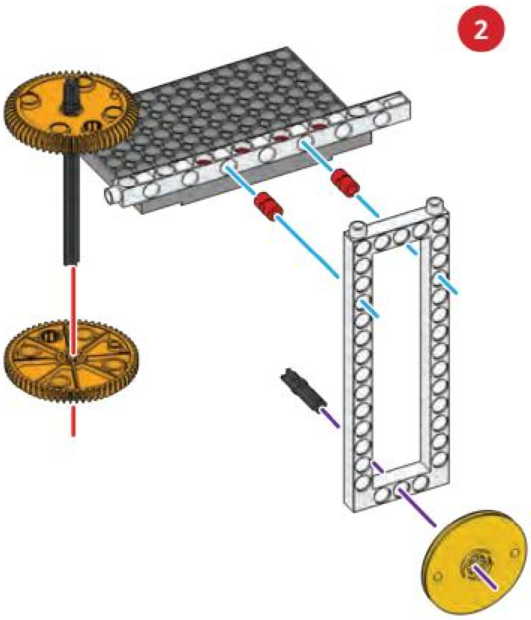
The fixed pulleys on sailboats spare you tedious distances and cumbersome handles.

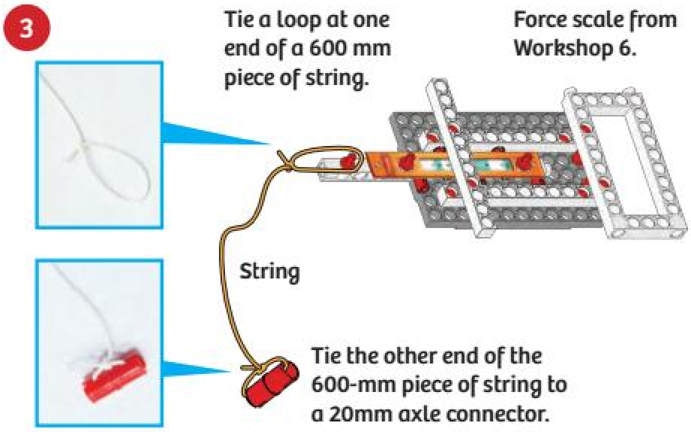
WORKSHOP 13: FIXED PULLEY

YOU WILL ALSO NEED

- *a half-liter (16-ounce) plastic bottle with some water in it*



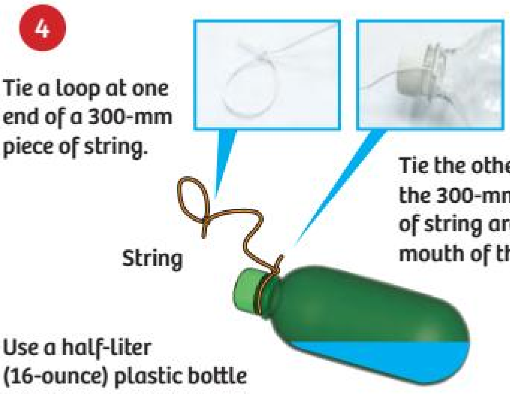




Tie a loop at one end of a 600 mm piece of string.

Force scale from Workshop 6.

Tie the other end of the 600-mm piece of string to a 20mm axle connector.



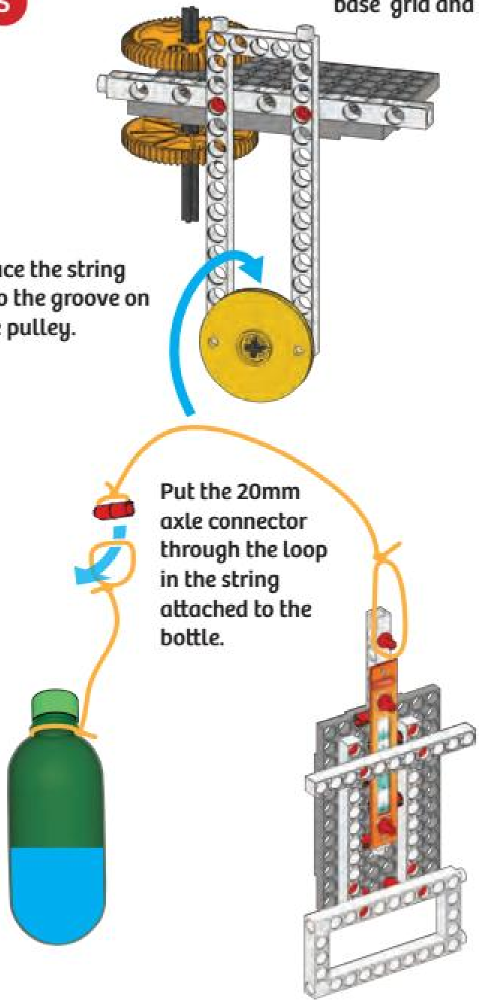
Tie a loop at one end of a 300-mm piece of string.

Tie the other end of the 300-mm piece of string around the mouth of the bottle.

Use a half-liter (16-ounce) plastic bottle with some water in it as a weight.

5

Attach the pulley assembly to the edge of a table with a base grid and gears.

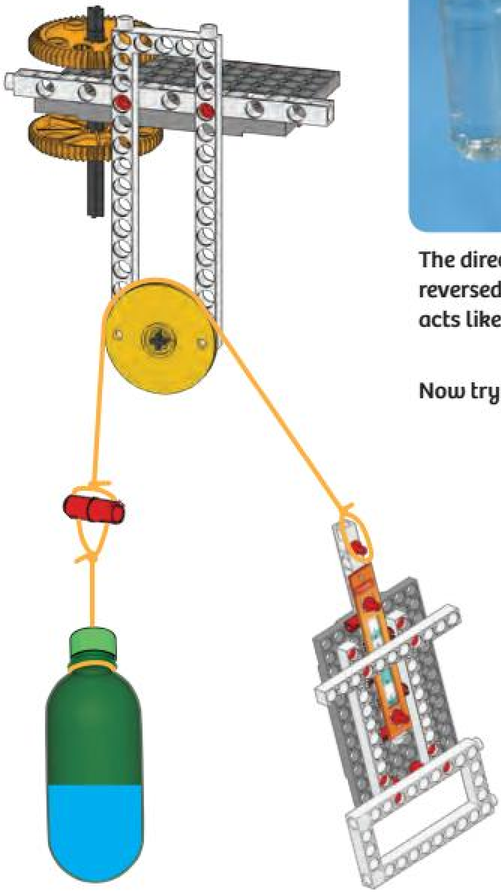


Place the string into the groove on the pulley.

Put the 20mm axle connector through the loop in the string attached to the bottle.

6

Done!



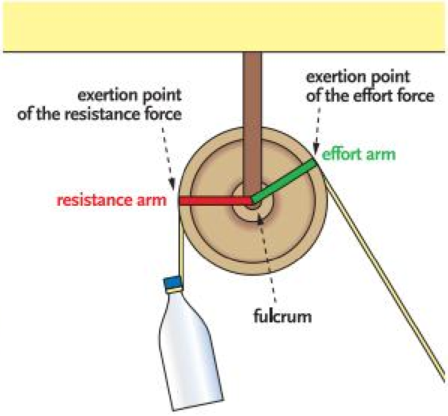
The direction of force is reversed by the pulley, which acts like a type one lever.

Now try Experiment 12.

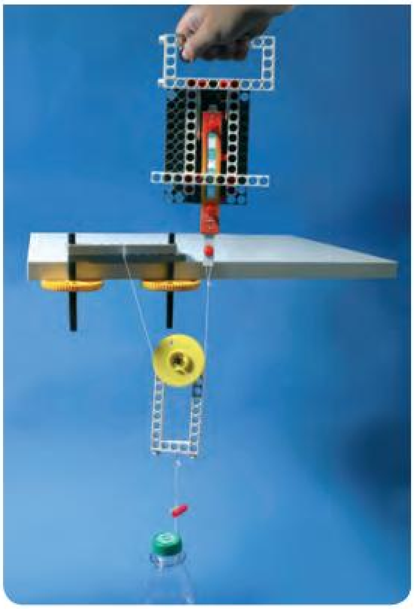
EXPERIMENT 12: TESTING THE FIXED PULLEY

Tie a half-liter plastic bottle filled with water to one end of the string, and tie the force scale about 50 cm (20 in) from that end. Pull the bottle up by the force scale without twisting it, and take the reading. The reading indicates the weight of the bottle: a little over 5 N (about 0.5 kg). Now untie the end of the string from the bottle, lead the string over the pulley, tie on the bottle again, pull it up, and lower it a little. Equilibrium has been attained. Finally, take the reading.

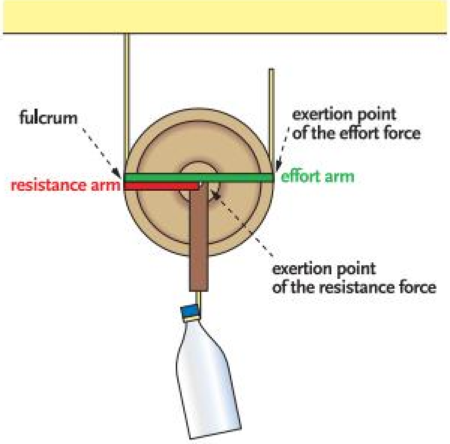
You got the same weight reading with and without the pulley, right? So you obtained no savings in force, you just pulled down instead of up. The fixed pulley works like a type one, equal-armed lever: load = force.



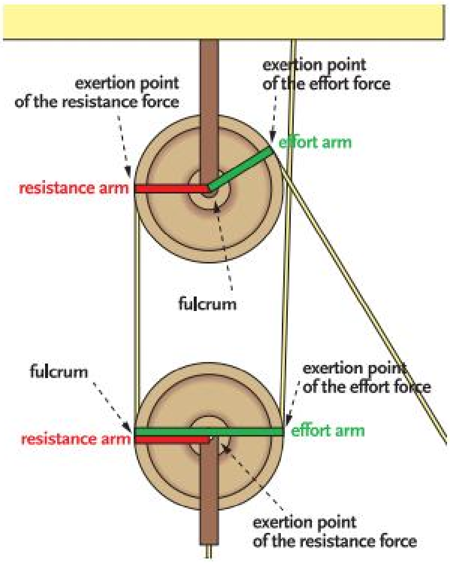
The fixed pulley works like a two-sided lever.



This is how we measure force with the movable pulley.



The movable pulley works like a one-sided lever.



Combination pulley: a combination of a fixed and a movable pulley.

Changing the Magnitude of the Force — the Movable Pulley

Things are different with a **movable pulley**. It can change the required force, reducing it to half the load. But how can a movable pulley cut the required force in half? The movable pulley hangs by two string sections, each of which takes on half of the load. This type of pulley works like a type two lever, as you can see from the picture here. The next experiment will show you that the savings in force must be "paid for" by doubling the length of the string.

EXPERIMENT 13: THE STRING EATER

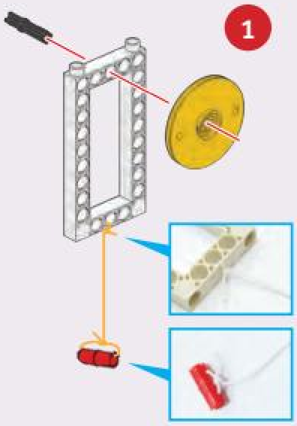
Build the model below. Hook the end of the string over the force scale as shown below, suspend the pulley with the bottle from the string, and read how much force you saved.

Fixed Pulley and Movable Pulley Combined — the Combination Pulley

If you want to not only cut the required force in half but also change its direction, then what you need is a simple **combination pulley**. It consists of a fixed and a movable pulley.

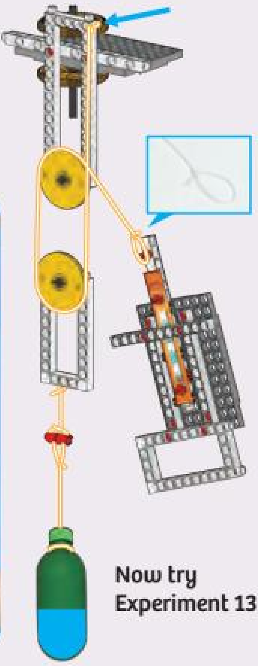
WORKSHOP 14: SIMPLE COMBINATION PULLEY

1



Use the fixed pulley again (see pages 36-37 for assembly), as well as the 0 to 7.5-N force scale, and the second pulley assembly for the load. Pay attention to the way you should thread the string through the components.

2



Now try Experiment 13.

But you can achieve an even greater savings in force. The more pulleys the combination pulley has — more accurately, the more strings there are running to and fro — the more force you save. The load is simply divided by the number of strings.

As with all machines, when you pull on the string of the combination pulley it swallows up some of the force. The reason for that is provided by another basic principle of mechanics:

There are no machines without losses.

Above all, there are losses caused by the friction of the axles and the strings. That is why your force scale shows a slightly higher value when you pull steadily on the string than when in the resting position.

Forces on a Sloping Path — the Inclined Plane

A wheelchair cannot climb stairs. That is why there is often an extra path designed for wheel chair users, alongside the section with stairs used by other pedestrians. If you were pushing your heavily-loaded bicycle along, would you prefer to push it up the wheelchair ramp or carry it up the steps? Without a doubt, the ramp would be better. You know that the ramp requires less effort. But why is that?

The ramp is an **inclined plane**, a surface that lies at a slant relative to horizontal. In order to observe experimentally how forces are distributed on it, we will first assemble a force scale for 0 to 2 N. In addition, we will build a test vehicle and an inclined plane, which we will attach to the force scale as shown in the instructions, so they can be rotated relative to each other.

WORKSHOP 15: TEST VEHICLE ON AN INCLINED PLANE

❶

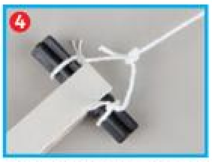
Tie a 200-mm piece of string to the axle.

❷

Tie the string to the other axle as shown.

❸

Cut off the extra string.

❹

Tie a 700-mm string to the center of the loop.

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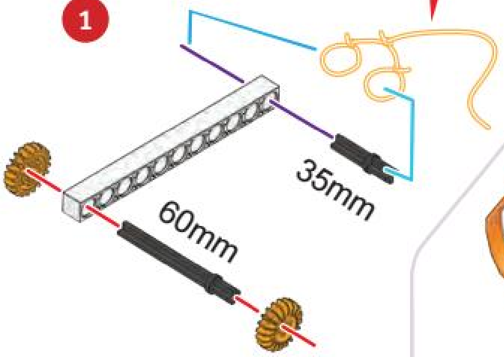

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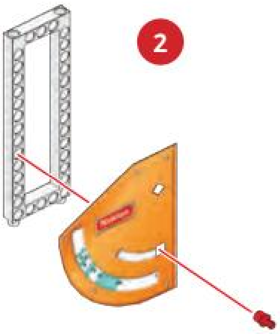

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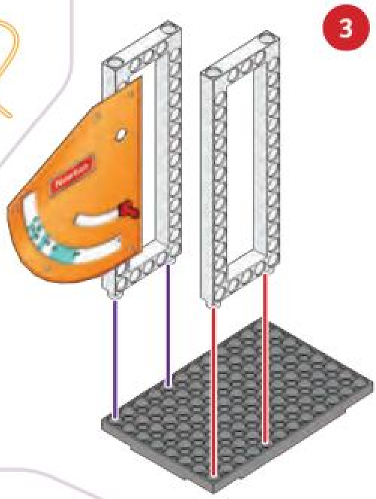

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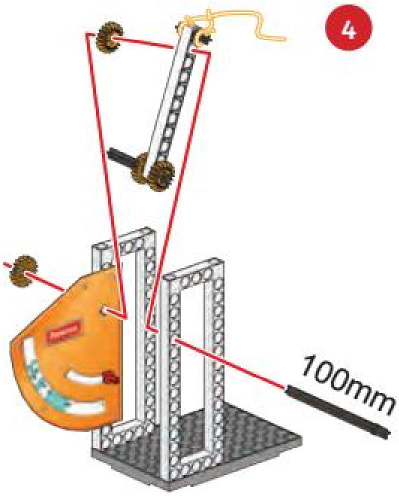

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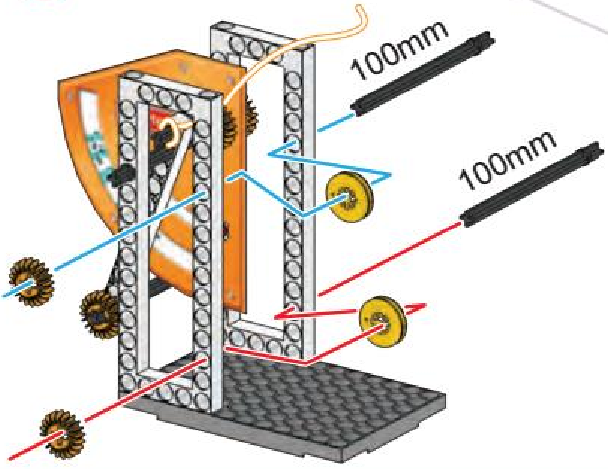

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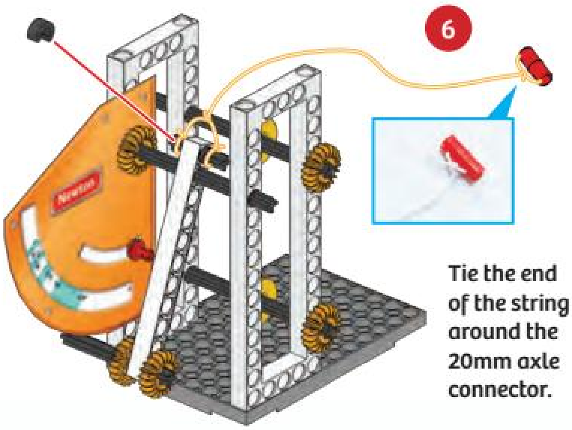

Tie the end of the string around the 20mm axle connector.

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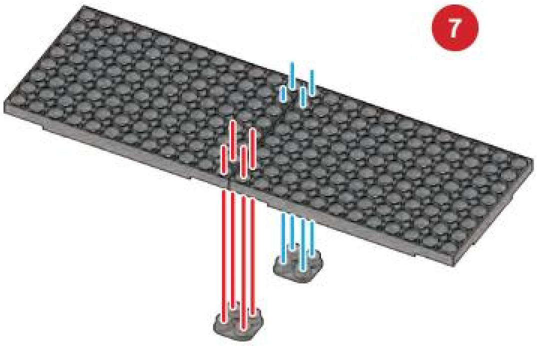

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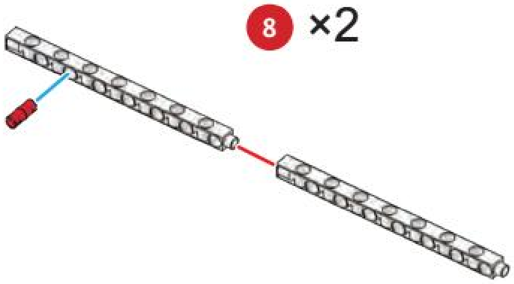

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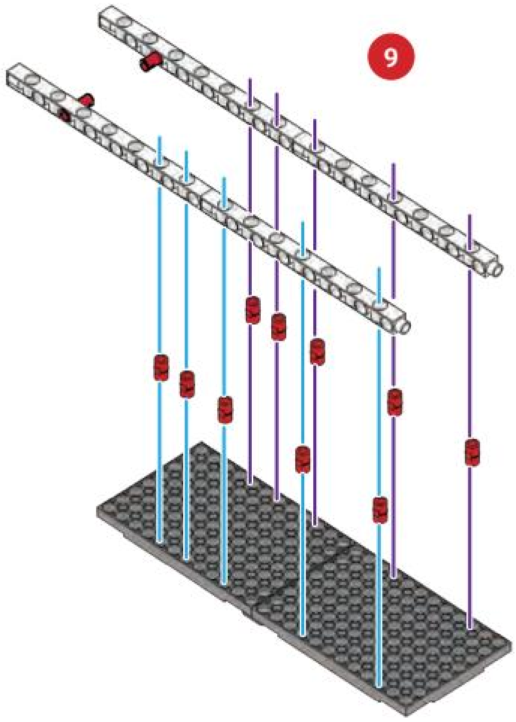

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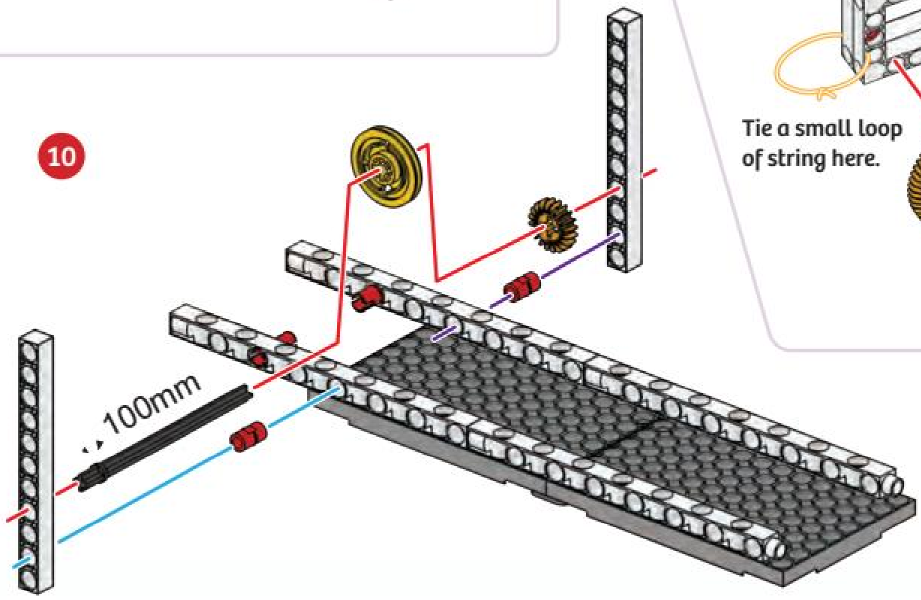

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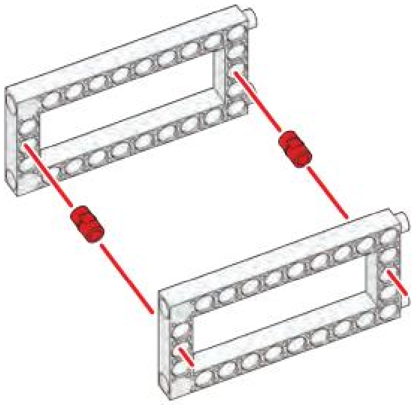

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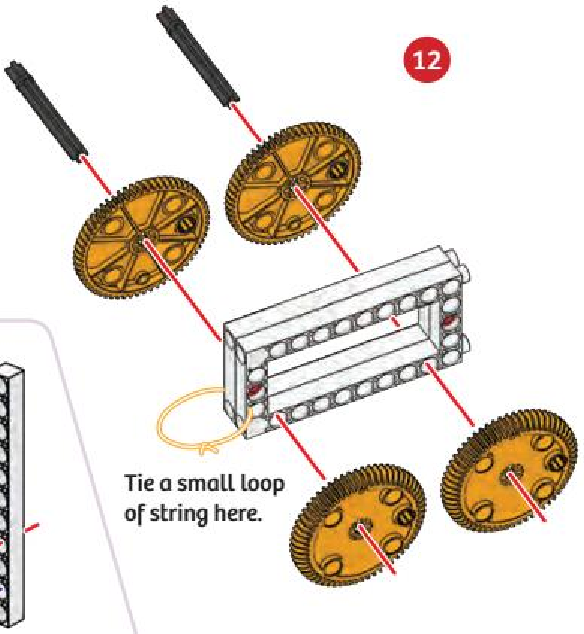
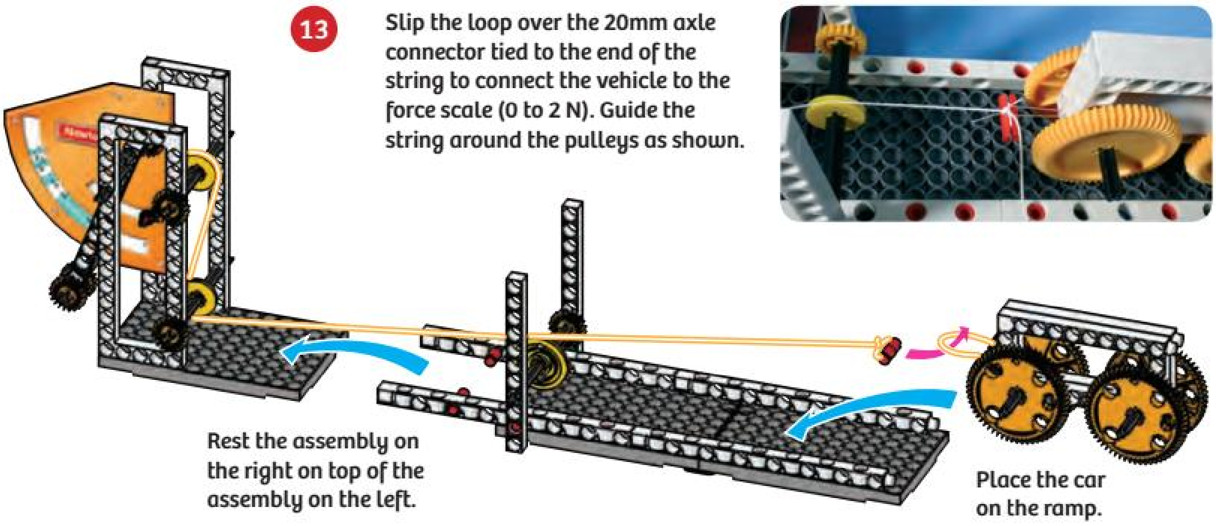


Tie a small loop of string here.

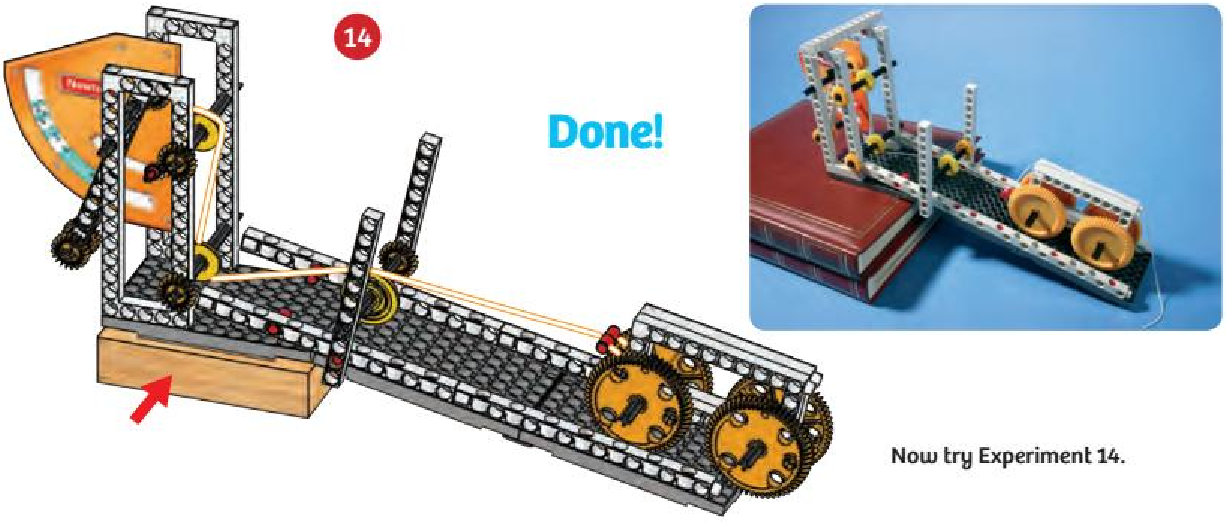
13 Slip the loop over the 20mm axle connector tied to the end of the string to connect the vehicle to the force scale (0 to 2 N). Guide the string around the pulleys as shown.



Rest the assembly on the right on top of the assembly on the left.

Place the car on the ramp.

14



Done!

Now try Experiment 14.

EXPERIMENT 14: ON A SLOPE OVER A PRECIPICE

Step 1: Place the force scale at the edge of a table and let the vehicle dangle down by the string. As you take the reading, nudge the pointer bar upward and tip the force scale so that the string unwinds over the pulleys. The pointer indicates the weight of the vehicle.

Step 2: Next, place the force scale on a stack of two or three thick books and connect it to the inclined plane with the 20mm axle connectors. Take another reading. Now the force is considerably less. Once again, the question is raised: why is the force reduced on the inclined plane?

The answer: because the force of the weight is distributed into two individual forces.

Of course, the basic principle we learned before applies here as well; the savings in terms of force must be compensated for by adding distance. A road sign announces an incline in the road of 15%. That means that a car has to drive about 10 m in order to move just 1.5 m higher (1.5 divided by 10 = 0.15 or 15%).

The driver has to take a longer stretch of road into account in order to get his car over the mountain. If the side of the mountain is too steep for a car to be able to drive up it on a straight road, then switchbacks have to be built — that is, the road has to wind back and forth.

DID YOU KNOW?

Why is it called a pulley?

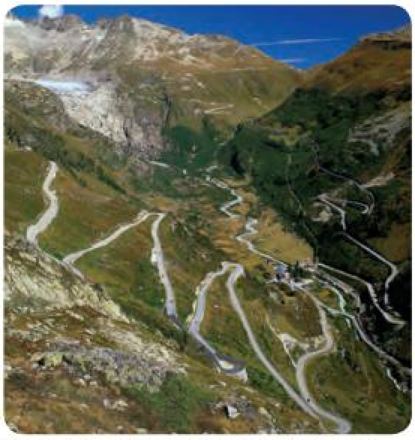
You might think a pulley gets its name from the fact that you can use it to pull things up. In fact, the name comes from polos, Greek for "hinge."

The sign indicates that the road will drop 1.5 m over a distance of 10 m.

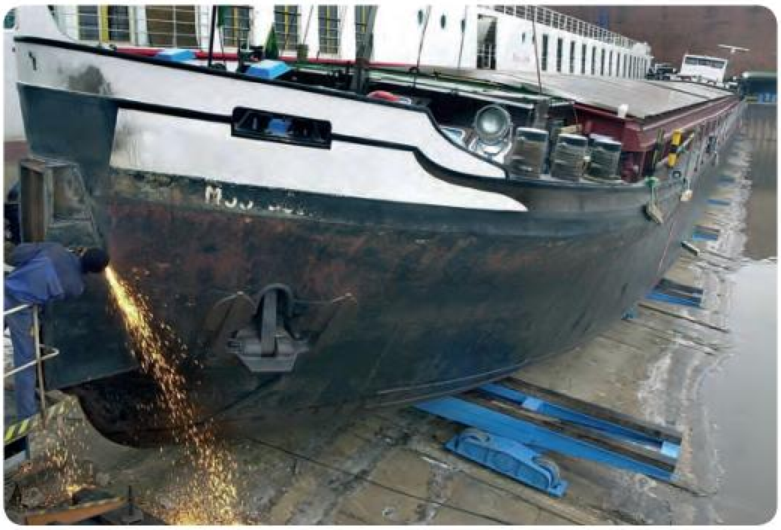
Resisting Force — Friction

As you now know, there are no machines without losses. But even objects that aren't machines, or parts of machines, are slowed down in their movements. A flying ball rubs against the air, a rubber dinghy that you pull through the water rubs against the water. When one body moves inside another (air, other gases, and water are non-solid, flowing bodies or "fluids"), there is frictional resistance — in short, **friction**. If two solid bodies move against each other, there is also friction. This kind of friction also slows down movement. In a state of rest, there is no friction. It only arises when a body is pushed into motion or is already in motion. Friction inhibits its movement. Friction works parallel to the surface of contact and in the exact opposite direction from the direction of movement, so it acts as a braking force. Friction, too, is a force.

Keep your force scale assembled to perform the next few friction experiments.



A switchback is a zigzagged inclined plane.

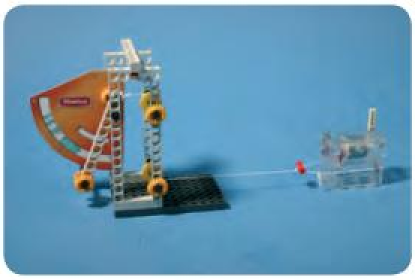


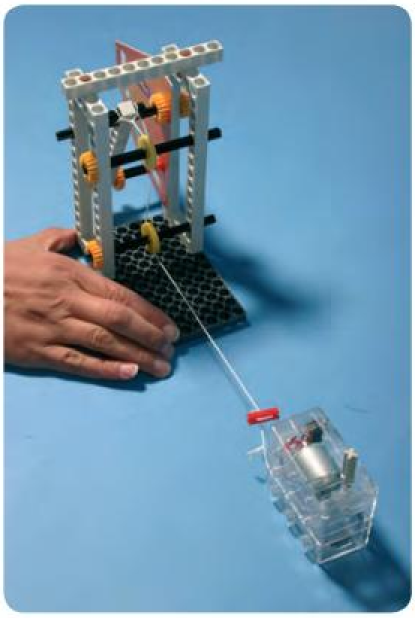
This inclined slide track, on which the heavy ship will glide into the water when it is launched, is painted with a special soap to reduce friction.

EXPERIMENT 15: MEASURING FRICTION

Step 1: Tie the **motor box** to the end of the force scale string. Slide the force scale slowly along the table surface, until the string is taut. Now push a little more until the motor box looks like it is just about to move. Read the force measurement. That is the force of friction that arises between the plastic housing of the box and the table surface.

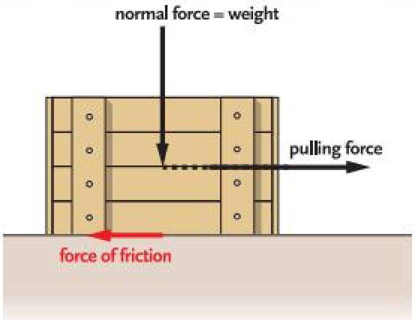
Step 2: Repeat the experiment, but this time keep pushing steadily on the force scale so that the motor box slides along behind it. Look at the pointer. Most likely, your table has a wooden surface. If you can rustle up a mirror or a picture with a piece of glass over it, repeat the experiment on the smoother surface.



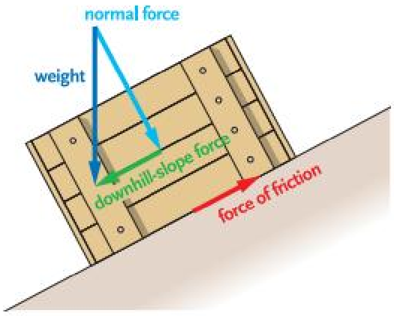


What did you observe? The pointer made a little jump to the reading that you took in the first experiment, and then dropped a little. The friction was greater at the start than it was during forward movement. In the first step of the experiment you measured the **static friction**, while in the second step you measured the **kinetic friction**. Kinetic friction is always noticeably less than static friction. You can sense that when you want to push a crate along the floor. Once you have moved it from its spot, you need less force to keep it going. It's the same when you push a car. At first you need a big show of strength, and then it gets easier. In this case, there is another type of friction at work as well: namely, rolling friction. It acts as a brake when a 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

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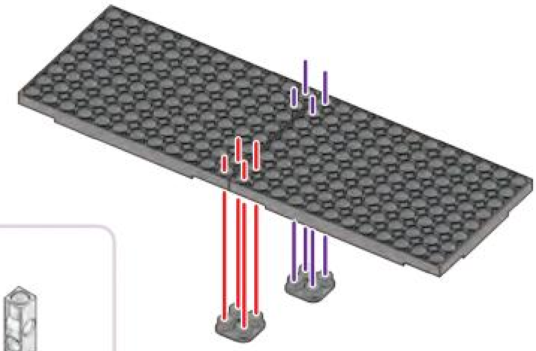

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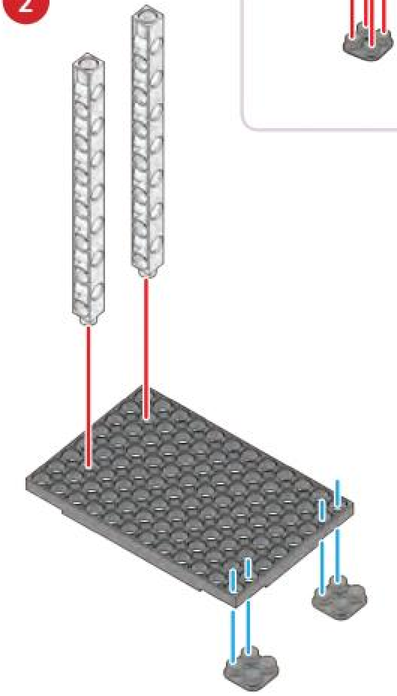

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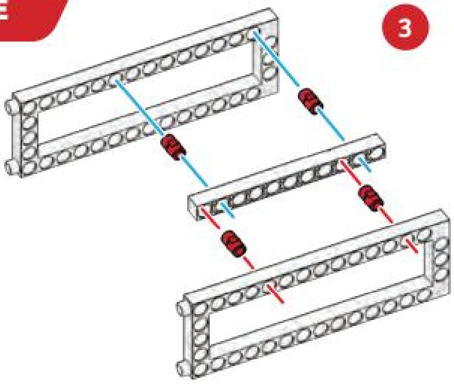

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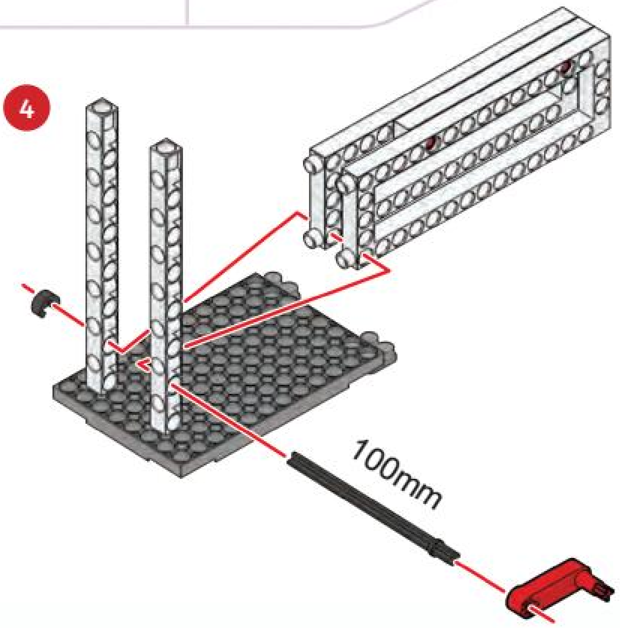

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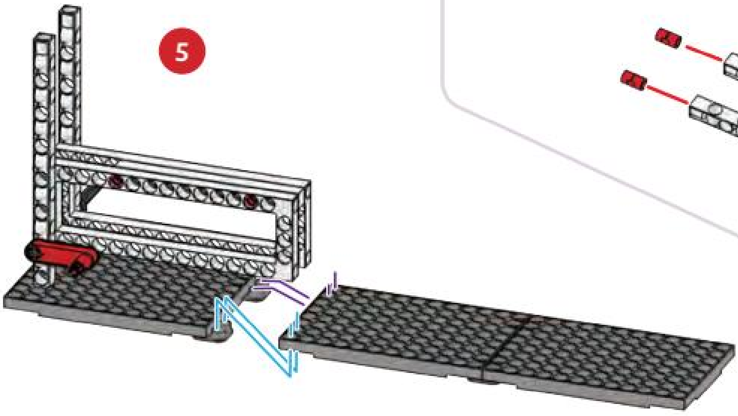

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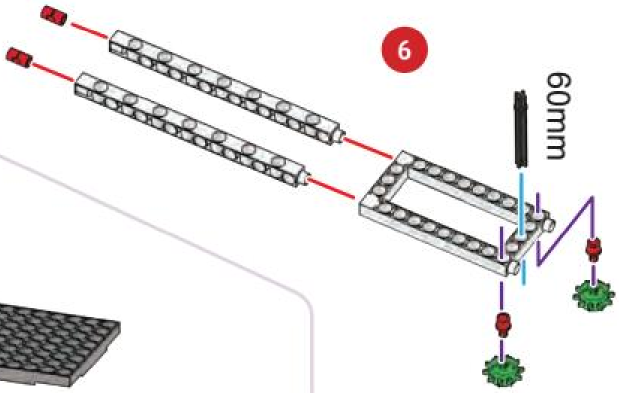

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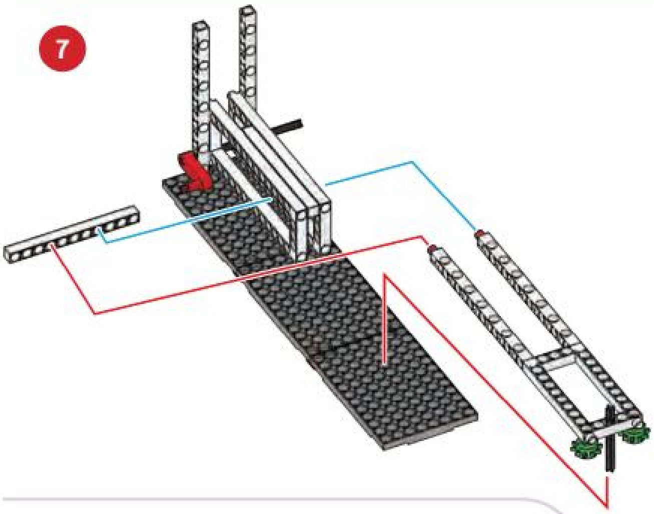

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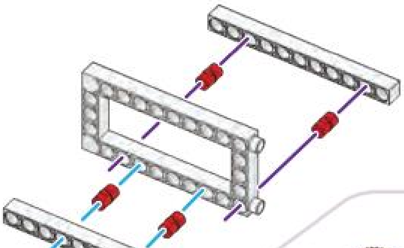

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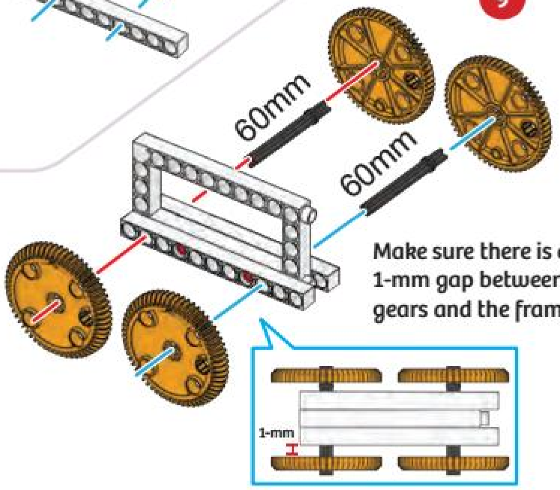
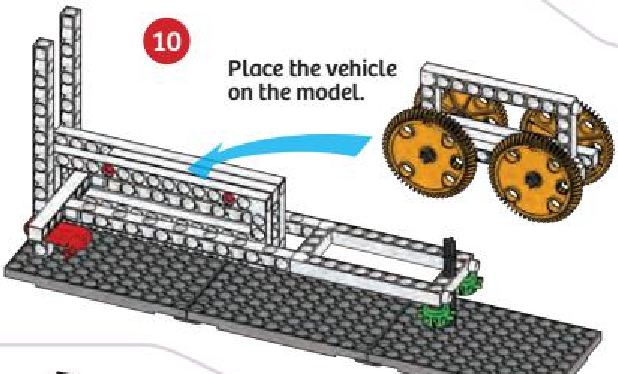


Make sure there is a 1-mm gap between the gears and the frame.

10

Place the vehicle on the model.



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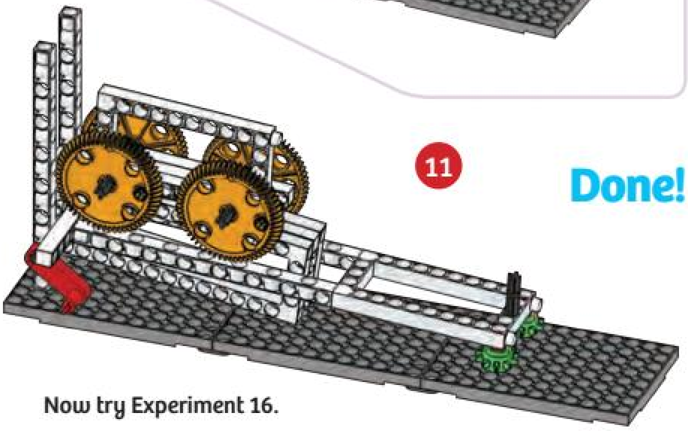
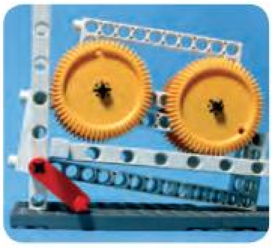
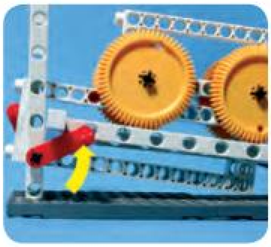
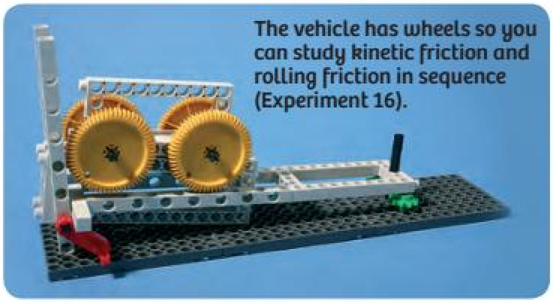


Done!

Now try Experiment 16.







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

DID YOU KNOW?

Sleds from the Stone Age

Sleds, too, are a discovery of stone-age people, who used transport sleds to carry things on land. That wouldn't have been too difficult on snow or mud, but how far can you pull a sled on dry land? Not until about 5,000 years ago, when people began to get around on wheeled animal-drawn carts, could they push into the interior of land masses, looking for new places to settle, opening new trade routes, and trading with unfamiliar people. Until then, they were more likely to travel along rivers and other bodies of water in boats.

A railways hump yard uses a slight slope to switch a car to one track or another.

Minimal friction loss in a ball bearing.

EXPERIMENT 16: FRICTION MAKES IT HAPPEN

Place the vehicle from Workshop 16 at the top of the ramp. Its framework — its runner — is now resting on the inner slide. The slope of the ramp is not enough to make the vehicle slide: the static friction is too great. Now push it a little with your finger. Does it keep sliding? No. So the slope isn't enough for the kinetic friction, either. Now lift the crank handle. The ramp's roadway lifts up against the wheels. The sled becomes a car and starts rolling. And that happened even though the slope didn't change. The reason is that the rolling friction is slight.

The area of the frictional surface does not affect the force of friction. What is decisive is the normal force perpendicular to the contact surface and how smooth or rough the surfaces of both bodies are. If you performed the friction experiment with the motor box on a mirror or glass surface, you could see that the friction was less than on a wooden table.

4,500 years ago, the Egyptians used simple machines to move three-ton stone blocks up the 150 m-tall Great Pyramid of Cheops. They constructed ramps of stone cubes or earth, and pulled and pushed the blocks up the ramps on wooden rollers.

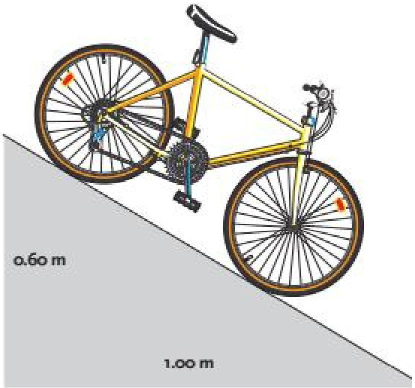
Ball bearings take advantage of the fact that rolling friction is slight: rather than the wheel turning directly on the axle, there are balls that roll between them. Your bicycle's wheels, steering wheel, fork and pedals also turn with the help of ball bearings.

Friction Wanted!

Imagine that instead of rubber tires, your bicycle had perfectly smooth steel tires. Then on smooth and straight stretches of downhill road, you would leave all your competitors behind you. After all, smooth steel creates a lot less friction against the road than rubber does. But what about when you wanted to go uphill? You would bear down on the pedals with all your weight and — the steel tires would just spin. And around curves? If you were leaning even just a little bit, the smooth steel tires would slip out from under you and you would be lying on the asphalt.

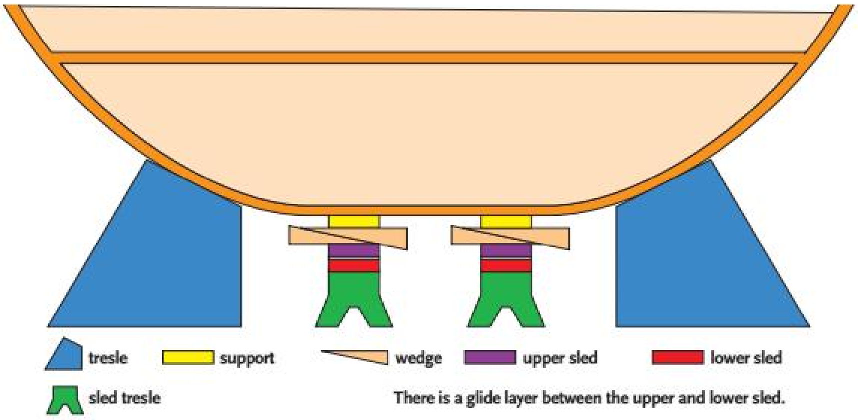
With bicycles and other road vehicles, a great deal of friction is needed to keep the wheels safe from slipping. The shape of the tires increases friction and grip. And how would you stop your bicycle if you couldn't brake? There are characteristic friction factors for the friction between two surfaces. In order to determine them, one places one of the bodies on top of the other and then tilts the bottom one until the one on top of it begins to slide. Then one divides the height of the slope by its length. The kinetic friction factor for rubber tires on asphalt, which applies in situations of braking and deceleration, is 0.3. The static friction factor, on the other hand, is 0.6 — if you pulled on the brakes in a standing position, your bicycle would only start to slide when it was on a slope about as steep as what you see in the picture.

Whether on cars, bikes, or washing machines — most brakes take advantage of high kinetic friction factors. Now maybe you can explain why it is that a fast-moving train (steel wheels on steel tracks) has such a long stopping distance and why a stretch of track only allows a very flat angle of incline.



Wedges Lift Ocean Giants

The heaviest vehicles built are giant tankers and container ships. But how does one of those ocean giants get into the water in the first place? There isn't a crane in the world that can lift it to place it in the water. There are two possibilities. First possibility: the ship is built in dry dock, a harbor basin sealed off by gates. If the basic construction has progressed far enough for the ship to float, the gates are opened, the harbor water flows into the basin, and soon the ship is floating in water.



But not all shipyards have an appropriate dry dock, or the dry dock may not be free. In that case – this is the second possibility – the ship is constructed on a building slip, a slanted platform situated close to the water. While under construction, the ship's growing weight is securely supported lengthwise on iron or concrete trestles, until it is ready to be slipped into the water on a sled. But how is it placed onto the sled? That can only be achieved by the simultaneous hammer blows of many workers. Even in the age of machines and computers, nothing works better than two simple, time-tested machines from the Stone Age: the inclined plane and the wedge. Added to that is an equally age-old vehicle, the sled! And finally the hammer — a 10,000-year-old Neolithic tool.

A ship is raised on sleds with wedges — represented schematically in the diagram above , and shown in the photograph to the left. In the process, it is simultaneously released from the trestles upon which it was supported. Strong steel cables and hooks hold it firmly in place. On launch, they are released, the ship usually gets a push from a hydraulic press, and then it slides down the track. Then a brake anchor is thrown and the ship is towed to the shipyard quay.

DID YOU KNOW?

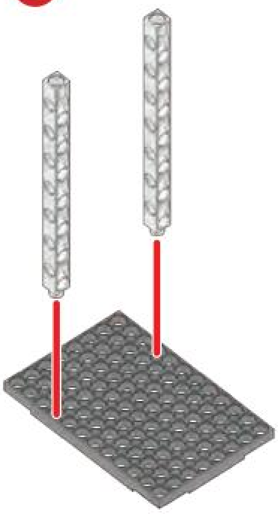
Stone-Age machines

The Stone Age is still alive inside many modern machines. Even complex machines are built out of simple ones, and therefore use discoveries from Ice Age cultures. The wheel did not appear until about 6,000 years ago, while the screw was discovered around 2,200 years ago.

A few days before launch, two pairs of sleds are pushed under the ship. Each pair has an upper and a lower part. Between the two parts is a glide layer made of soft soap or Teflon-coated steel. Next, long and slender beechwood wedges, spaced closely apart, are inserted over the upper sled part from the side. In time to bursts of a whistle, hundreds or more dockworkers beat on the wedges with sledgehammers. With each blow, the ship rises by a fraction of a millimeter – thanks to the action of the wedge, which we will now investigate in an experiment.

WORKSHOP 17: WEDGE AND STUCK RACK

1



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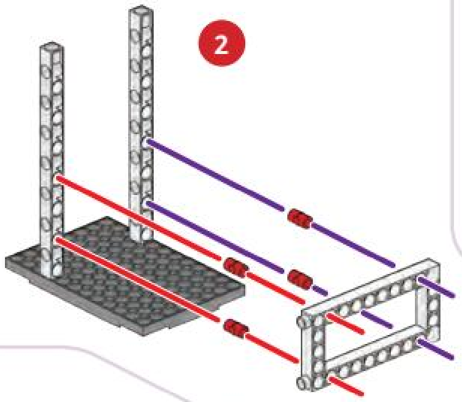

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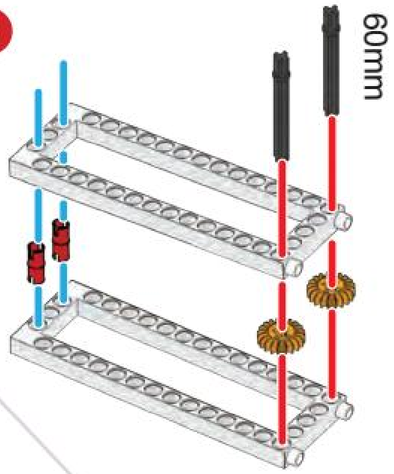

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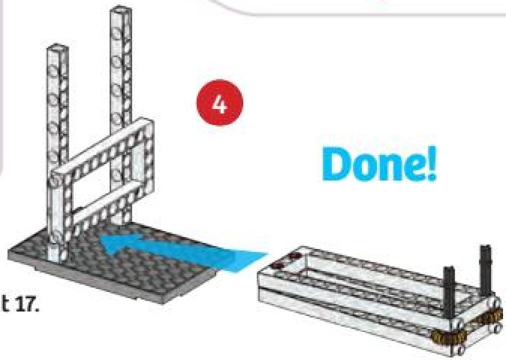
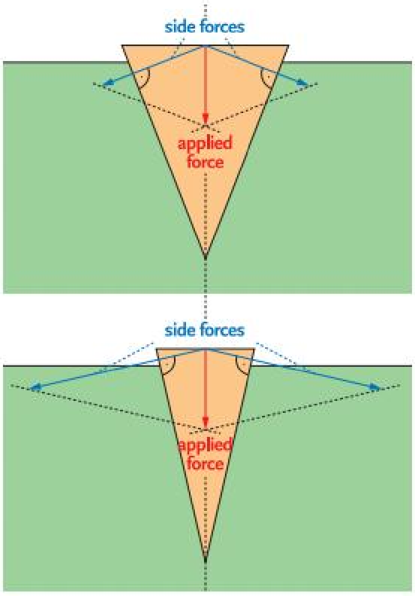


Now try Experiment 17.

Now try Experiment 17. You will definitely be surprised how easy it is to loosen the rack from the base grid with a wedge.



The power of wedges: stubby wedges (above) produce small side forces, pointy wedges produce large ones (below).

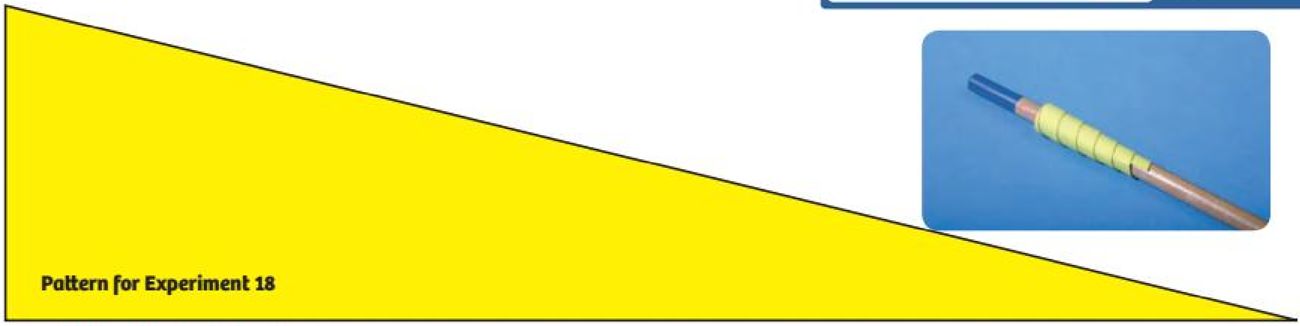
EXPERIMENT 17: WEDGE WORK

Start by pulling the rack up out of the base grid, without using the wedge. Then stick it back into the grid, but only after you have placed the wedge beneath it. Now push against the rear of the wedge.

The rack lifts up a lot more easily now, doesn't it? Let's take a closer look at the wedge and its show of force: It consists of two inclined planes joined at the base. The force that is exerted at its rear divides into two side forces, perpendicular (at right angles) to the sides of the wedge. The narrower the wedge, as you can see in the diagram, the greater the side forces. Of course, the narrower wedge must also travel a greater distance between the pieces that the wedge is pressing against. But the gain in power is usually worth the price of the longer distance.

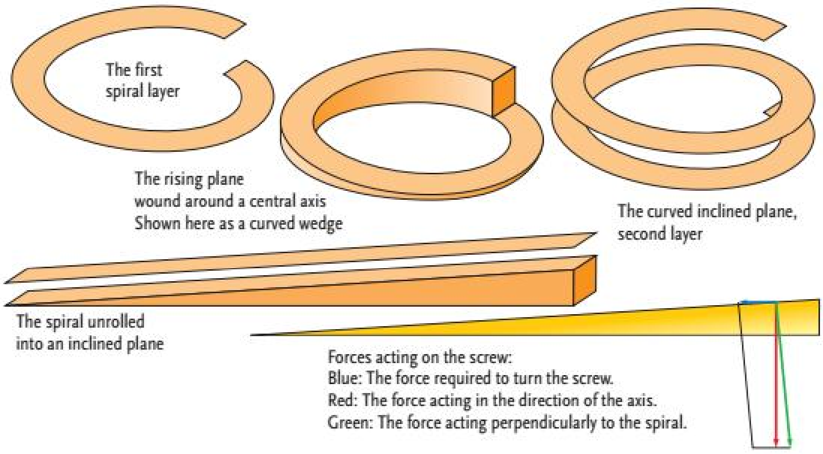
Wedges are usually made from wood or iron, and they are used to drive objects apart or to split an object (wood, stone). But they can also be used to attach components to one another, for example in pieces of furniture.

WORKSHOP 18 Screw



Slanted and Twisted — The Screw

The **screw** also has the inclined plane to thank for its power yield. You can picture a screw as a plane leading in a circle around an axis and at the same time rising steadily upward — in other words, as a rotated inclined plane. The following diagram makes the spiral path of the inclined plane clear:



Construction of a metal bolt

EXPERIMENT 18: SCREW

Copy the drawing at the top of the page onto a piece of paper and cut it out. Then wind it around a round pencil, starting at the high end (the end at the left, above).

With a screw, the small amount of force with which it turns acts on a circular path. The force that comes out of that, in other words, the resulting force, acts in a straight line in the direction of the axis. The screw's turning motion is thereby transformed into a forward motion, also called its advance. Here, the same law applies that applies to the wedge and other machines: the force gained in the direction of the axis is paid for with a longer distance in the turning direction.

But what determines the distance of the advance? The rise in the spiral does. The more turns the screw goes through in order to move a centimeter forward or backward, the smaller its degree of incline, the shorter its advance, and the greater the gain in force. This gain can be increased by the tool you use — for example, if you use a wrench with a long handle or a screwdriver with a fat grip. Those features increase the torque.

You will recall that friction has a role to play in the way an inclined plane works. The steeper the incline, the more easily the braking force of friction is overcome. And you also know that the degree of friction depends on the surfaces of objects. In addition, you have learned that friction can be desired or undesired.

But if a screw is a rotated inclined plane, what role does friction have to play? It all depends on what the mechanics of the screw are being used for. First, the kinds of screw for which friction is desired: friction between metal and metal is small, between metal and wood or synthetic materials relatively large. If you want to screw a metal screw into a metal thread or attach a metal nut to it, it should remain

The spiral stairway, a special kind of screw

While a metal screw rotates in a nut or threaded hole, wood and tin screws cut their own thread.

A helicopter's rotor blades are mounted at a slant. As rotating inclined planes, they produce lift, which is intensified by the blades' profile.

fixed in place and not loosen itself. So metal screws usually have a small degree of incline, or pitch, to their thread. Screws used for wood or synthetic materials, on the other hand, often have a steeper pitch. Those are the kinds of screws usually used for attaching assembly components to one another.

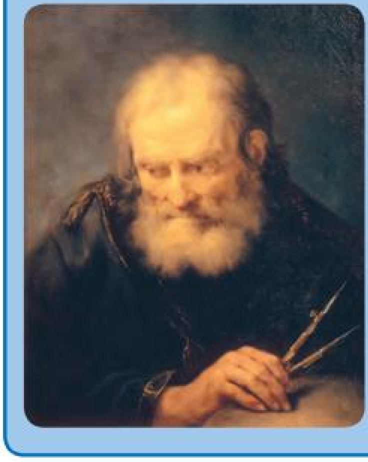
A drill is also a type of screw for which friction is desirable. Its tip is equipped with very hard cutting edges that eat their way through the object and cast off splinters of wood or metal under considerable friction loss. Screw forces with desired friction are also at work in car jacks, vises, and screw clamps.

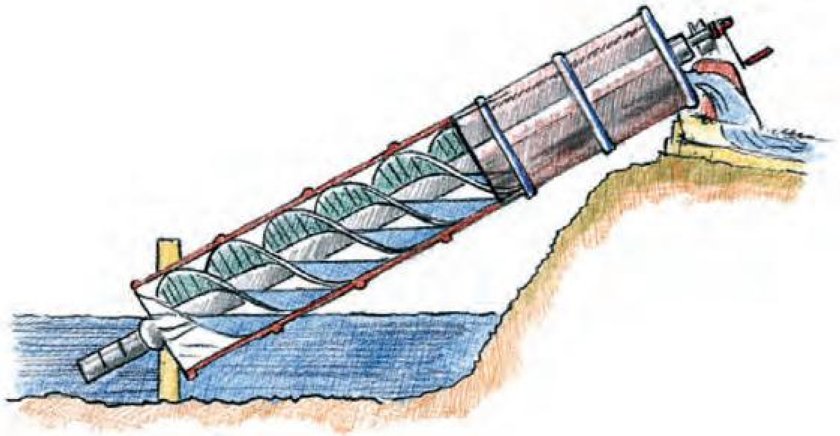
Friction is not desired, by contrast, in the case of ship propeller screws and airplane propellers. They are supposed to cut through air or water with minimal friction while at the same time thrusting off a lot of air or water in order to move the vehicle forward. They achieve that by means of a very high rotation rate. Helicopter rotors are also designed to provide the vehicle with lift.

DID YOU KNOW?

The inventor of the screw

The Greek mathematician and physicist Archimedes (287-212 B.C.) constructed a screw for use as a water pump. He also discovered the pulley and the drill bit, which is also based on the principle of the inclined plane.





Archimedes' screw sits inside a pipe. As it moves through its steep spiral, it pushes liquids and heavy solid material, such as concrete, upwards.

The Car Wheel — an Equal-Armed Lever

Wheels have existed for at least about 6,000 years, since the end of the Neolithic age. Archeologists came across the earliest evidence for wheels while performing excavations of what used to be the Sumerian civilization between the Tigris and Euphrates rivers in Mesopotamia. There, they unearthed clay tablets with pictographic representations of wheeled vehicles. Wheels certainly existed before then, however. At first, they would presumably have been wooden disks sliced from a section of tree trunk, into which an axle was bored. A disk only becomes a wheel when it can turn on an **axle** or turn with an axle in a housing. Before it was ever used on a vehicle, the wheel probably served as a potter's wheel.

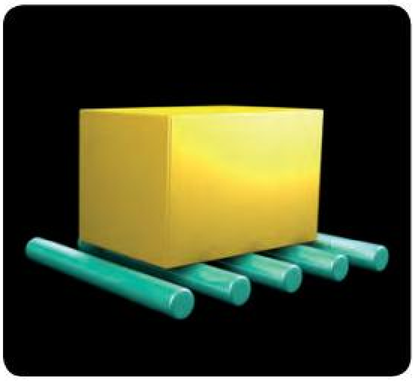
Neolithic people must have transported heavy loads on rollers made of tree trunks. Over long distances, that method would have been very cumbersome from our perspective, since the rear roller would constantly have had to be moved to the front as the object rolled forward.

For heavy loads over shorter distances, however, rollers are still used even today at construction sites and in heavy transport equipment. With respect to friction, rollers have no disadvantage relative to wheels, as you will see in the next experiment. In the experiment, an object will be pushed on top of its base. Two pairs of wheels, each pair fixed on a common axle and lacking any housing, will play the role of the rollers.

6,000 years of wheel history: from simple wooden disks to Formula 1 tires

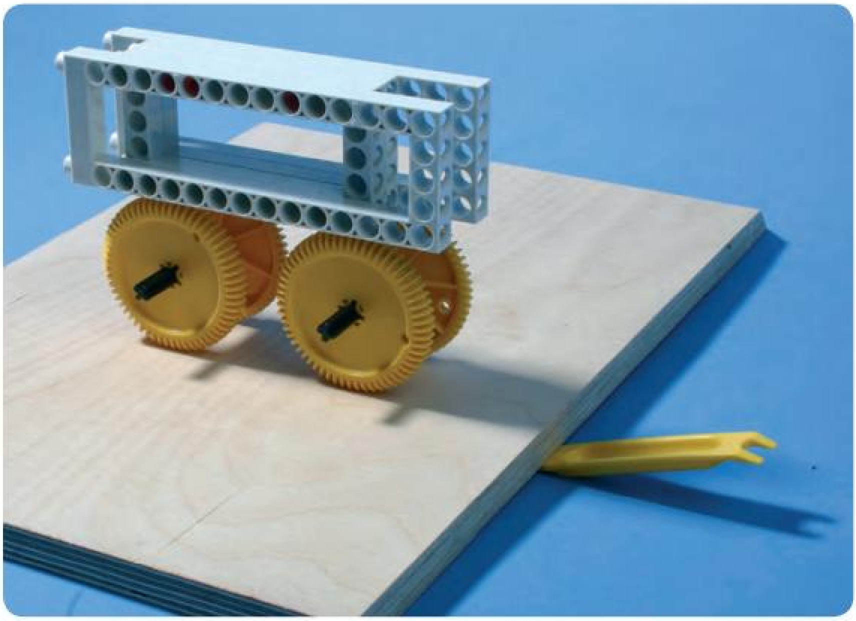
EXPERIMENT 19: WHEELS AND ROLLERS

Step 1: Build the model pictured below. Push the **gears** onto the **axles** so that they can move like rollers beneath the outer frame of the vehicle frames resting on top of them. Place the two resulting "wheel rollers," one behind the other, on a wooden board. Push the thinner end of the **part separator tool** under the board, so that it stays in place there. Now place the vehicle frame on top of the rollers. Be sure that the rollers are straight and do not touch each other. Press carefully on the part separator tool and watch for the moment when the body begins to roll on the inclined plane.
Step 2: Now disassemble the rollers and turn the vehicle frame into a car with wheels mounted on axles turning in a housing, as shown on page 44. Repeat the rolling experiment with the car you have just built.

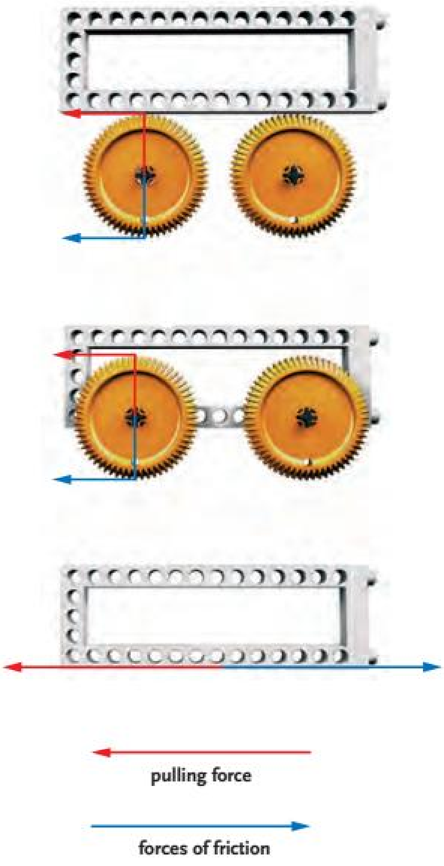


Transport on rollers.

You can see that in both cases — regardless of whether on rollers or wheels — the object starts to roll when the board is at the same modest tilt. So the static friction must be the same for both means of transport. If you like, you can also use the same method to compare kinetic frictions.



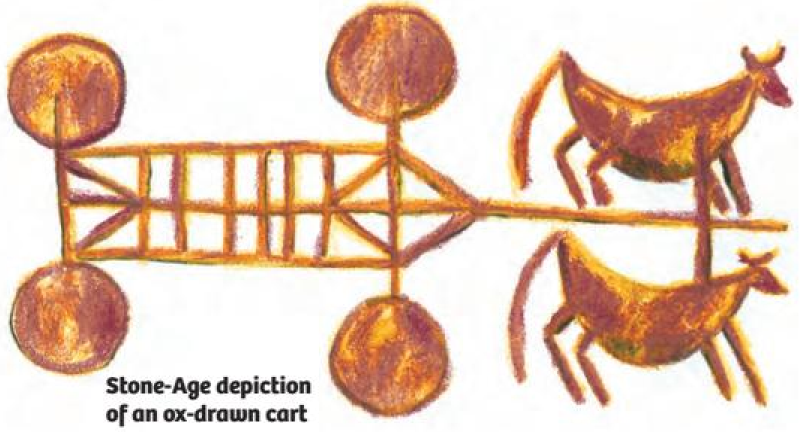
The pair of wheels acts like a roller with a small contact surface. The force of friction, as you know, is independent of the size of the contact surface.



As equal-armed levers, roller and wheel provide no gain in force, but their friction against the ground is smaller than it would be if the object were dragged along the ground directly.

Rollers and car wheels are equal-armed levers, so as wheels they provide no gain in force, and their friction on the ground is the same. Still, the friction is significantly less than it would be if the object had to be pulled along the ground without wheels or rollers. Just try pulling your bicycle along while applying the brakes!

What advantage did wheels provide relative to the rollers? The undercarriage remained attached to the vehicle body, sparing the effort of moving the rollers. The cart fit the ground better, because it only needed two narrow wheel tracks instead of a broad track for the roller. On top of all that, it was a versatile means of transport, easily hitched to draft animals for hauling things over long distances.

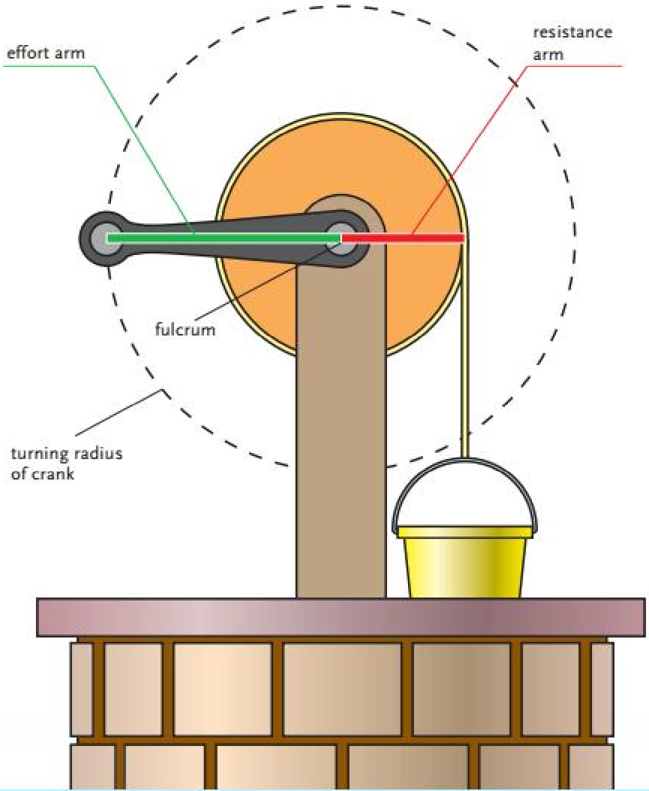


Stone-Age depiction of an ox-drawn cart

The wheel on a car or cart is not a simple machine. A wheel becomes a simple machine when it changes the size of the applied force, the way an unequal-armed or one-armed lever does, or— as a pulley does — its direction.

The wheel can also be a simple machine when there's no wheel to be seen at all — for example, when a lever moves around a central point of rotation. A crank is that kind of a wheel. At old farms, you can still sometimes see wells where water is cranked up in a bucket. The crank's effort arm is longer than the resistance arm of the central drum that the crank is attached to. If it is, say, twice as long, then the force at the crank handle is cut in half, resulting in the bucket at the end of the rope seeming only half as heavy.

A steamroller being used in street construction.



The crank makes a circle.

Getting in Gear

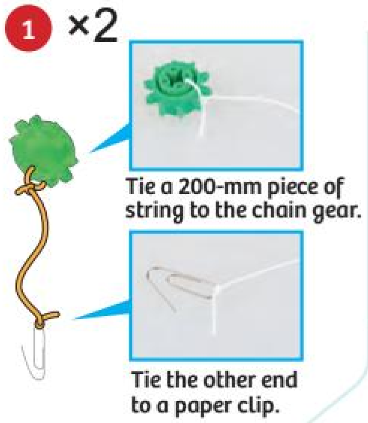
Forces can be transferred from one wheel onto another, and thereby increased or reduced. When used in that way, the wheels are connected to each other at their edges — usually by way of a **chain**, a **transmission belt**, or **gear teeth**.

On the edges of the wheels, equal-sized forces are at work. But the effort arms of the large and small wheels are of different lengths, giving rise to different torques. In the adjacent examples, the force transferred (by chain, belt, or gear) from the periphery of the smaller wheel to the larger one creates a greater torque at the larger wheel. Let's test it.

WORKSHOP 18: TRANSMISSION OF FORCE

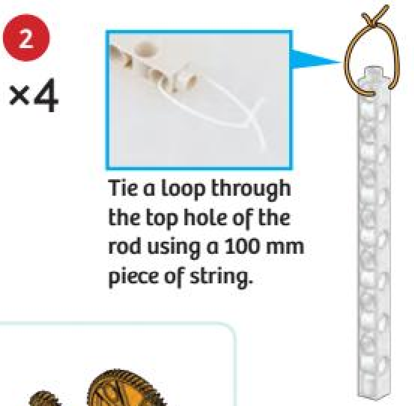
YOU WILL ALSO NEED

- *a few paperclips*
- *heavy book*
- *length of string (Do not use the string provided in the kit as this workshop requires you to cut the string. We suggest using dental floss or sewing thread.)*

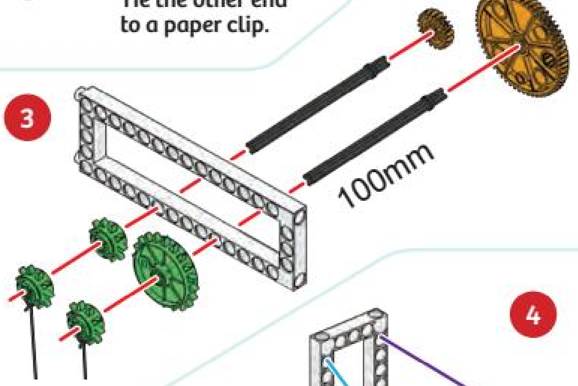


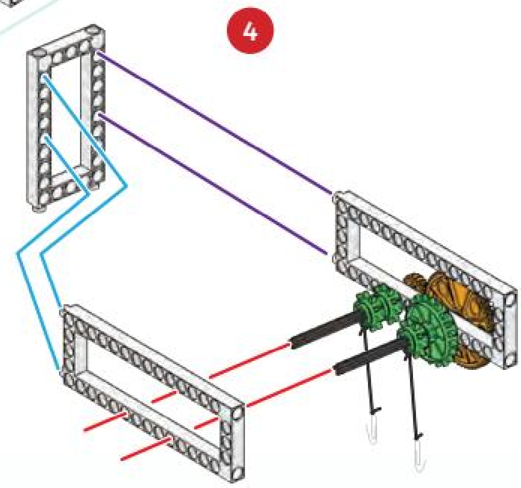
Tie a 200-mm piece of string to the chain gear.

Tie the other end to a paper clip.

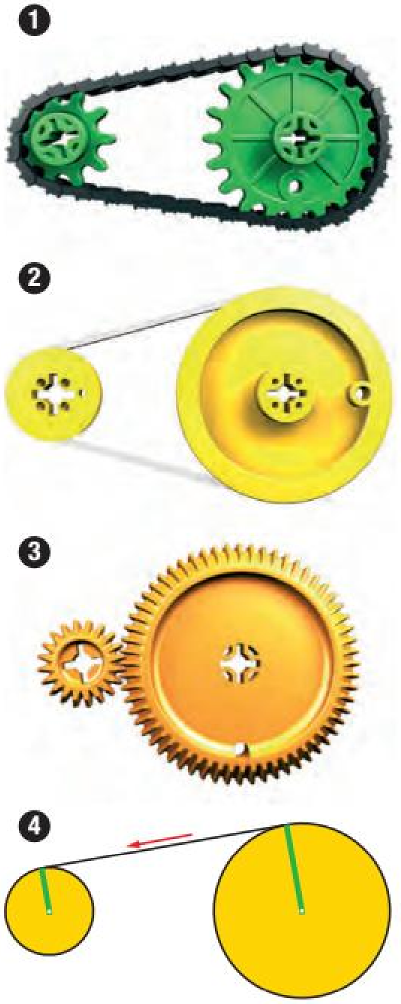


Tie a loop through the top hole of the rod using a 100 mm piece of string.



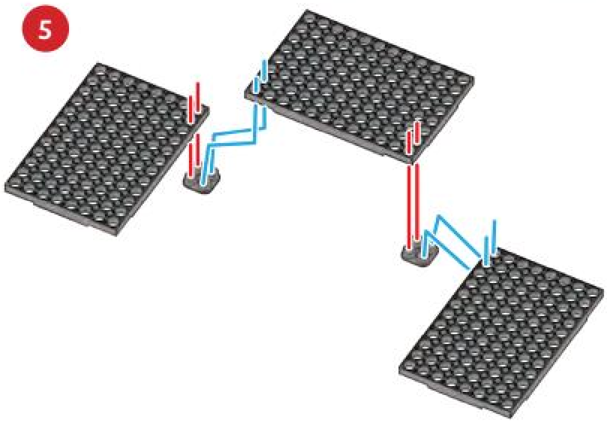


Each axle has two chain gears on the inside for stability;when pushed together,they act as a spool for the string.



Transmission of force with wheels:
1: Transmission of force over sprockets and chain.
2: Transmission of force over belt wheels (belt pulleys) and transmission belt.
3: Transmission of force over toothed wheels.
4: The force operates on levers of different lengths.

5



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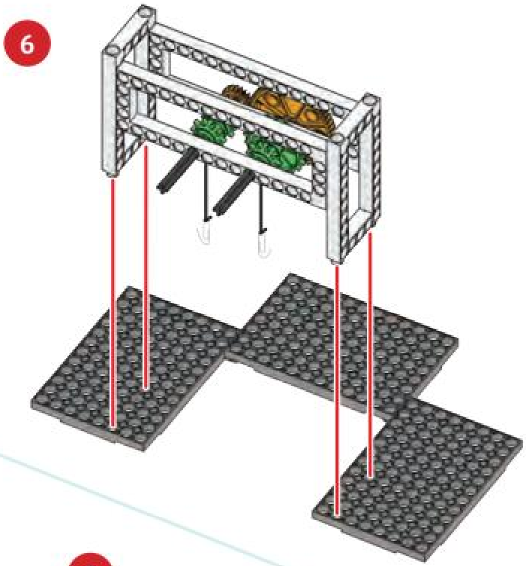

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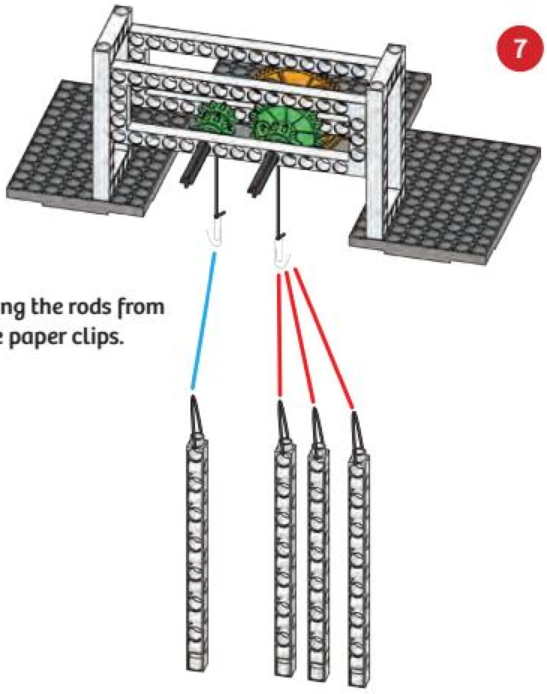
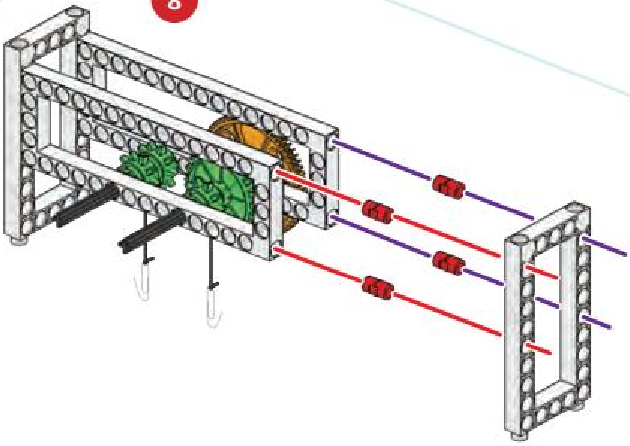
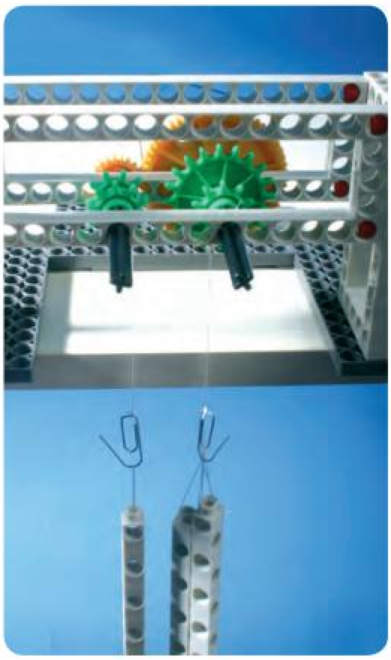


Hang the rods from the paper clips.

8





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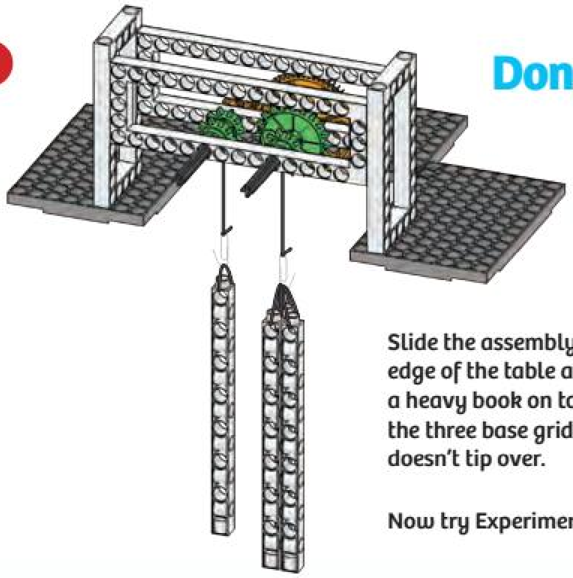


Done!

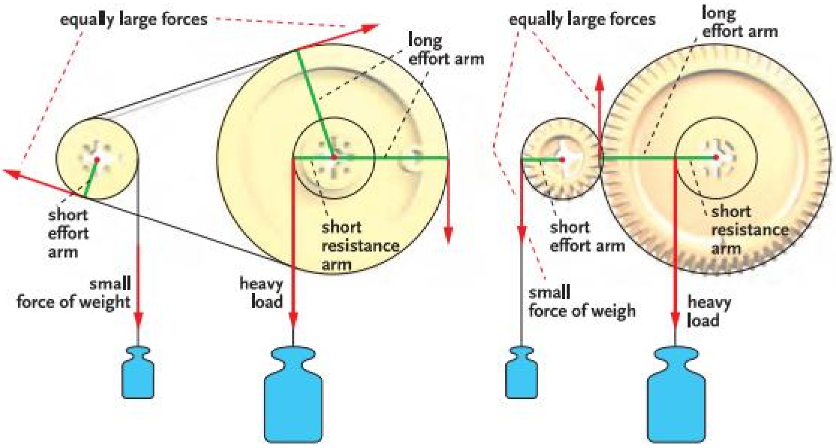
Slide the assembly to the edge of the table and lay a heavy book on top of the three base grids, so it doesn't tip over.

Now try Experiment 20.

A bicyclist can use a gearshift to adjust to the hills of a street. The transmission system allows the force on the pedals to be kept fairly constant.

EXPERIMENT 20: TRANSMISSION EQUILIBRIUM

Suspend a rod from the left string of your assembly (Workshop 18), and suspend one from the right string as well to start with. What happens? The left rod pulls the right one up, even though both are equally heavy. Now hang a second rod from the right string. The same thing happens again, only slower, right? Finally, hang a third rod from the right string. Now everything just hangs there without moving. Jiggle the assembly a little so that the axles and strings sit right. Equilibrium has been achieved.



Forces of leverage with the transmission of forces between wheels. Left: over a belt and transmission cables; right: over gear wheels.

When forces are transmitted using wheels the following rule applies: the force gained is paid for with a greater distance. Because the wheels are connected to each other at their peripheries, a point on the edge of the smaller wheel moves the same distance in 1 second as a point on the edge of the larger wheel. In other words, they have the same peripheral speed. To move the same distance, however, the smaller wheel with the smaller circumference has to rotate more frequently than the larger wheel — it has a higher rate of rotation. If the smaller wheel has a diameter of 1 cm and the larger one a diameter of 3 cm, the smaller one has to turn three times for every single turn of the larger wheel. The ratio of the two rotation rates is 3:1 (three to one). Another term for that is the **transmission ratio**.

The small wheel in our experiment, with its 20 teeth, has to turn 3 times as frequently as the larger one, which is 3 times the size and has 60 teeth. Since the string spools holding the weights on the two axles are equally large, the one for the smaller wheel winds off 3 times as much string as the one for the larger wheel. Only then are the forces involved in the transmission in equilibrium. A crane achieves an increase in force when the relatively small force supplied to a wheel by a quickly-turning motor is transferred to the wheel of slowly-turning cable pulley. In that system, there are many transmission wheels combined into one set of gears. In a gearbox, rotations are transferred from one axle to one or more other axles, usually through toothed wheels, cables, cords, or chains.

Drive shafts of automobiles also turn very quickly, at speeds up to 10,000 rotations per minute! In order for the power of the engine to move a vehicle weighing a ton, it has to be multiplied by the gear assembly as the high rotation speed is correspondingly reduced. The car — unlike most crane cables — has to be able to move at varying speeds, however.

For that reason, the transmission ratio in a car's gearbox has to be adjustable. That is achieved with a gearshift. You start in first gear and then, depending on the desired driving speed, you switch up to fourth or fifth gear. We will investigate the way that a gearbox increases power and decreases rotation speed with an electric crane that we will construct with a two-speed gearbox. To take our readings, you should assemble the force scale for 0 to 7.5 N.

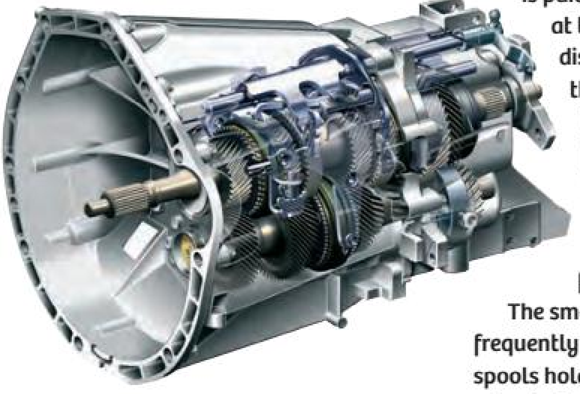
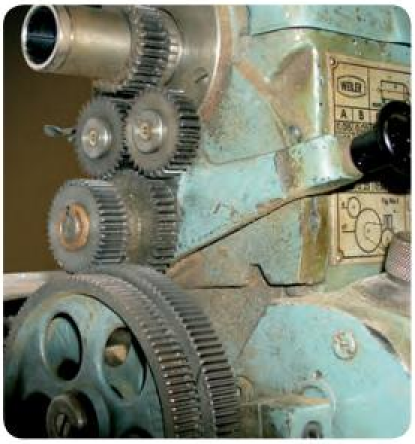


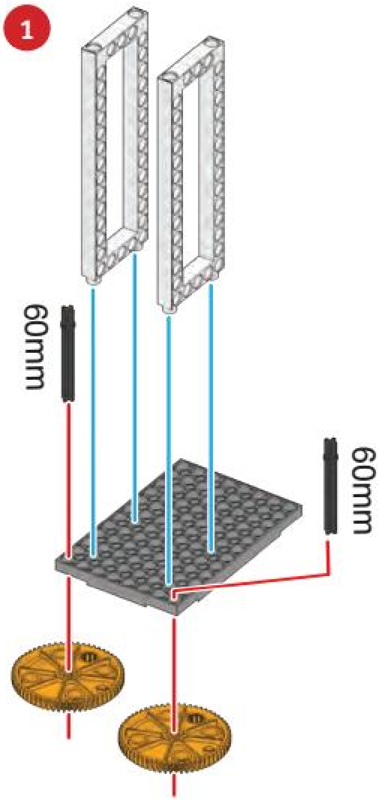
Diagram of the gearbox of a car



Gear assembly of a lathe

Two-Speed Crane with Gearshift WORKSHOP 19

1



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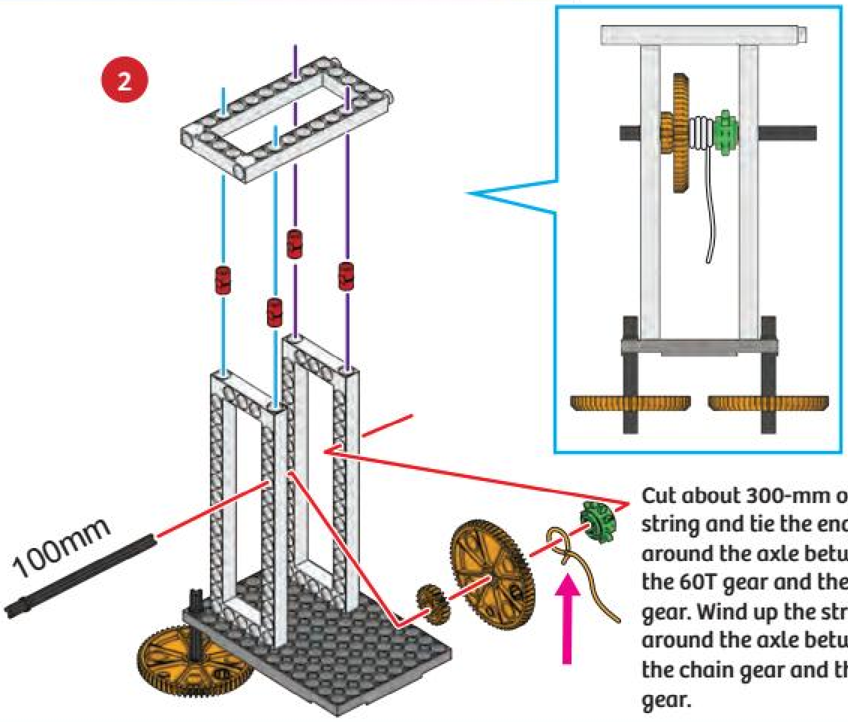
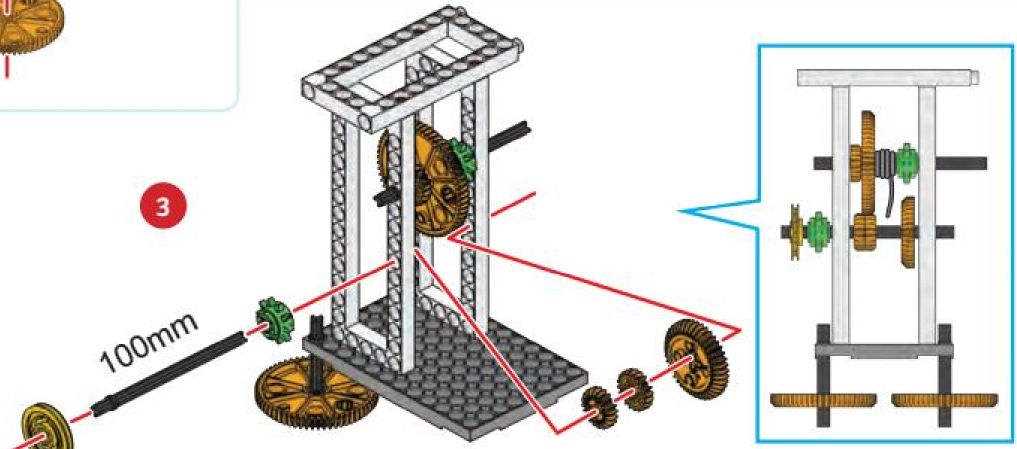


Cut about 300-mm of string and tie the end around the axle between the 60T gear and the chain gear. Wind up the string around the axle between the chain gear and the gear.

3



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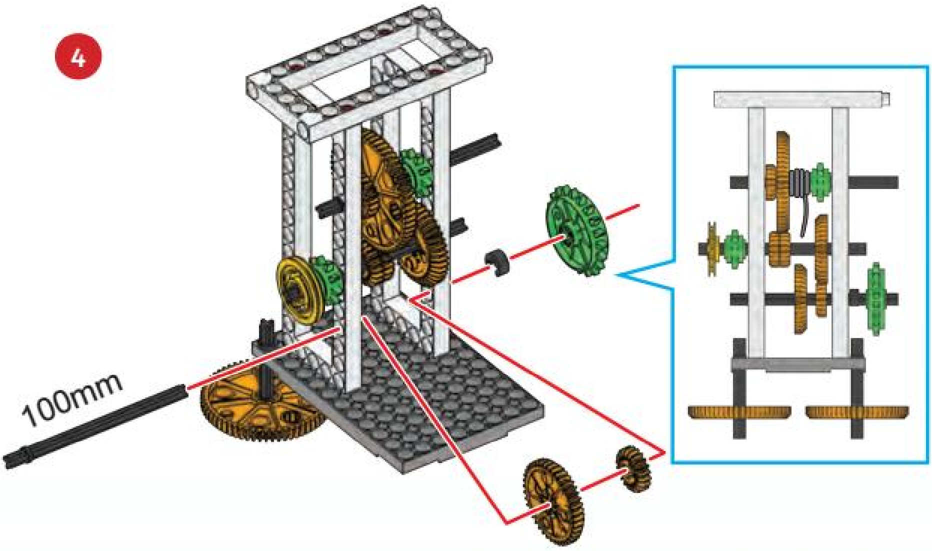
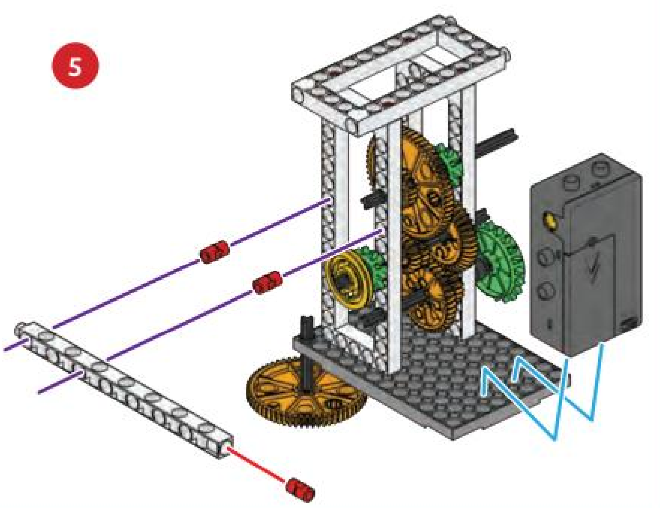
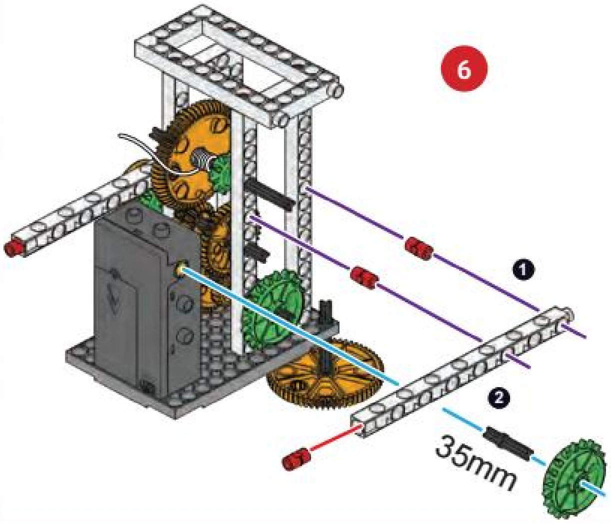
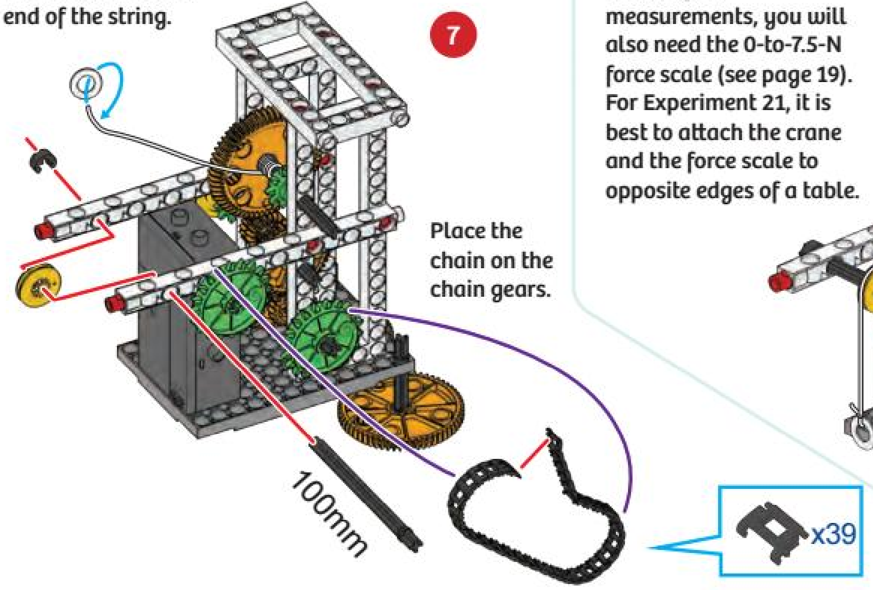




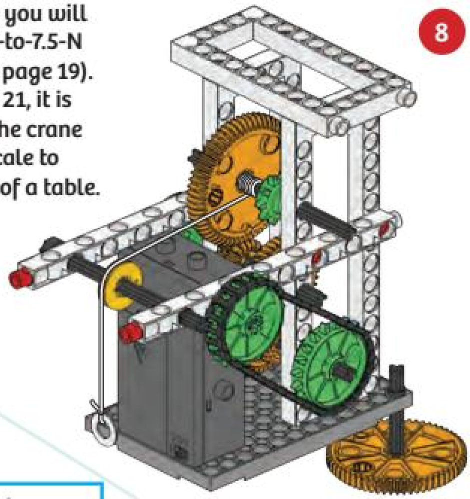


Tie a washer to the end of the string.



Place the chain on the chain gears.

To take your measurements, you will also need the 0-to-7.5-N force scale (see page 19). For Experiment 21, it is best to attach the crane and the force scale to opposite edges of a table.



Done!

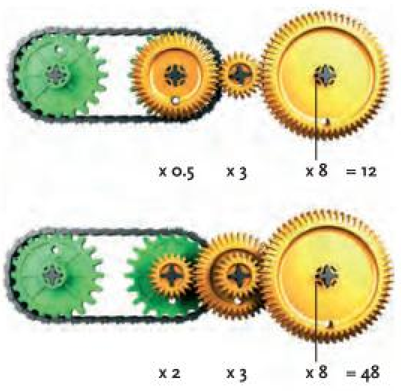
Now try Experiment 21.

EXPERIMENT 21: POWER TEST IN TWO STEPS

Before getting to the force measurement, first check to make sure the gears shift easily. Push the shift wheel's axle back and forth, letting the gears interlock. If they clash, it may be because of the distance between the shift gears, which should be greater than the thickness of a gear. Then switch on the motor and let the string wind up without any load. Next, attach the crane and force scale to two opposite sides of a table, as shown above. Tie the end of the string to the axle of the force scale. Now engage the higher gear, turn on the motor, wait until it comes to a stop and take your reading. Then do the same in lower gear by adjusting the middle axle.

How do you do the two-step increase in power? Take another look at the gear wheels arranged in a line.

In high speed, the gears increase the force 12-fold, in slow speed 48-fold. So in lower gear, the crane pulls four times as many newtons as in higher gear. Do your force readings on your force scale confirm this?

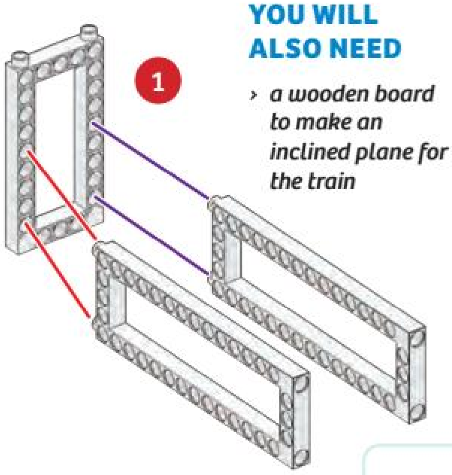


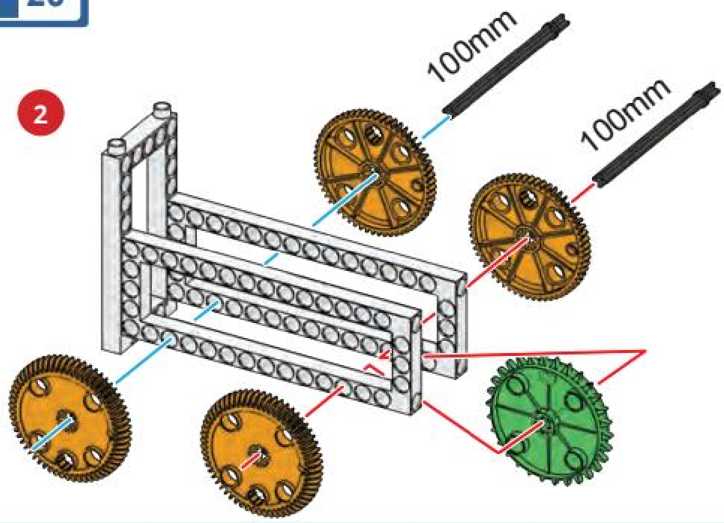
Increase in force in the crane gearbox: Above in high speed, below in low speed.

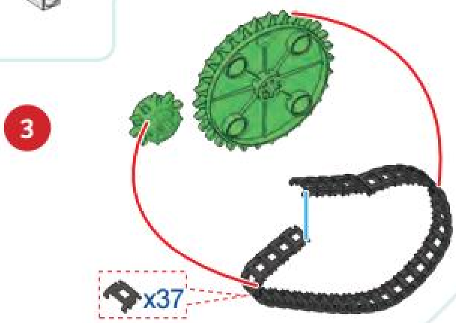
Cogwheel Train WORKSHOP 20

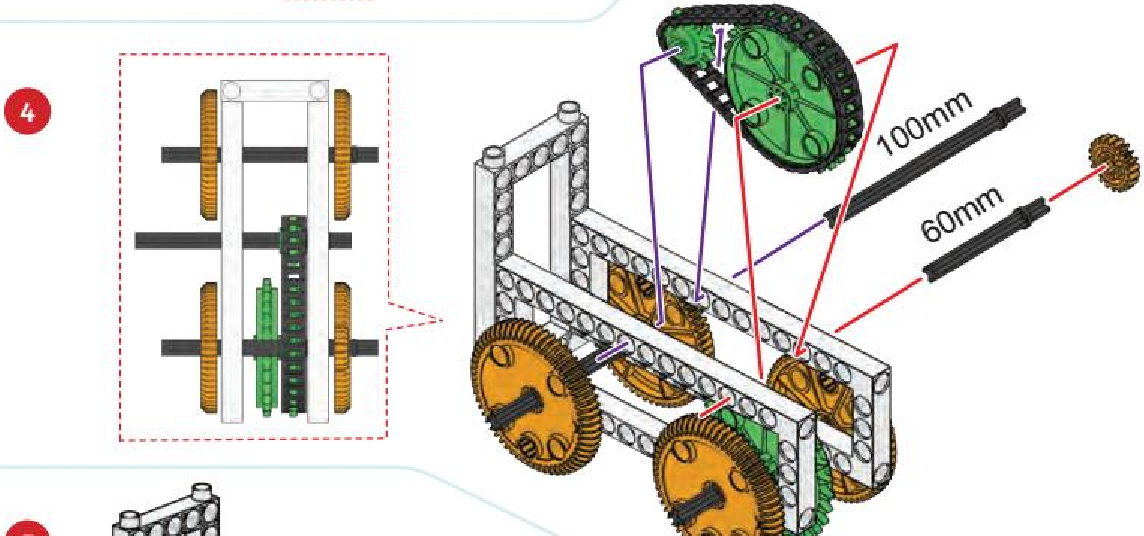
YOU WILL ALSO NEED

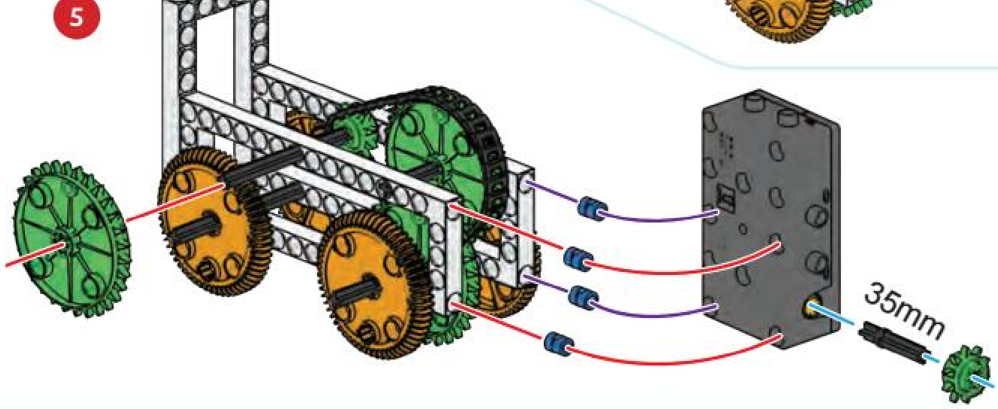
- › *a wooden board to make an inclined plane for the train*











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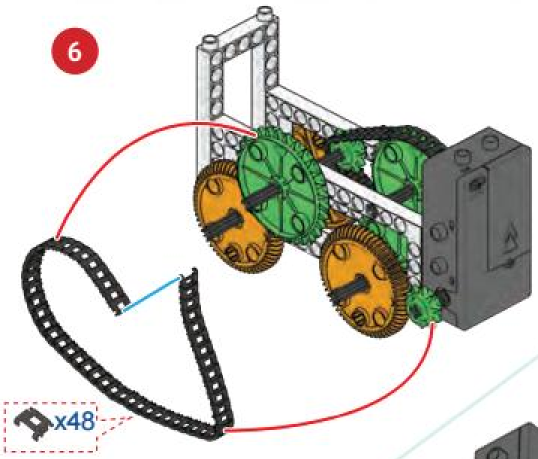

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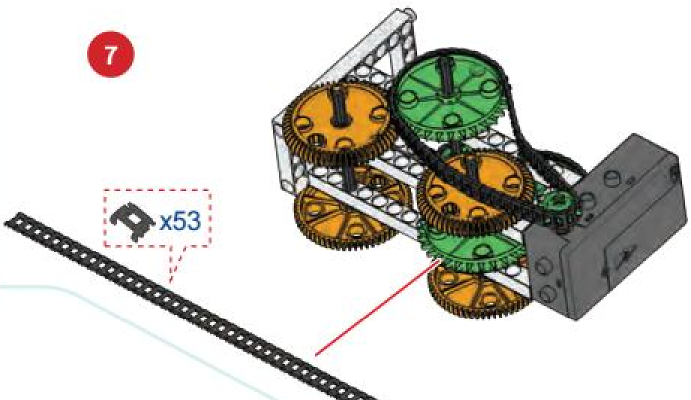

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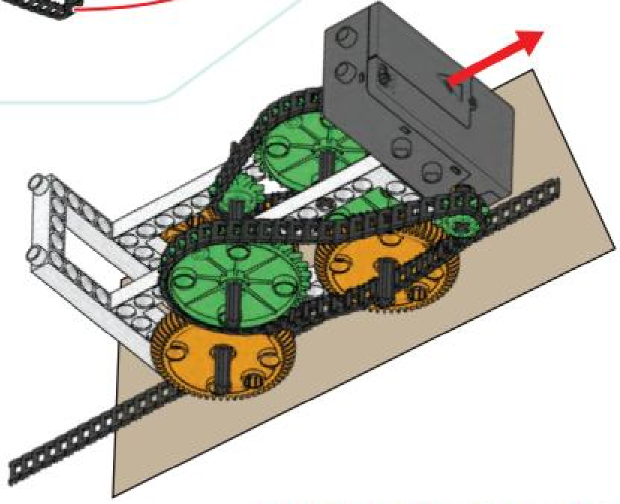


Done!

Use the wooden board to make an inclined plane for the train. Lay the remaining chain down on the board. The heavy motor box will give your train some surplus weight on the incline, and help the 60T gear on the front axle keep a good grip on the stretch of chain.

The train will climb even better if you attach strips of cardboard, 3 cm wide, 1 mm thick, and about 40 cm long, to the board on either side of the chain, for the wheels to roll on.

Tooth by Tooth up the Mountain

Vehicles that need to apply a lot of force to do their work must also be slow, because they need to strongly multiply the force of their engine. Examples are mountain trains, which have to contend with steep inclines. Because the wheels of a normal train would slip on the tracks, a mountain locomotive uses a gear that has teeth that fit into gear or cog holes running between the tracks.

You can build your own cogwheel train. Your model will be able to handle inclines of up to 55%! Instead of tracks, it will run on strips of cardboard.

Transmission of Force with a Crank Drive

With a **chain**, forces and movements can be redirected from a circle into a straight line. Because the chain interlocks with multiple teeth of the gear, it can leave the wheel again at any of a number of spots and thereby be transferred onto a straight line again in correspondingly many directions. Of course, the chain can only transmit pulling movements, because if it were used to push it would come undone. The situation is different with what is called a rack, which is a rigid toothed bar into which the teeth of a gear can fit. Between a **rack** and a gear, forces and movements can be transmitted in both directions, both pulling and pushing.
There are also many machines in which forces must be transmitted from a turning motion to a to-and-fro motion, or the other way around from a to-and-fro motion to a turning motion. This is the task of a crank drive. The best-known kind of crank drive can be found in a car. A car's crank mechanism transmits the to-and-fro movement of the pistons to a rotating movement by way of the bar.

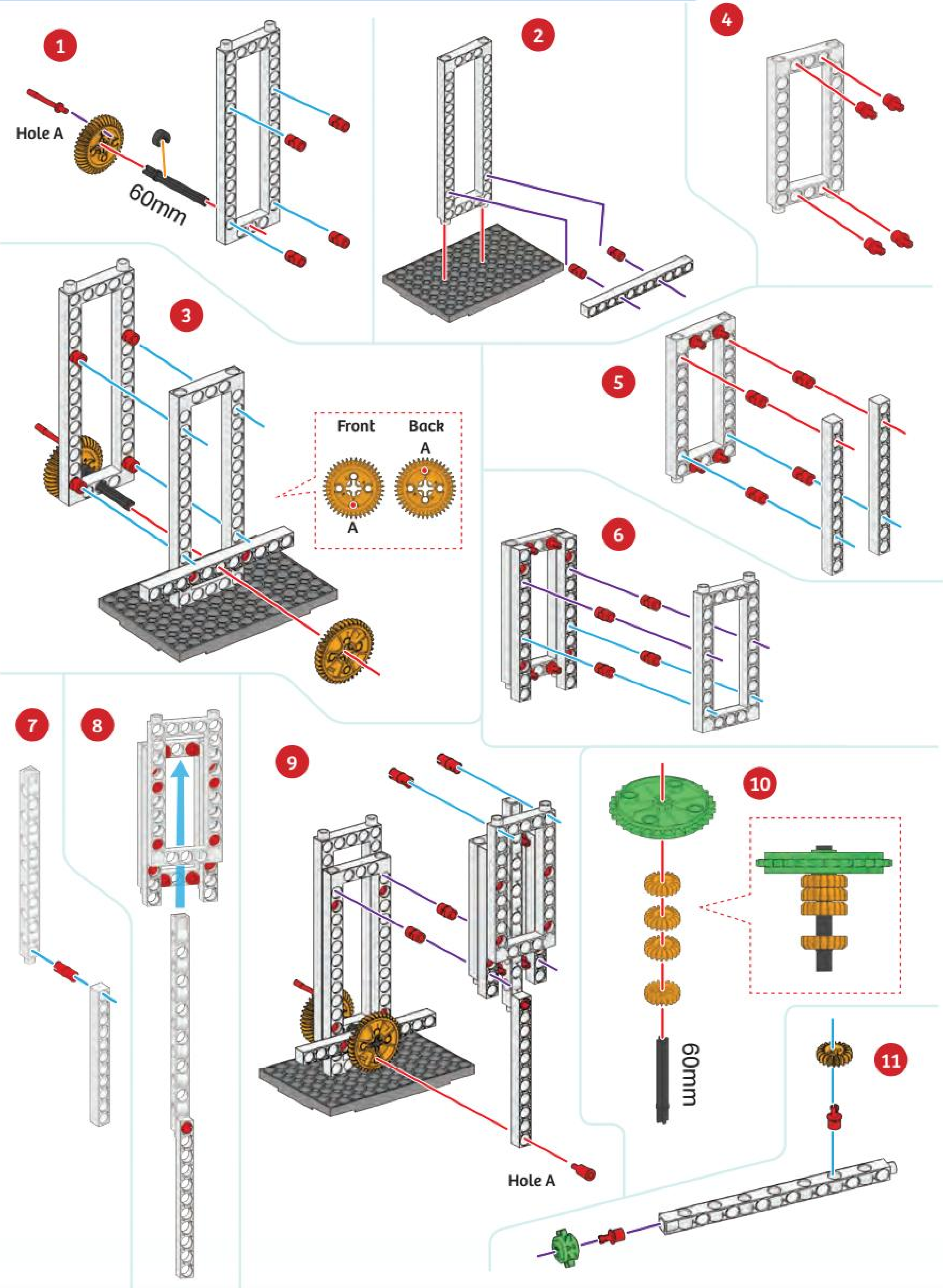
Our jumping jack on the next page also works with a crank mechanism. It uses the rotating movement of the crank wheel to derive an up-and-down movement of the push-stick. The movement conversion is achieved with the help of a drive rod connecting the push-stick and crank wheel. If you want to dress up your jumping jack, try to cover as many mechanical parts as you can. Attach pants and jacket with axles.

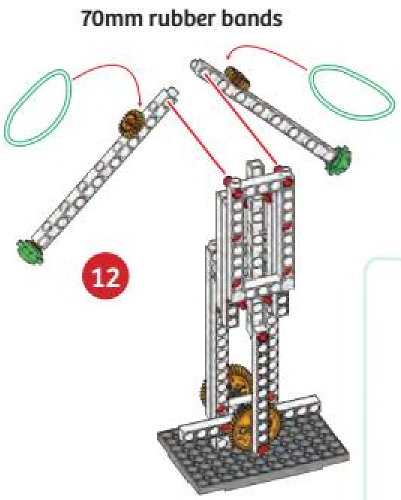
DID YOU KNOW?

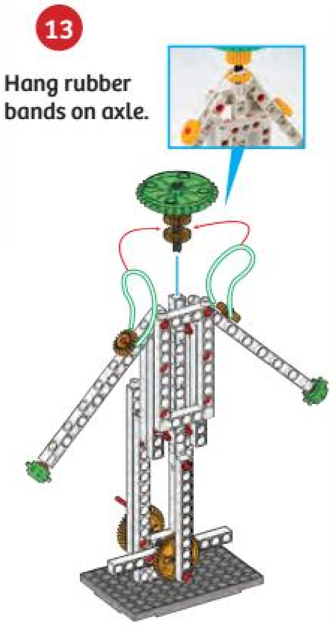
A very good climber

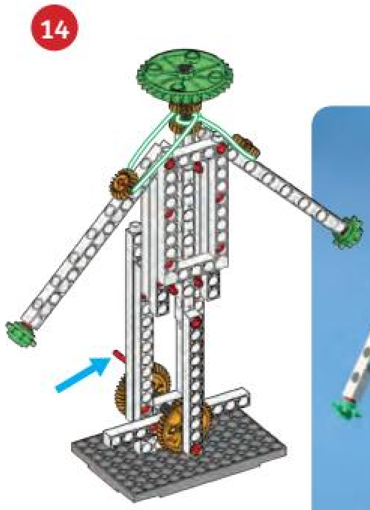
The steepest cogwheel train in the world, the Pilatus train near Lucerne in Switzerland, can climb at a 48% angle.

Jumping Jack with Crank Drive WORKSHOP 21







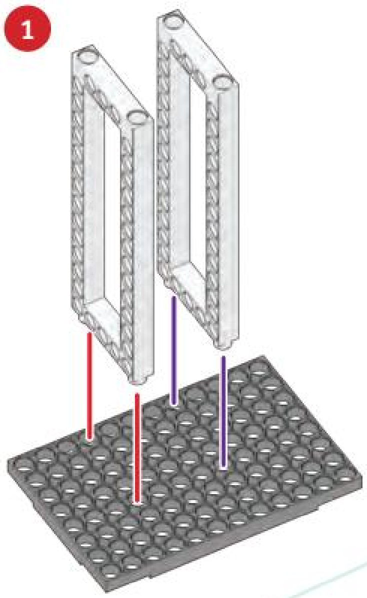


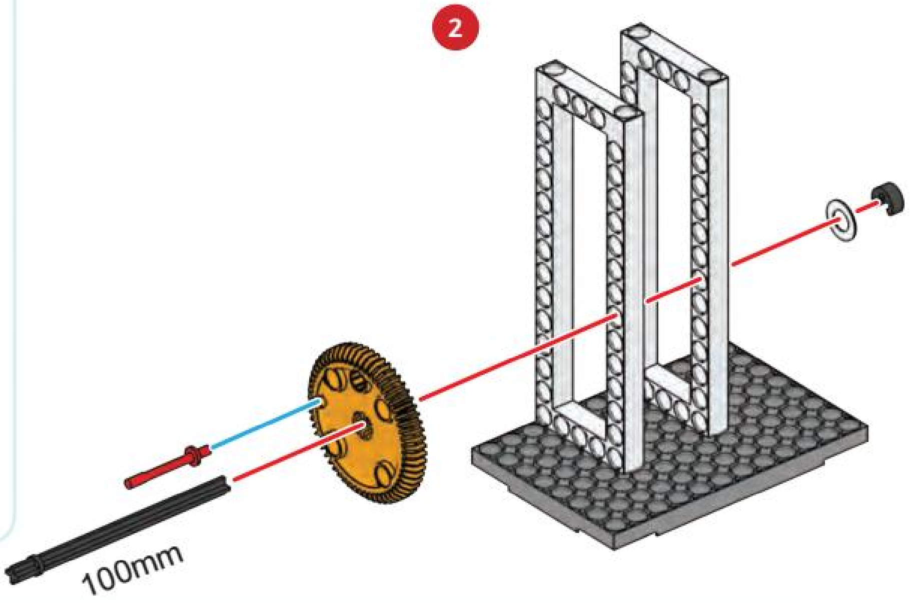
The model's arms move up and down when you turn the crank.

When Timing Counts...

An engineer who builds transmission systems doesn't always want to increase or reduce forces. Sometimes, the goal is just to speed up or slow down movement. Often it's a matter of some sort of switching, measuring, or guiding process linked to revolution speed or the tempo of a back-and-forth motion. (Examples from later chapters are the pendulum clock and centrifugal force switch.) Certain visual effects and optical tricks also depend on a fast tempo. Using appropriately high speeds, it is possible to create the appearance of color and — as in movie and television film — make moving pictures out of static images. The human eye is sluggish, and can only differentiate at most 5 individual images per second; as soon as there are more than that, they start to blur together. A film camera takes 25 to 30 individual pictures per second and the same number are projected per second onto a television or movie theater screen. Our hand-crank theater has just one film consisting of just two pictures. When you turn the crank, the two pictures blend into one image. Part of the movement of the support structure is masked by the white aperture.

WORKSHOP 22: HAND-CRANK THEATER





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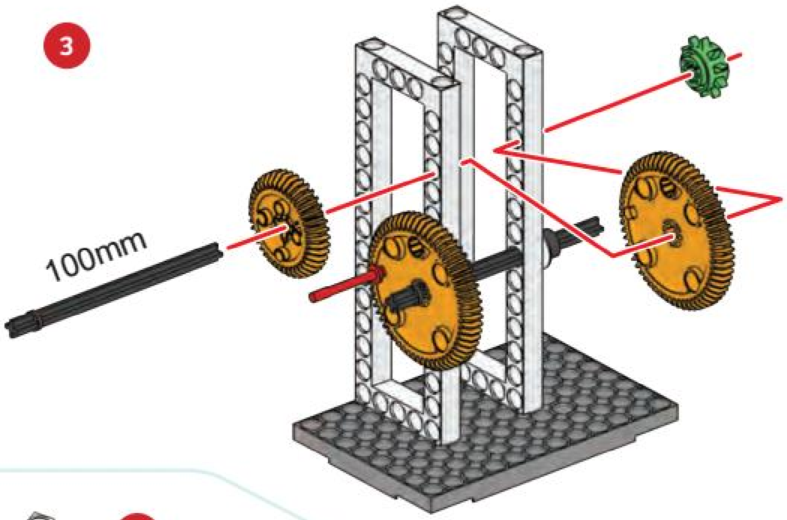

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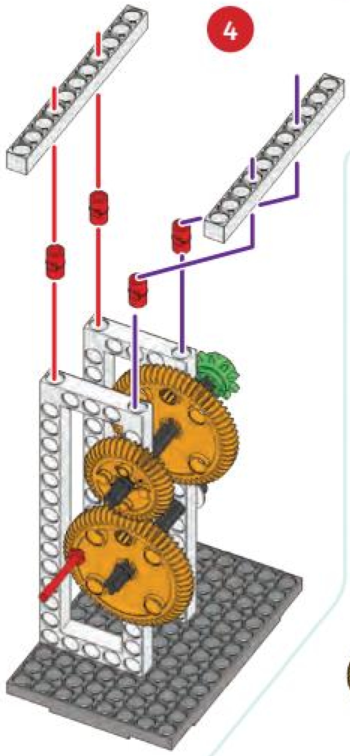

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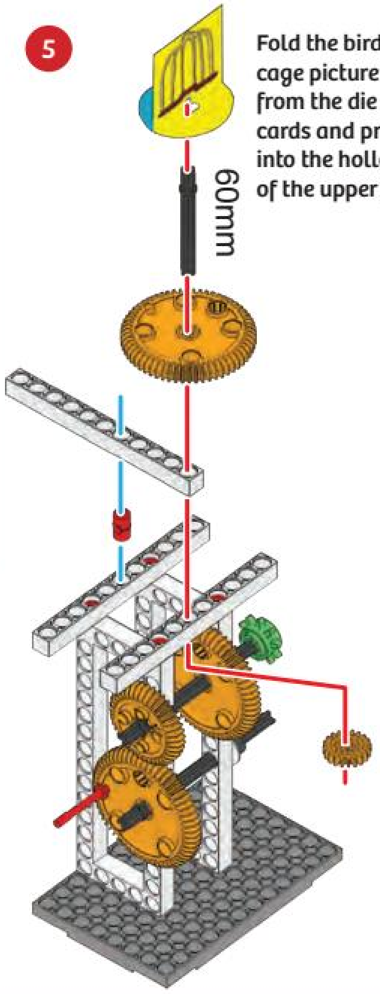
Fold the bird- and-cage picture card from the die cut cards and press it into the hollow side of the upper gear.



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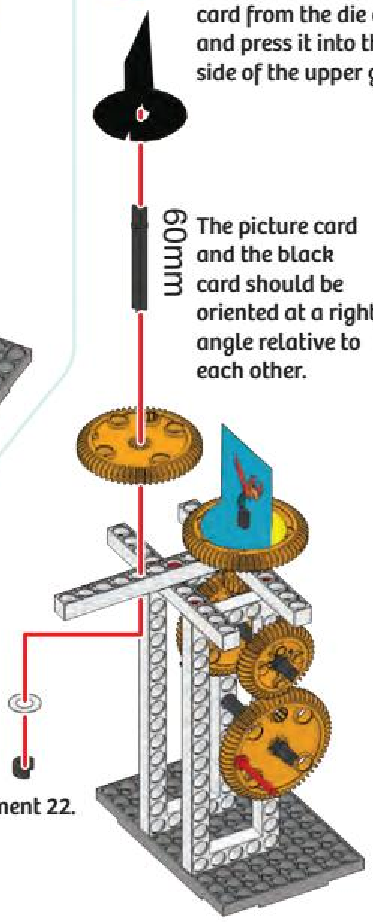
Fold the plain black screen card from the die cut cards and press it into the hollow side of the upper gear.

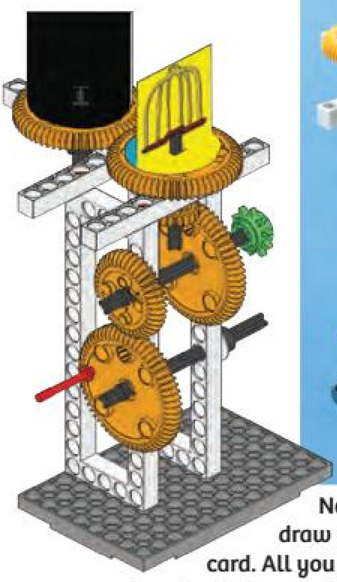
The picture card and the black card should be oriented at a right angle relative to each other.



Now try Experiment 22.

7

Done!



Note: If you want, you can also draw your own pictures on the picture card. All you have to do is fold it backwards, turning its inner white side out. How about a fish in an aquarium? If the screen or image cards come loose because of the rapid movement, you can reattach them with a glue stick.

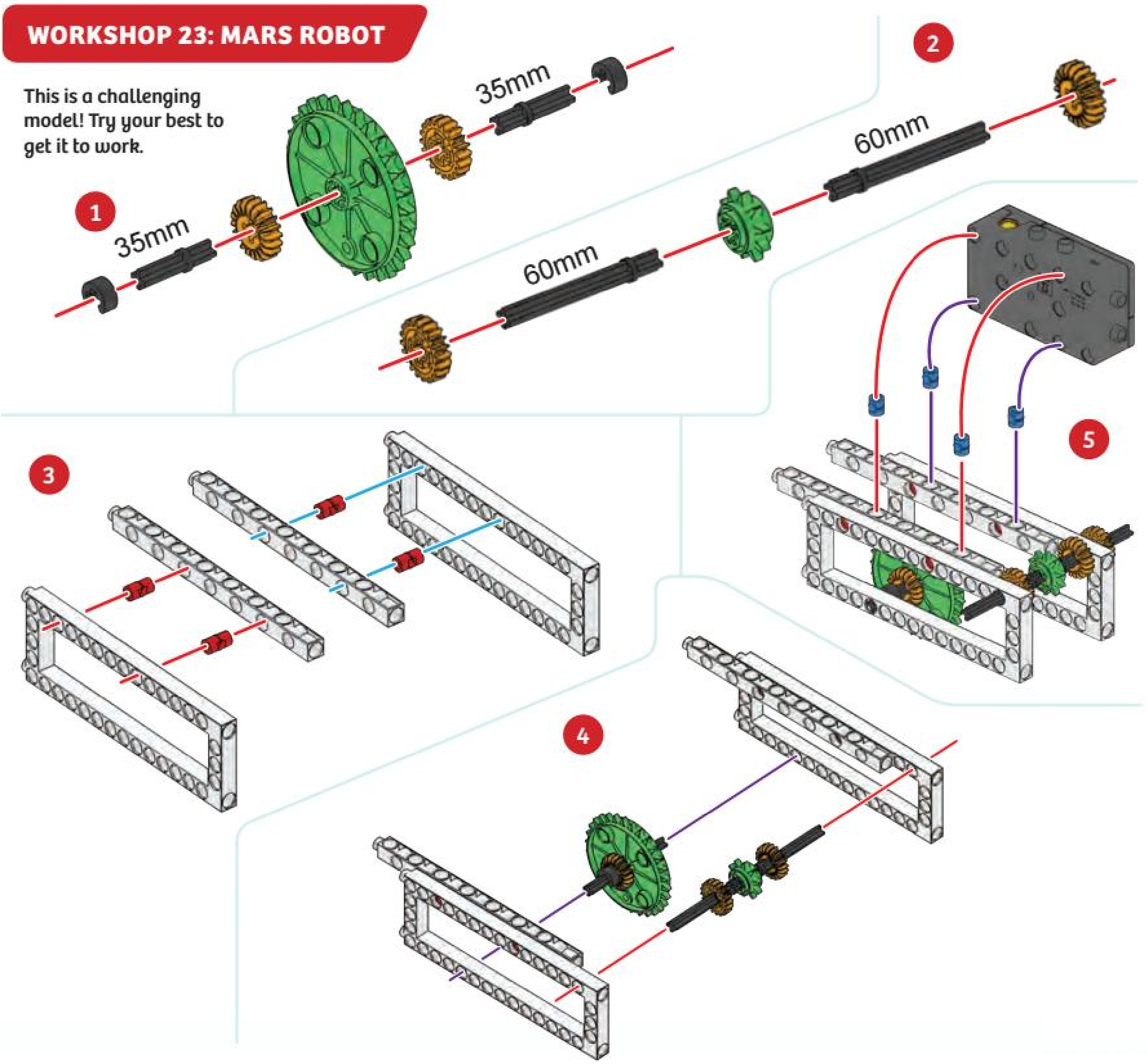
EXPERIMENT 22: THE CAGED BIRD

Hold the assembly in the light of a window, or under a reading lamp that illuminates the picture from above. The background should be dark. Rotate the crank slowly, then gradually faster. The outlines and the colors will start to blend together. Now, take the black screen card away. Do you see the difference? The blended image is a little lighter now but not as sharp. The speed with which the images change before our eyes is so great that we imagine the bird to be sitting in the cage. When you show this trick to your friend, be sure to be the one turning the crank, so you can reveal the bird's secret when you want to.

You have now learned about several types of energy transmission, and become quite a mechanic in the process. Maybe you're now confident enough to assemble our Mars robot, which transmits energy and movement in multiple ways: with gears , with chains, with cranks, and with levers. This robot scrambles forward and backward like a spider over rocky and smooth terrain. When its legs fail it, the caterpillar tread under its belly comes to its rescue.

WORKSHOP 23: MARS ROBOT

This is a challenging model! Try your best to get it to work.



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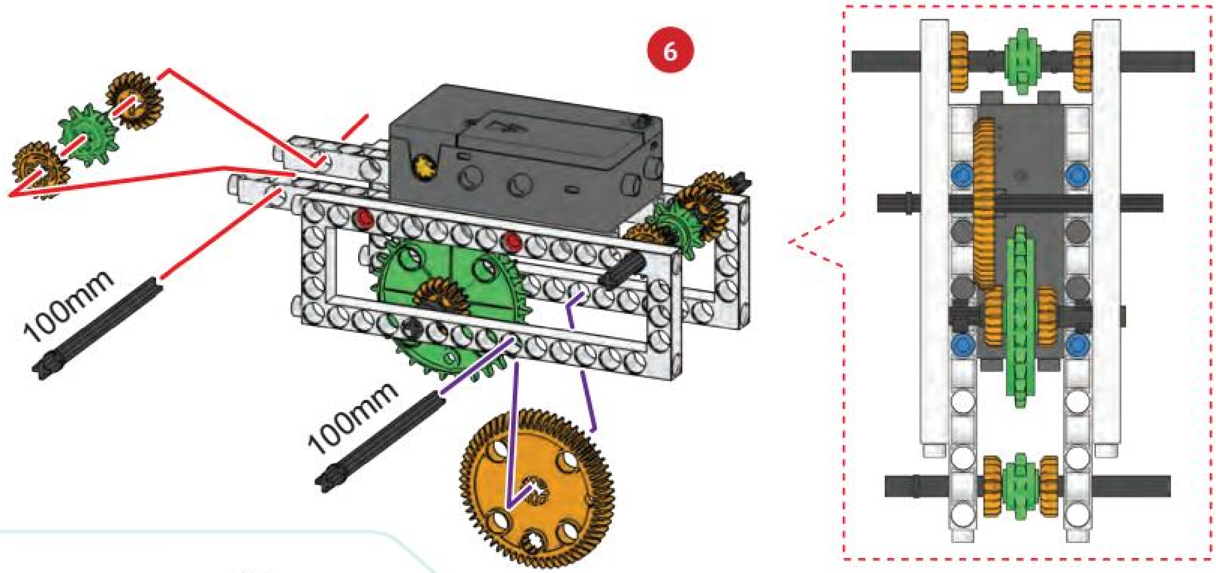

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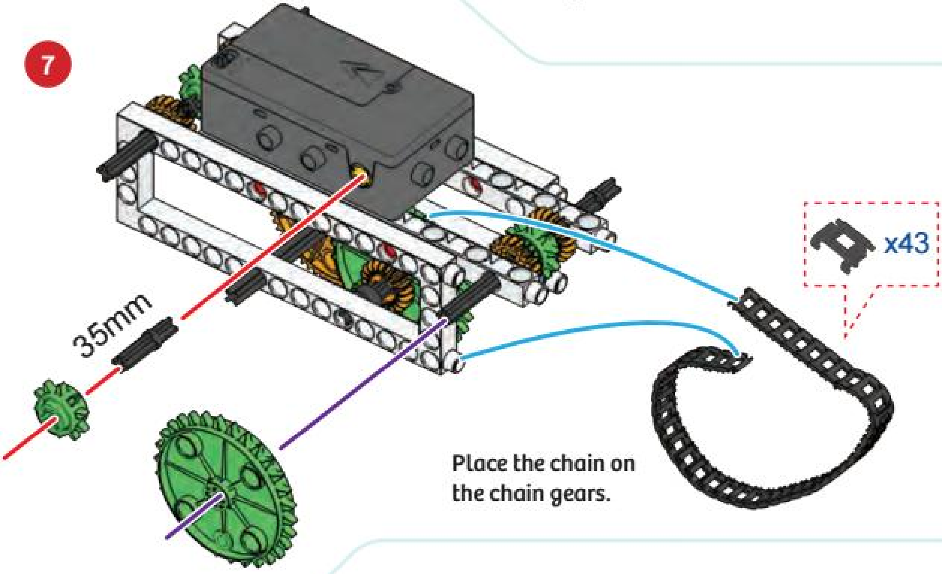
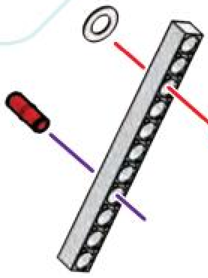
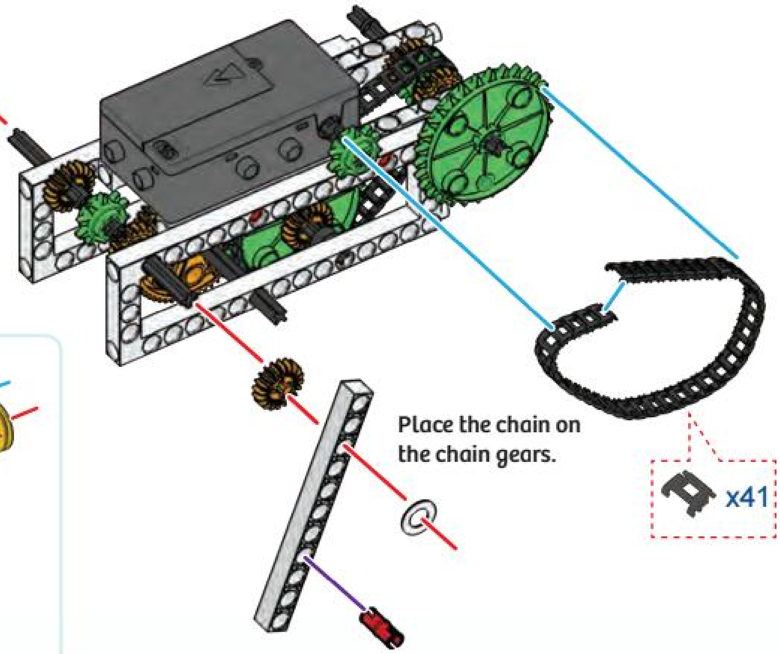


Place the chain on the chain gears.

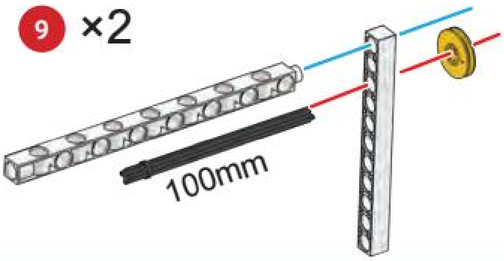
8





Place the chain on the chain gears.

9 ×2



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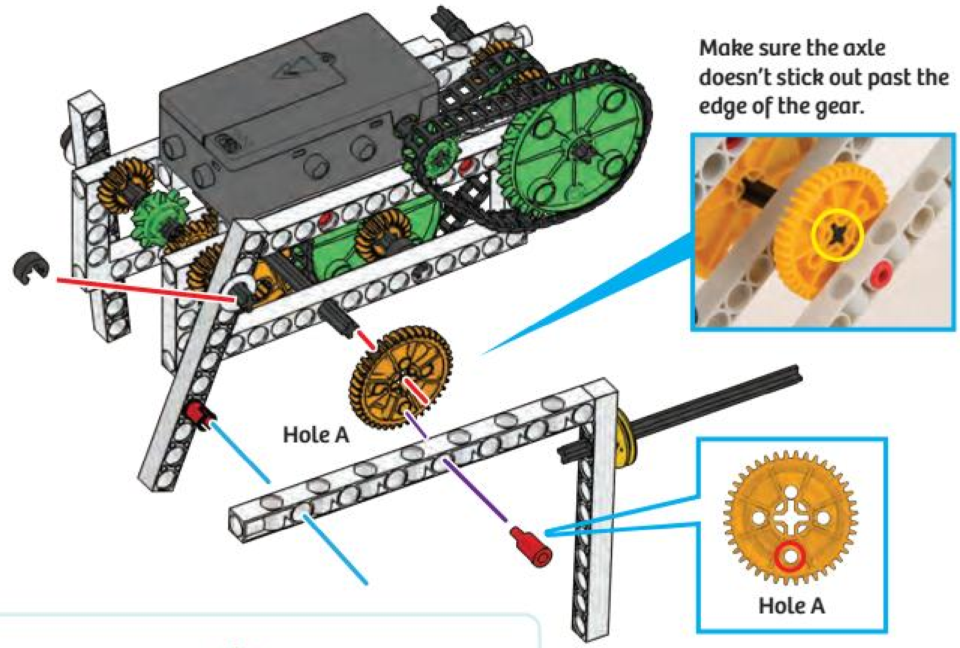
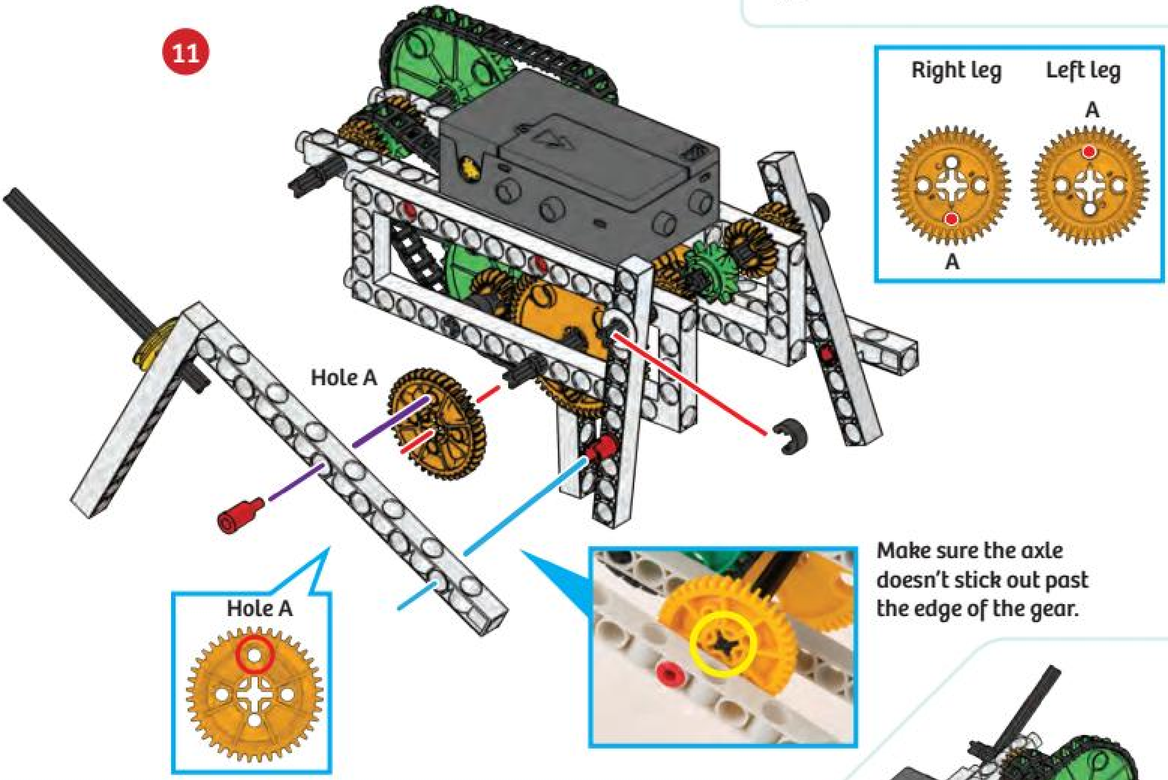


Make sure the axle doesn't stick out past the edge of the gear.

11



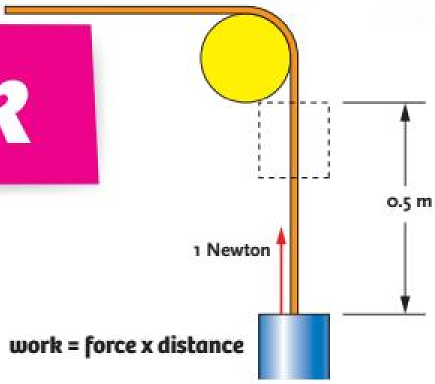
Make sure the axle doesn't stick out past the edge of the gear.

12

You can adjust the gait of the Mars Robot by varying the angle of its front legs. Both drive chains should hang a little loose. Check each time before starting the robot to make sure the axles sit securely in the holes of the rods.

Done!

Forces at Work



In the crane experiment in the last chapter (Experiment 21), you were able to see how the force pulling on the cord could be changed with the use of a gearshift. In low gear, the force was about 6 N, about 4 times as great as the 1.5 N exerted in high gear. These, at least, are the top forces that the motor can muster with a fully charged battery. (If your results were different, it probably had to do with the battery being less than fully charged.)

Those are the forces that the motor was able to put out. But a crane's cable should be able to move and lift something, and its motor has to be able to do that work without dropping its load. In these cases, it can only do that if just 4 N, or 1.5 N, of force is pulling on the end of the line. So the crane can handle a load of about 0.4 kg (400 g), or 0.1 kg (100 g).

KEYWORD: WORK

The transfer of energy, measured as the product of the force applied to a body and the distance moved by that body in the direction of the force.

What is Work?

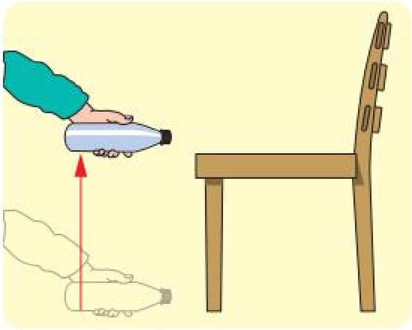
Let's assume that the crane has to lift the smaller load of 0.1 kg to a height of 0.5 m, in both gears. In both cases, it would do the same amount of **work**, namely lift the load 0.5 m. Right? True, it would do the work more quickly in high gear, but the time it takes to do the work is not what's under discussion here. In both cases, the crane does its job. It's the same as with homework assigned for school: one student may need an hour to finish it, another student maybe half an hour. But both students do the same work.

But how do we measure work? The crane's work consisted of exerting a force of 1 N over a distance of 0.5 m. A physicist would say: if a force moves an object a certain distance, then it "performs work" with respect to it. Work is equal to the product of force times distance:

Work = Force x Distance

Described in the relevant units: work = newtons x meters, or newton meters, abbreviated Nm. The newton meter (Nm) is the unit of measure for work. Other equivalent terms are joule and watt second: 1 newton meter (Nm) = 1 joule (J).

If distance is always part of the definition of work, a mere effort of force is not, in itself, work. For example, you hold a full bottle of water for one minute in your outstretched hand. Your arm starts to shake. How much work have you accomplished? None! Only when you move the bottle can you start talking about work.

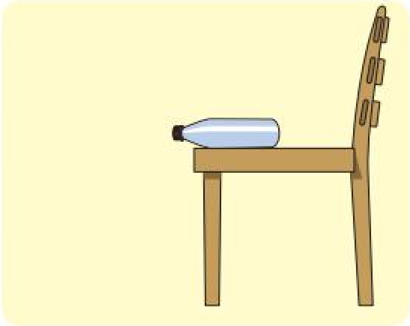


Just holding the bottle doesn't count as work. But you perform work when you lift it onto the chair.

Energy Can Change into Work

Let's stick with the bottle example. Imagine that there's a chair on the table, and you have lifted the bottle from the table surface up to the seat of the chair, thereby performing work. Now you put the bottle down on the seat of the chair. So what is the result of all your work? Has your effort been wasted? Not at all, it's sitting there on the seat of the chair, in the form of energy. Energy? But there's nothing moving! True, but there could be. Stored work is called energy. And this energy can be turned back into work again. A physicist would say:

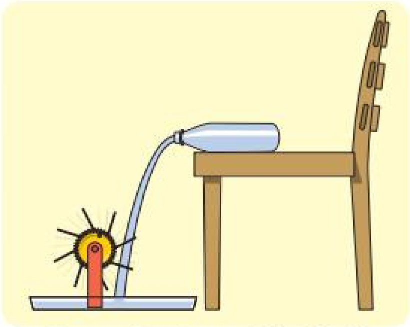
Energy is the capacity of an object to do work.



The bottle on the chair contains potential energy.

Like work, energy is measured in joules or watt seconds.

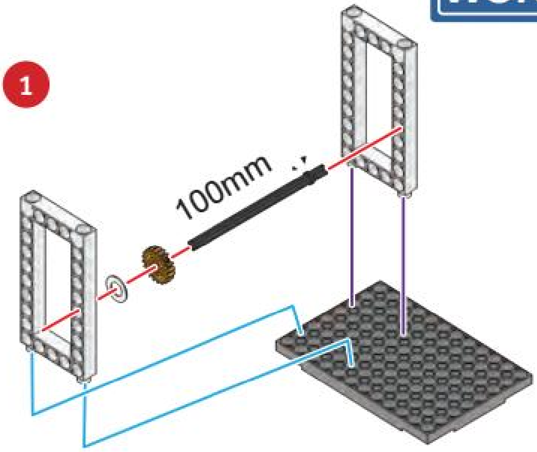
Let's stay a little while longer with our bottle example, and let it do some work for us. We will build a small water wheel that pushes a drive rod back and forth, thereby doing work in its own turn. If you are able to attach a small saw blade to the drive rod, you have built a model of a water-powered sawmill, which still operate today in isolated, water-rich mountainous regions.



The stream of water contains kinetic energy.

WORKSHOP 24 Water-Powered Sawmill

1



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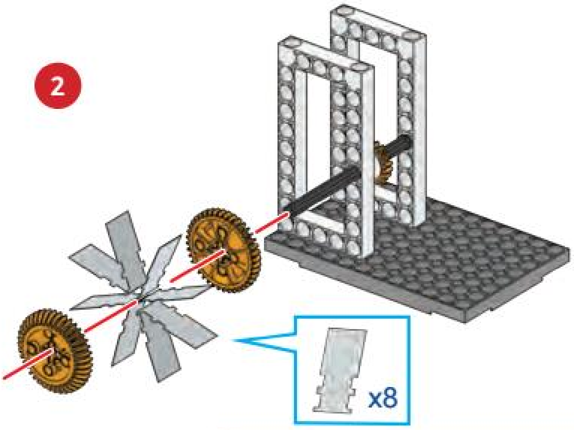
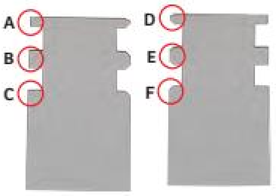


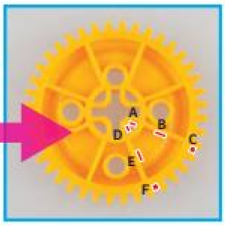
Waterwheel assembly



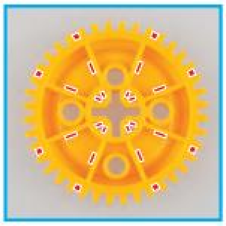
Insert the die cut plastic sheet into the interior compartments of one of the gears and hold them in place with the other gear.

① Put one gear in place.

② Insert 2 blades into the gear at points A – F.

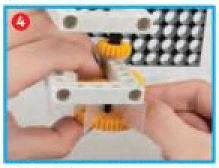


This picture shows points A – F.



In the same way, insert the other 6 blades.

③ This picture shows all 8 blades in place.

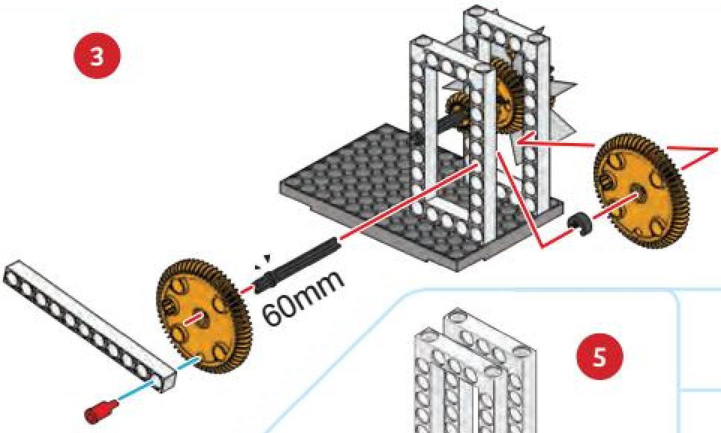


④ Attach the other gear. Adjust the blades to fit.

⑤ Adjust the blades one by one to fit the second gear.

The waterwheel is finished.

3



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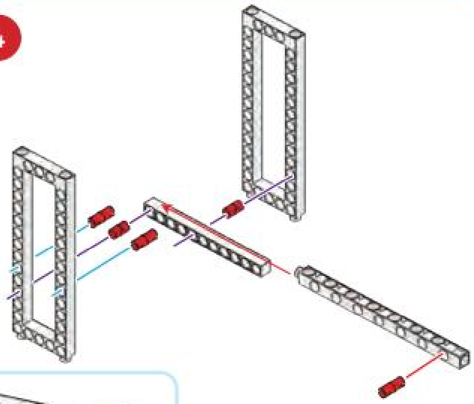

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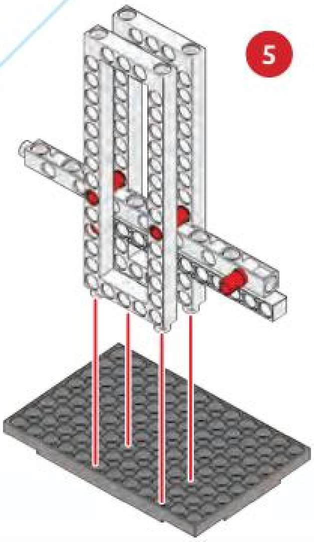

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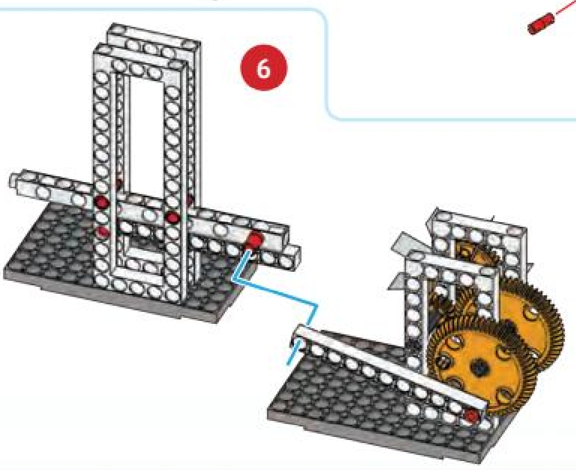

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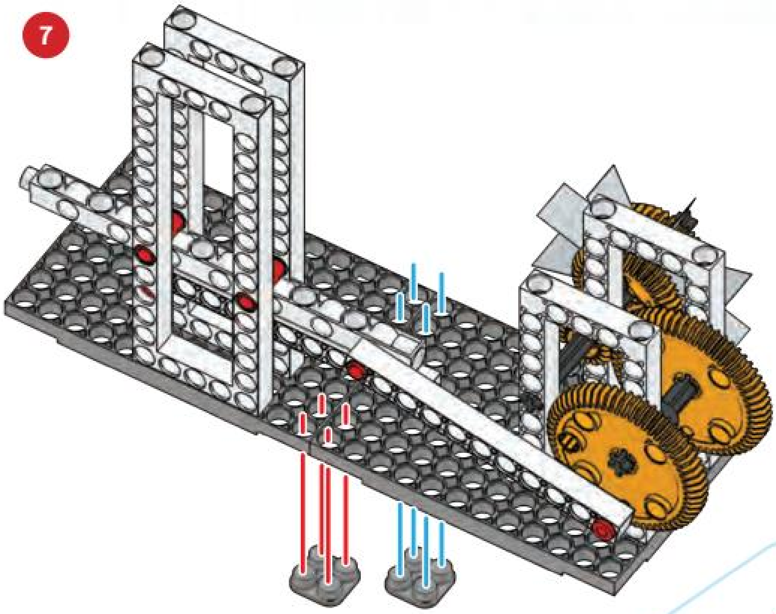

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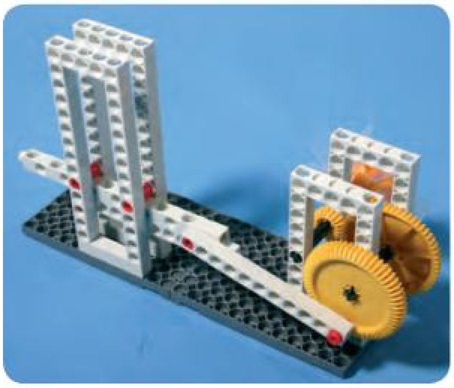
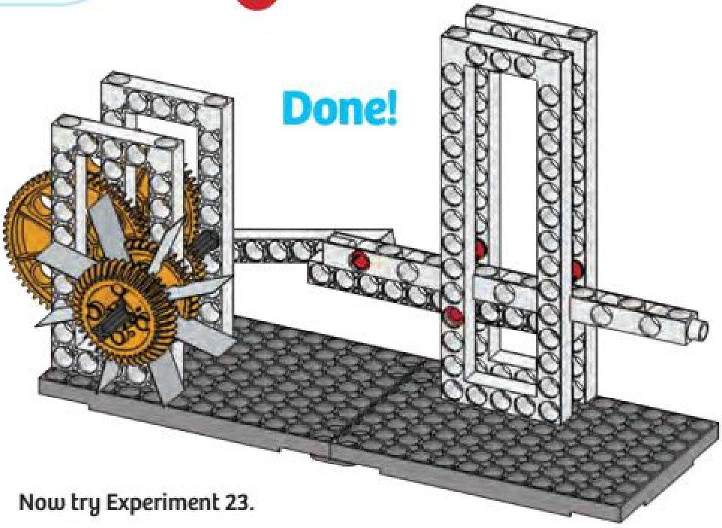
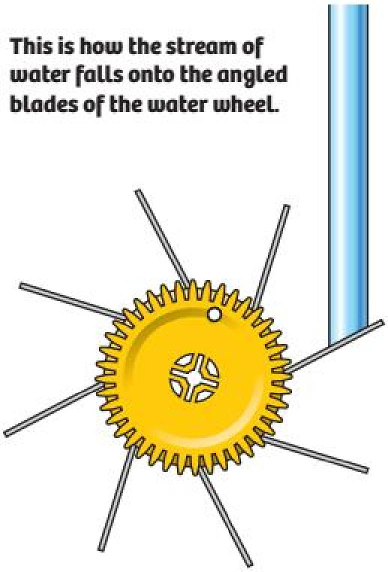




Done!

Now try Experiment 23.

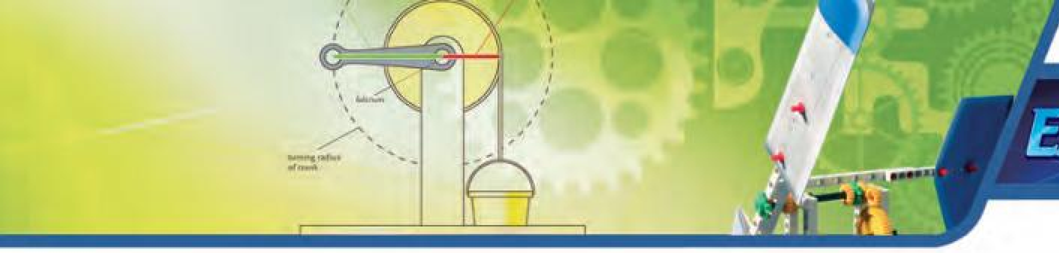
This is how the stream of water falls onto the angled blades of the water wheel.



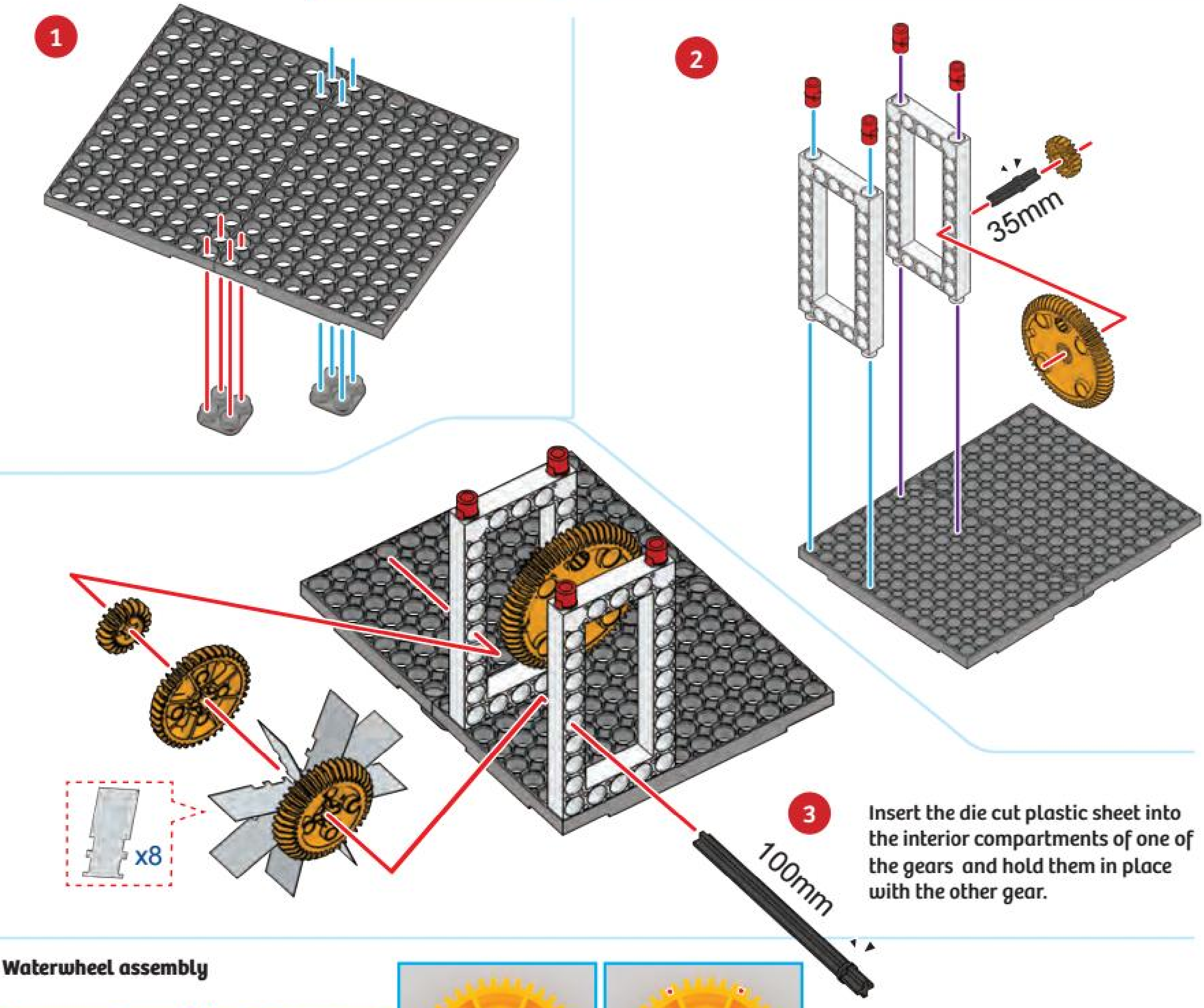
EXPERIMENT 23: ENERGY IN A BOTTLE

Place your water-powered sawmill in a bowl, in the sink, or in the bathtub and fill a bottle with water. Lift the bottle a little higher than the water wheel and let the water flow out slowly so that the stream hits the center of the blades. Then, gradually raise the bottle higher and higher. Repeat the entire procedure, but this time try to slow the back-and-forth movement of the rod a little bit by holding it between your thumb and forefinger. Do you notice something?

The waterwheel turns faster and faster as you raise the bottle higher. Why? Because the water's descent speed gets faster. When you repeat the experiment, you can verify that the rod moves with greater force as the water drops from a greater height. Of course, you can also try running your little power plant with a stream of water from a tap. The water pressure makes the machine run even faster and stronger. Then you can try building a small water mill. You can use its horizontal turntable as a grinding wheel (glue on sandpaper with a glue stick) or as a miniature potters' wheel for clay or modeling clay.



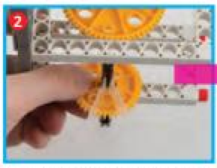
WORKSHOP 25 Water-Powered Potter's Wheel



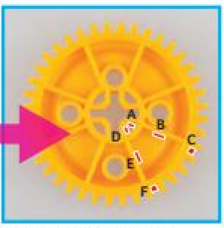
③ Insert the die cut plastic sheet into the interior compartments of one of the gears and hold them in place with the other gear.

Waterwheel assembly

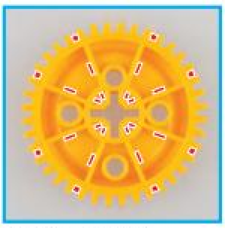
Put one gear in place.



Insert 2 blades into the gear at points A – F.



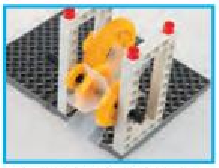
This picture shows points A – F.



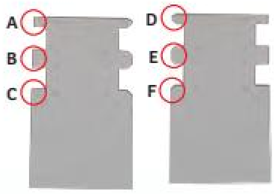
In the same way, insert the other 6 blades.

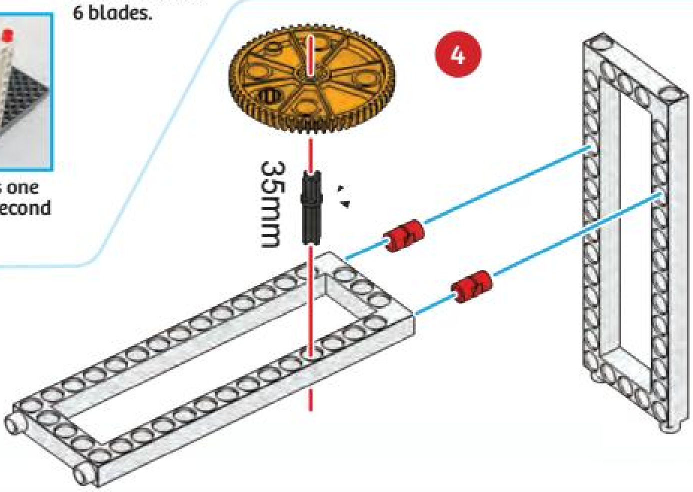
This picture shows all 8 blades in place.

Attach the other gear. Adjust the blades to fit.



Adjust the blades one by one to fit the second gear.





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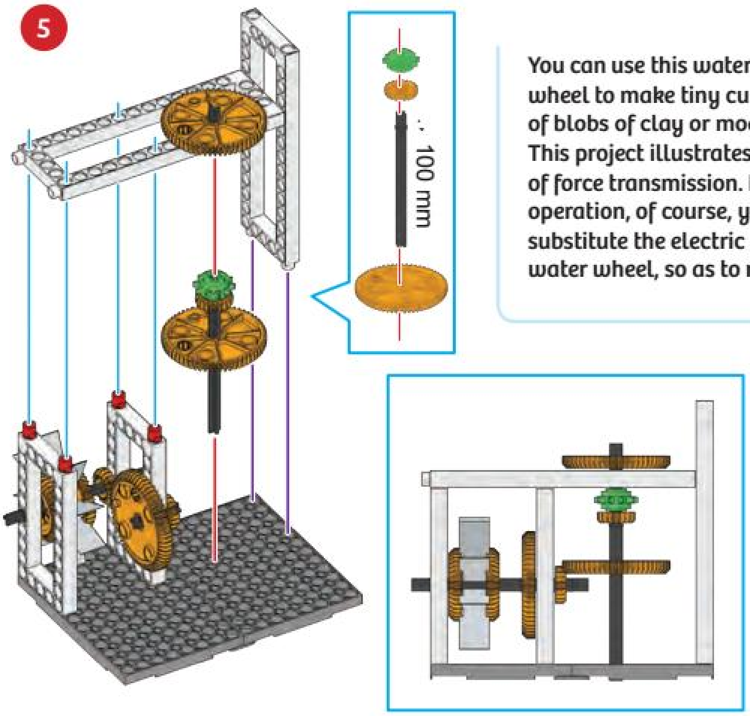
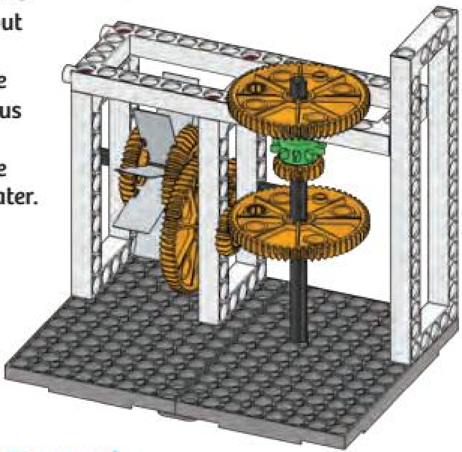


You can use this water-driven potter's wheel to make tiny cups or vases out of blobs of clay or modeling clay. This project illustrates the principle of force transmission. For continuous operation, of course, you could substitute the electric motor for the water wheel, so as to not waste water.

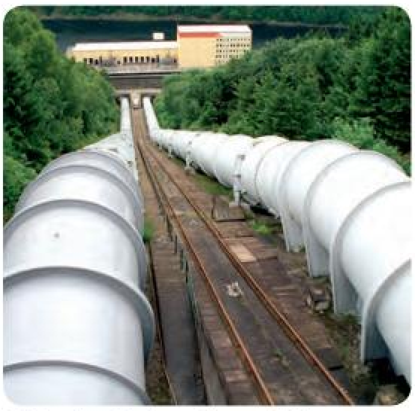
6



Done!

Energy is Changeable

All right, where are we in our work and energy experiments? You lifted the full bottle up a certain vertical distance, which was your work. Up there, the water in your hand was stored work. In other words, it was energy that was created by the higher location of the water. Physicists refer to this as **potential energy** (Latin: *potentia* = power, possibility). As the stream fell toward the wheel, the water went into motion. In the process, its energy changed its state: potential energy was changed into **kinetic energy** (Greek: *kinesis* = movement). The kinetic energy of the falling stream of water performed work on the water wheel. After your preliminary work, this was the water's work. Of course, not all the potential energy can be transformed into work at the drive rod. There are losses at the water wheel, and in the wheel housing and the saw track there are losses due to friction. Kinetic and potential energy are forms of mechanical energy.



Water shoots down from a high reservoir through these conduits onto the blades of a turbine.

This water wheel, a Pelton turbine, transforms the kinetic energy of water into mechanical energy. The energy turns a generator, which turns the mechanical energy into electrical energy (electricity).

DID YOU KNOW?

China's mega power plant

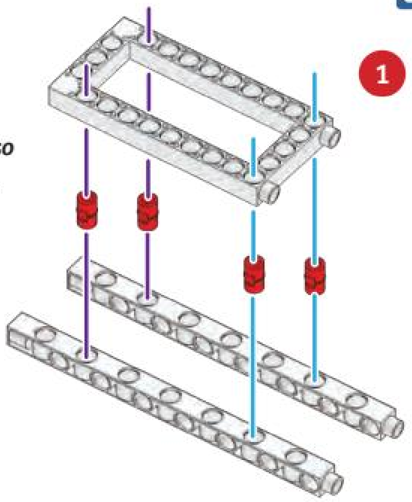
The largest hydroelectric power plant in the world is on China's Yangtze River. Starting in the year 2009, its production is supposed to be 18,200 megawatts (MW), or 18 billion watts (W). That is enough energy to provide electricity to 100 million people. In 2004, the first stage of the power plant was completed, producing 550 MW of energy which was fed into the power grid. To build the plant, the Yangtze River was dammed and a vast lake was created, flooding many valleys, villages, and towns. All of their residents were relocated beforehand; now, they live in new settlements above the lake's water line.

WORKSHOP 26 Rubber Band Car

YOU WILL ALSO NEED

- *a thin rubber band or elastic cord (You can also use one of the kit's long rubber bands, but you will have to cut it.)*

1



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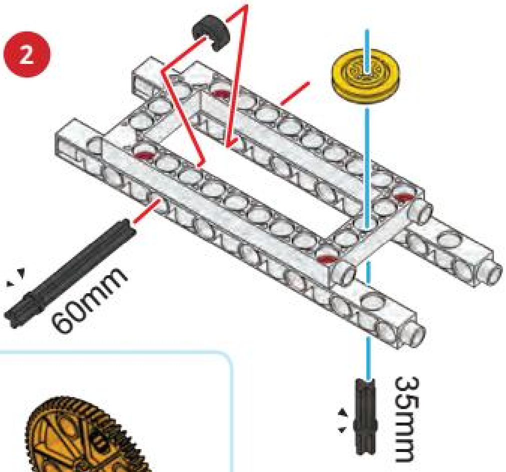

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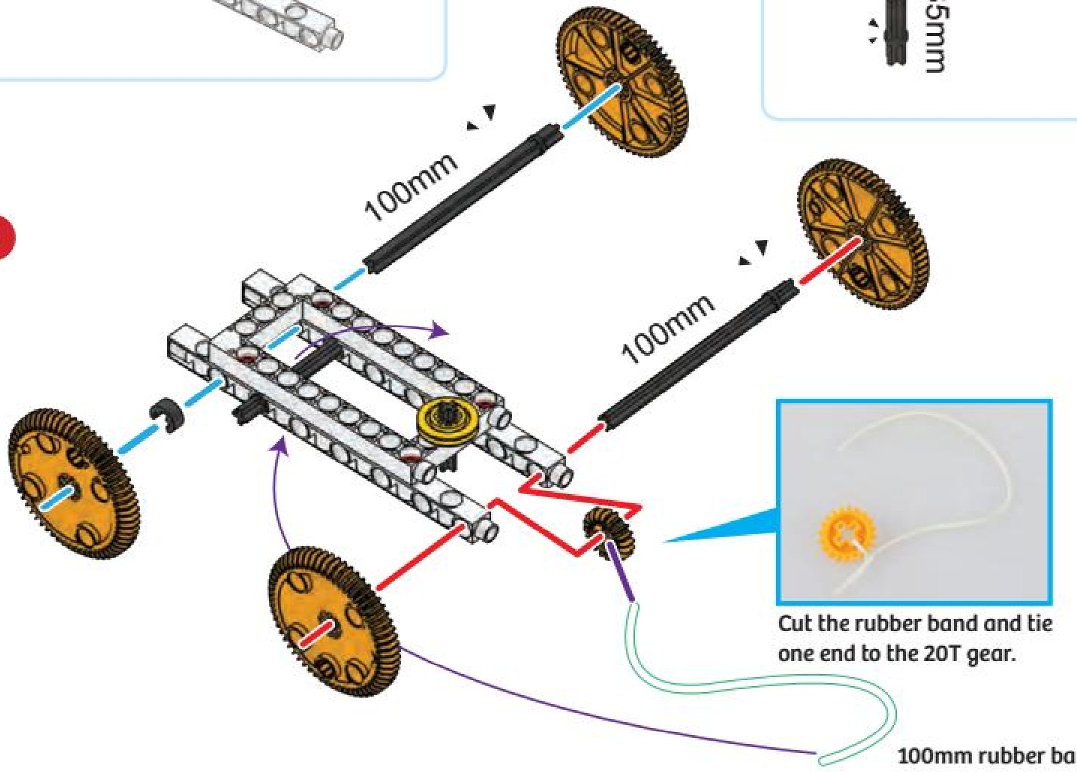
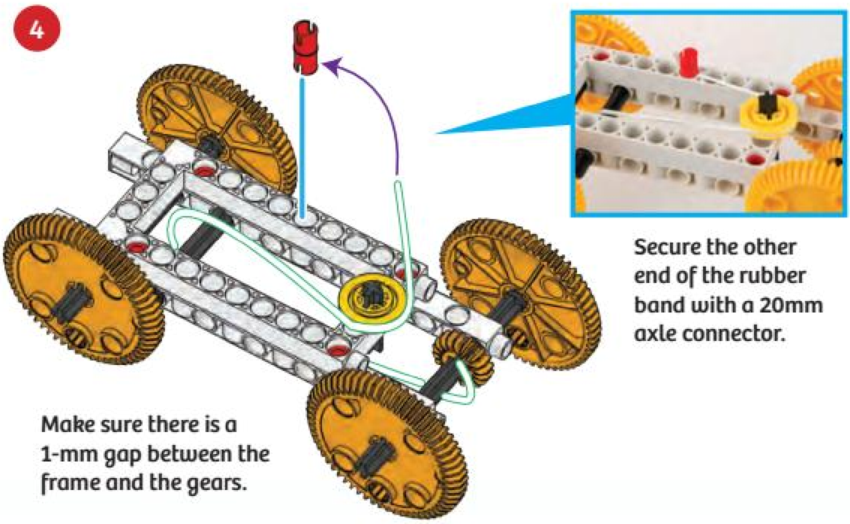


Cut the rubber band and tie one end to the 20T gear.

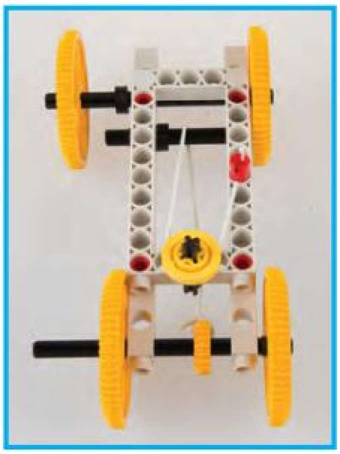
100mm rubber band

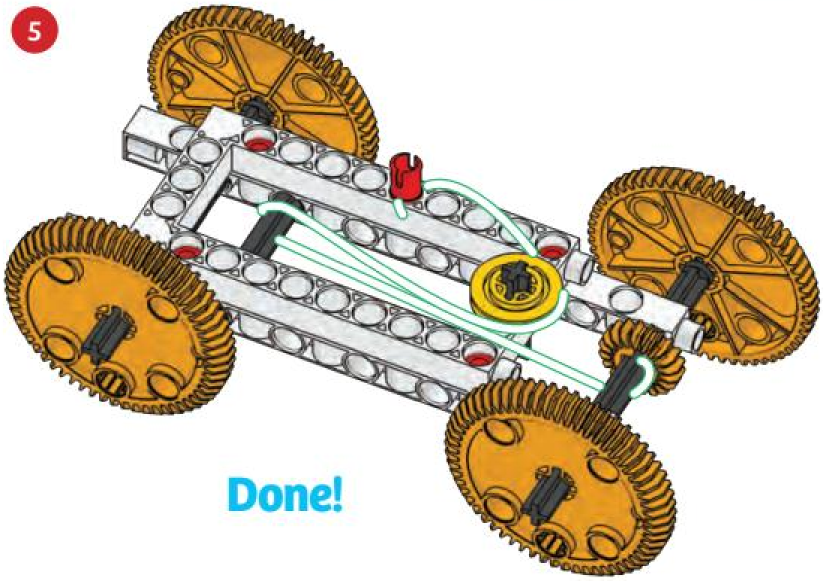
4



Secure the other end of the rubber band with a 20mm axle connector.

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





Find the most smooth and even stretch of floor in the living room to serve as a track, wind up the rubber-band motor (by rolling the wheels in reverse or turning a crank handle in one of the drive wheels), and set your car loose on its first test drive!

DID YOU KNOW?

The human bio-power plant

The human body requires a temperature of almost 37 degrees Celsius (°C), or 98.6 degrees Fahrenheit (°F). We "burn" some of what we eat in order to maintain this temperature. In a surrounding temperature of 18°C (65°F), we steadily give off about 75 Watts of heat, the same level of energy as a standard light bulb uses. When we start feeling cold, a little movement helps to bring things back into balance. We are, in effect, a biological power plant — a walking, talking, heating system. Our bodies get bio-energy by burning fats and carbohydrates from our food, which releases heat, uses oxygen, and releases carbon dioxide.

The kinetic energy of falling water is mechanical energy and is converted into mechanical work. The energy in a wind-up mechanical kitchen timer or toy car, in a spinning top (page 101), or in a swinging pendulum (page 89) — all of these are examples of mechanical energy as well. Energy also occurs in other forms: as heat energy, for example, or chemical or electromagnetic energy. Your water wheel works with gravity, which is, after all, what makes the water fall. The pendulum clock on page 90 works with an actual gravity motor. Even a rubber band can store energy: when it is pulled tight, it takes up energy, stores it as potential energy, and releases it as kinetic energy. All of these steps can be seen in the example of your rubber band car.

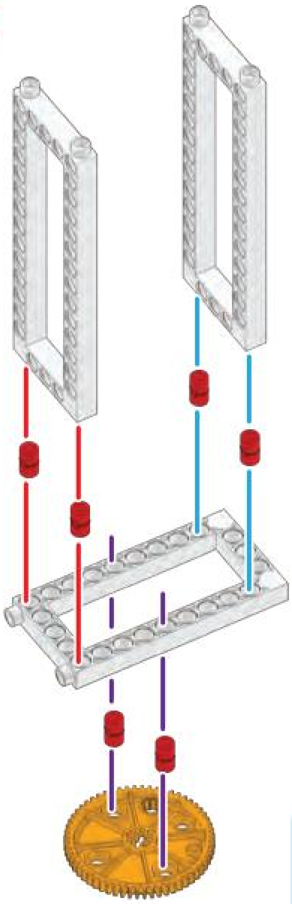
Forms of Energy and Conversion of Energy

By now you have learned a little about energy in the form of mechanical energy. But energy also comes in other forms: heat energy, chemical energy, and electromagnetic energy, for example. And energy can be converted from one form into another. After all, energy is the general capacity to do work, regardless of the specific kind of work at issue. When you let your electric motor run, the chemical energy in your battery is converted by the motor into electromagnetic energy and then in turn into kinetic energy. If you slow the motor by holding the drive axle between your thumb and forefinger without completely stopping it from turning, your skin gets warm.

The mechanical energy in the rotating drive axle is turned into warmth through friction. There are six different states that energy moves through: **chemical, electric, electromagnetic, mechanical, heat and nuclear energy.** With each change of state, some of that stage's energy gets lost, but energy as such never disappears. For example, not all the chemical energy from a battery is converted into electric energy in a circuit with an electric motor; part of it becomes heat and remains in that state. Also, when the electric motor turns a wheel, not all the electric energy is converted into mechanical energy in the wheel; some of it is lost to heat and some vibrates air particles to become sound. The same applies to other kinds of energy conversion.

WORKSHOP 27 Wind-Power Plant

1



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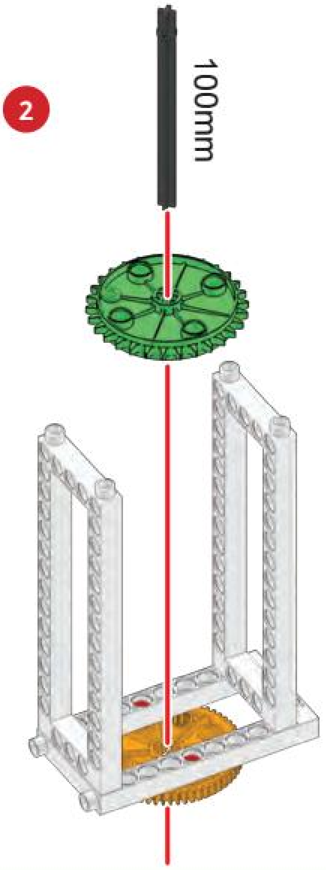

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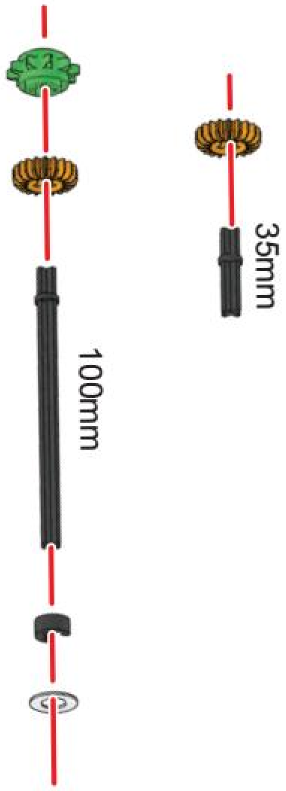

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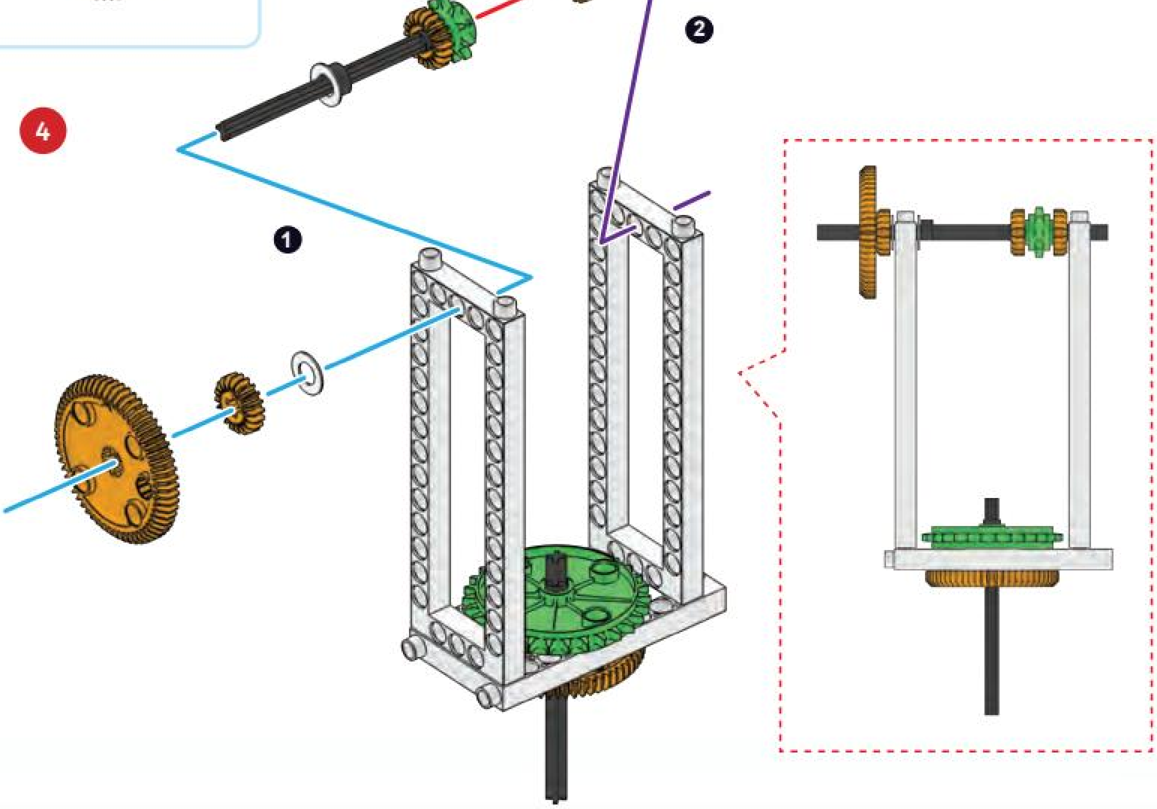

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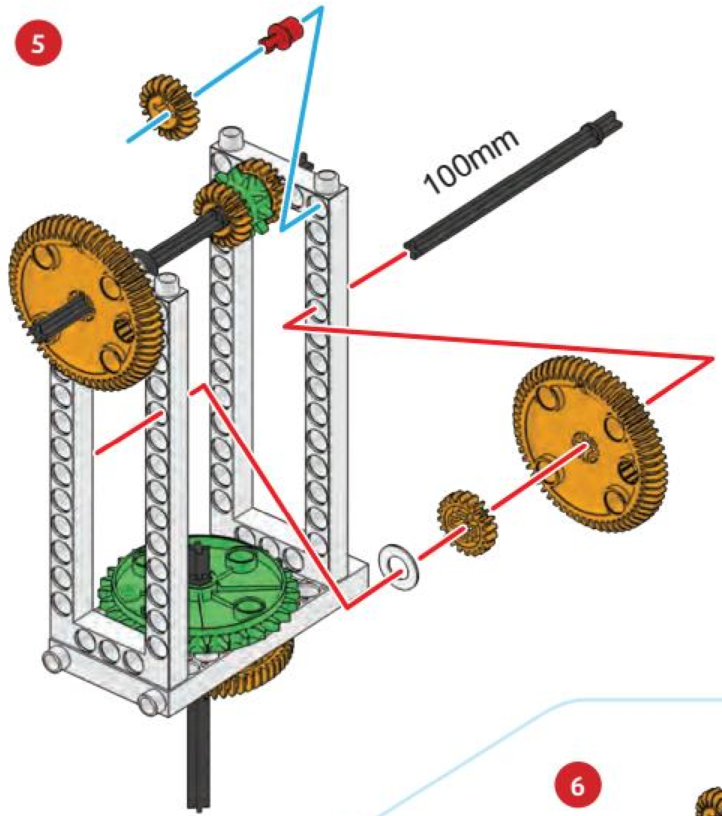

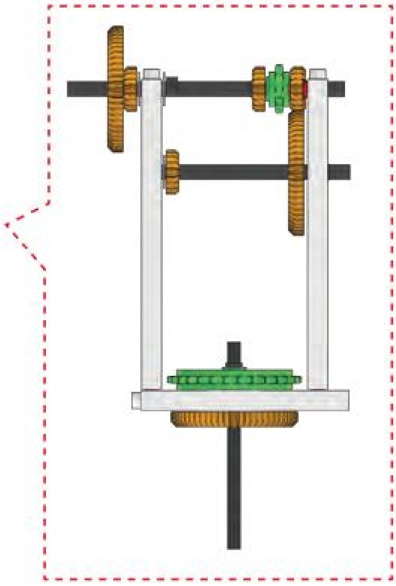

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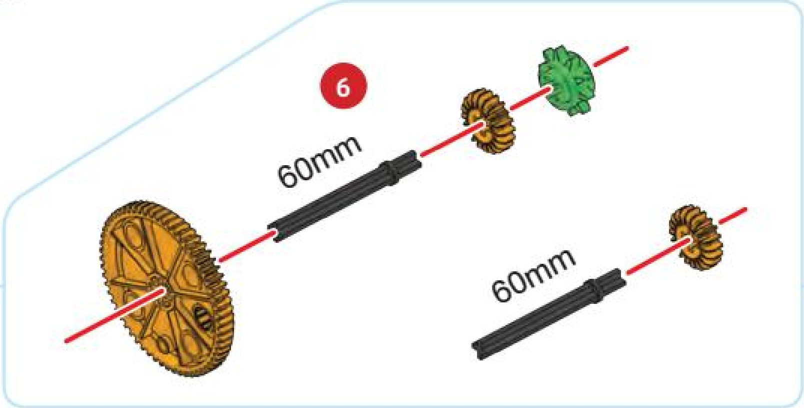

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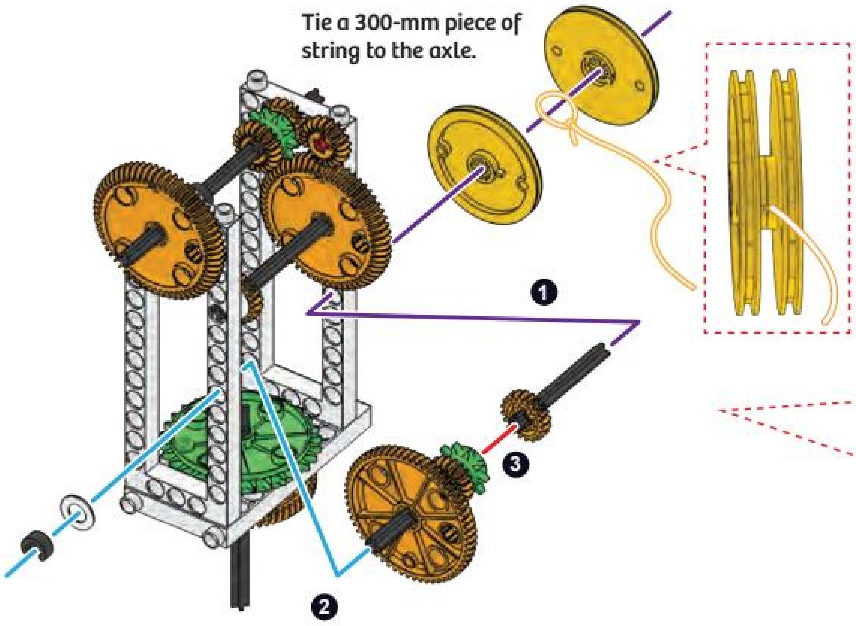
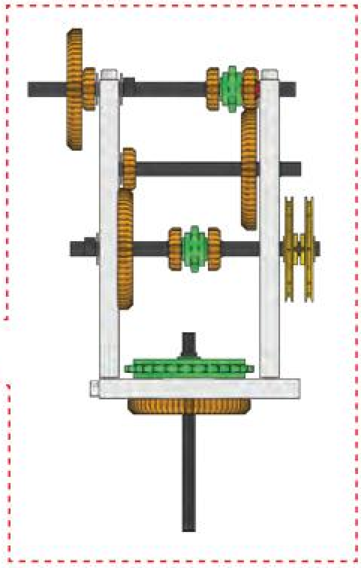

Tie a 300-mm piece of string to the axle.



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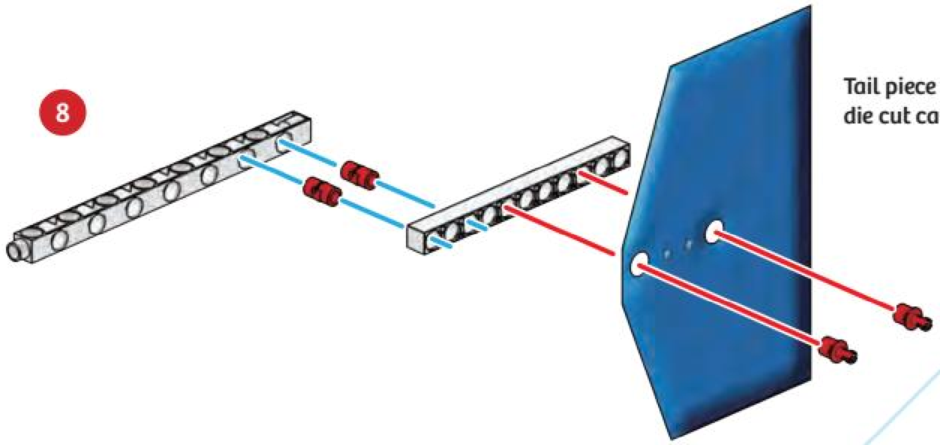
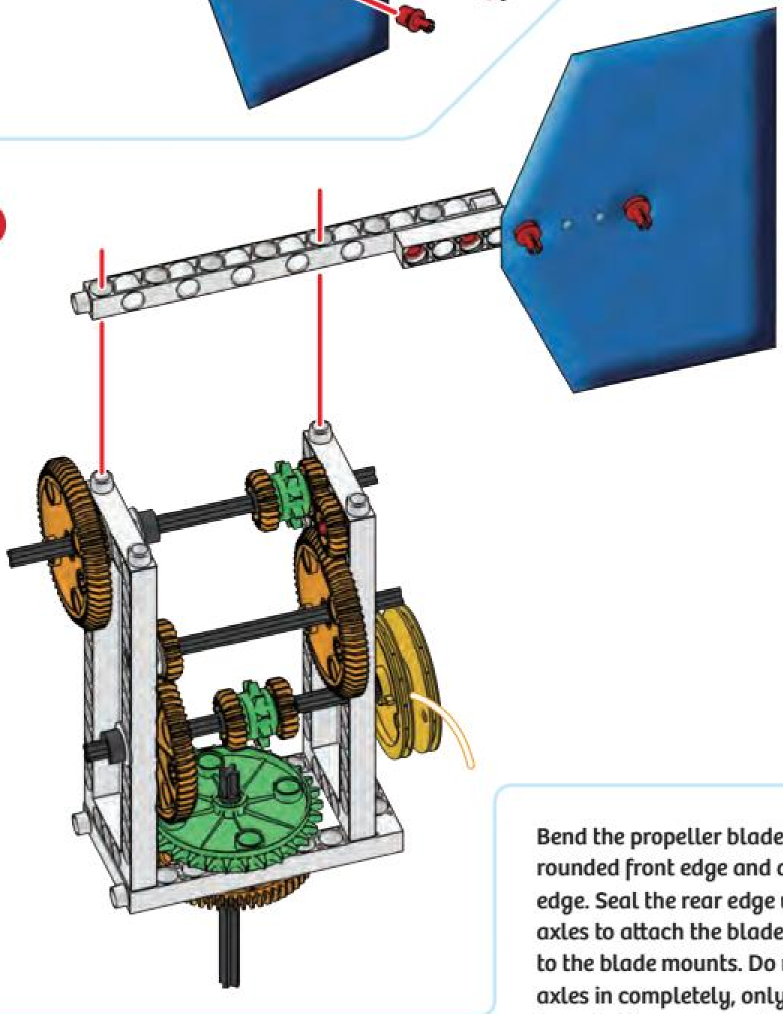


Tail piece from the die cut cards

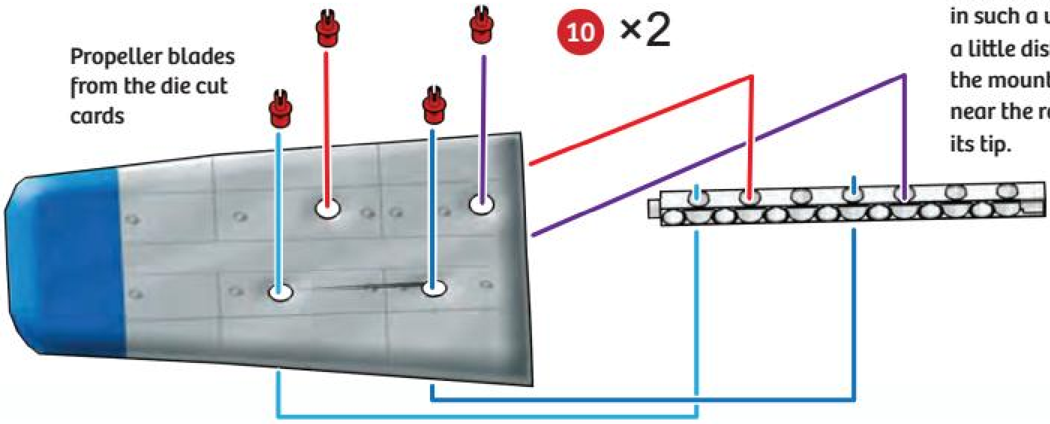
9



Bend the propeller blades to create a rounded front edge and a pointed rear edge. Seal the rear edge with tape. Use axles to attach the blades at the holes to the blade mounts. Do not push the axles in completely, only far enough to make them secure. The blade is cut in such a way that it will end up being a little distorted when it is attached to the mount, so it has a narrower angle near the rotor axle than it has towards its tip.

10 ×2

Propeller blades from the die cut cards



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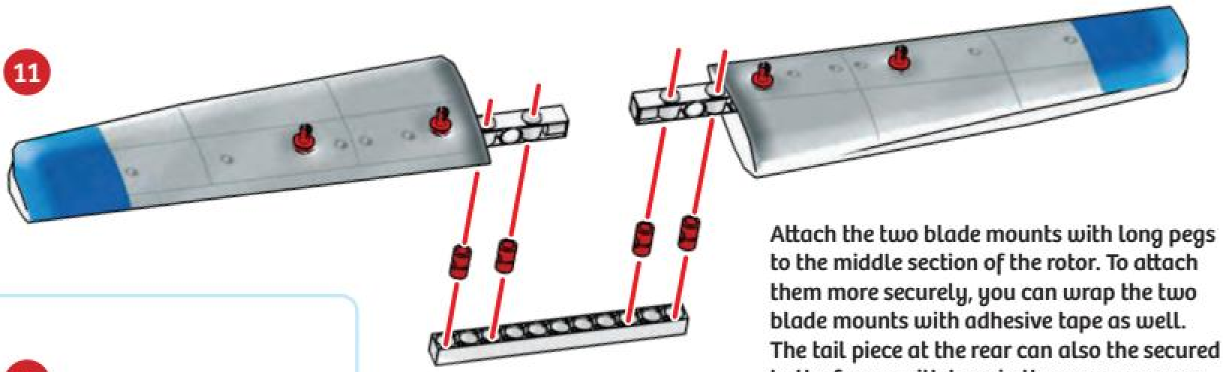
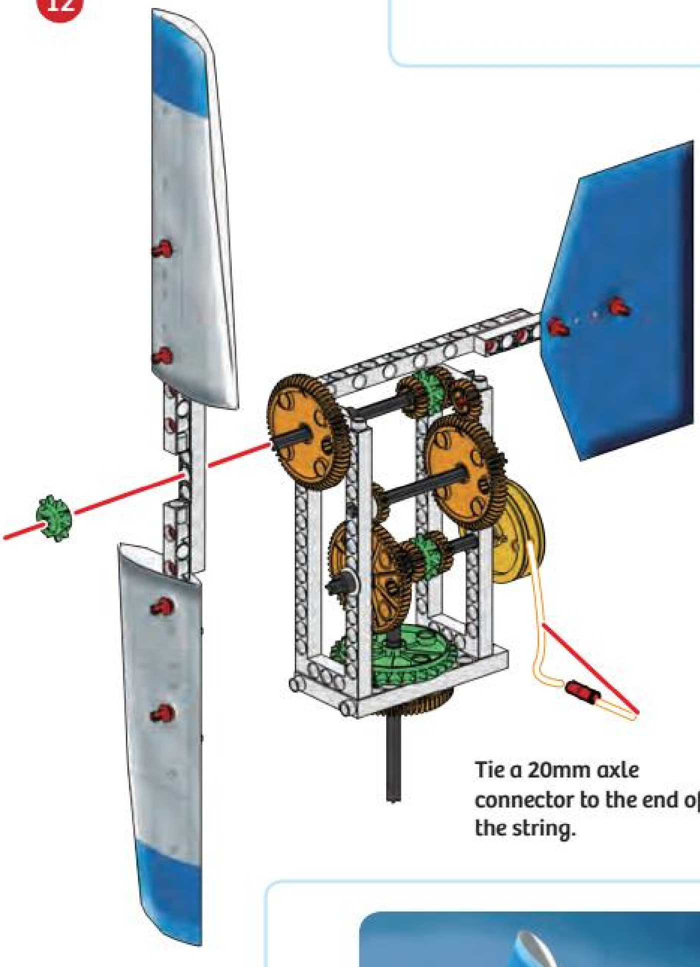


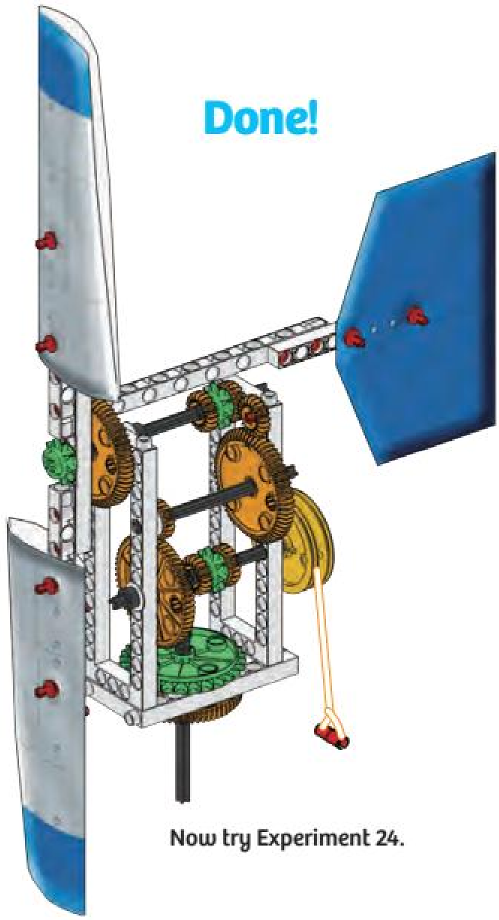
Attach the two blade mounts with long pegs to the middle section of the rotor. To attach them more securely, you can wrap the two blade mounts with adhesive tape as well. The tail piece at the rear can also the secured to the frame with tape in the same manner. To prevent jiggling, the pieces of the frame should also be secured to one another at the important axles with tape.

12



Tie a 20mm axle connector to the end of the string.

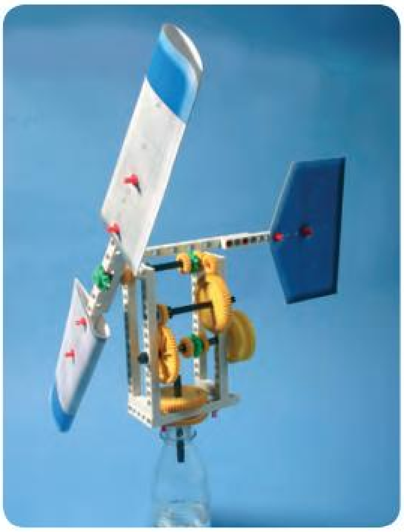
13



Done!

Now try Experiment 24.

For the mast, you can use a 1.5 meter-long (5 ft) bamboo pole or metal pipe of that length (from a garden center or building supply store). Whatever you use, the mast axle should fit into it exactly, so take it with you when you go to the store. The axle rod has to sit fairly tightly in the cylinder, but at the same time be able to rotate in it without sticking. If the bamboo pole has a joint in the way, you will have to cut it accordingly. You can also stand the turbine on a plastic bottle.



DID YOU KNOW?

Energy conservation theorem

Julius Robert von Mayer was born in 1814 in Germany. He was a naval doctor in Java and as a physicist preoccupied himself with the relationship between heat and work, among other things. His theorem about the conservation of energy became the foundation of the modern natural sciences.

Wind farms take the energy of moving air and convert it into clean power. The largest wind-power plants generate up to three megawatts (three million watts).

From what we have just learned about energy comes this fundamental law about the conservation of energy:

Energy cannot be created or destroyed, it can only change its state.

The total quantity of energy, in other words the sum of all changed and unchanged energy states always remains the same. Following Robert Mayer's theorem of the conservation of energy, our fundamental law can also be written as follows:

In a closed system, the sum of the different forms of energy taking part in the system always remains constant (of equal magnitude).

There are many machines that do nothing but convert energy. They are known as **energy machines**. They make energy available in a form in which it can be used for a specific kind of work. An automobile engine is a heat energy machine. It converts the explosive pressure derived from the combustion of fuel (chemical energy) into kinetic energy: the car has to move, after all. An electric engine is an energy machine too, supplying mechanical energy converted from electrical (electromagnetic) energy. Gigantic electric engines can be found in electric trains. They are fed energy from overhead power lines and "digest" it into energy that they use to move. By an opposite process, a **generator** (a dynamo) converts mechanical energy into electric power.

Wind-Power Plant

A wind-power plant is also an energy converter, because it captures the energy of moving air, also known as wind, with a rotor (propeller) and converts it with the use of a generator into electricity.

On the previous pages, you will find the directions for a wind-power plant that you can build yourself. It has no generator, but you can still perform power tests with it. It converts the kinetic energy of the air into rotation energy (energy in a turning motion, see page 103). Assemble it for the following test, if you want to measure its capacity according to our next topic.

EXPERIMENT 24: WIND-POWER PLANT TEST 1

For the test, look for a day that is windy but not too stormy and find an open space where you can stick the bamboo or metal pole firmly into the ground. The best place, of course, would be a big open lawn or field (see the picture on p. 78). If would be good to stabilize the mast with cord and tent pegs. Maybe you can find a railing or fence that you can tie the bamboo mast to. It should stand as straight as possible, so the tail piece stays balanced and the rotor can turn easily in the wind. Insert the wind power plant with its mast axle into the bamboo mast. It will immediately rotate its tail into the wind, and the propeller will start to turn. Try to bring the rotor to a halt by holding the rear wheel between your thumb and forefinger. Not very easy, is it? To stop the power plant for sure, grab it by the tail and turn it at a right angle to the wind. In this position, the wind will hit the rotor from the side.

What Is Power?

Up until now, time has had no role to play in our preoccupation with the physics of work. What we measured was force over a certain distance, i.e. newtons times meters (Nm), with the unit of measure for that being the joule (watt second). We paid no attention to the length of time that the force was applied.

When an ant carries a piece of hay that is 50 times as heavy as its own weight, that is remarkable. And when it needs only half a minute to go a meter, that is equally astonishing. Wouldn't we even say that it is accomplishing an enormous feat? We wouldn't be able to even lift 50 times our own body weight — 3,000 kg or 3 tons, more or less — let alone carry it. All right then, from our perspective, it really is a phenomenal feat that the ant accomplishes. Also, the fact that humans can measure it in newtons, meters, and seconds is pretty impressive too.

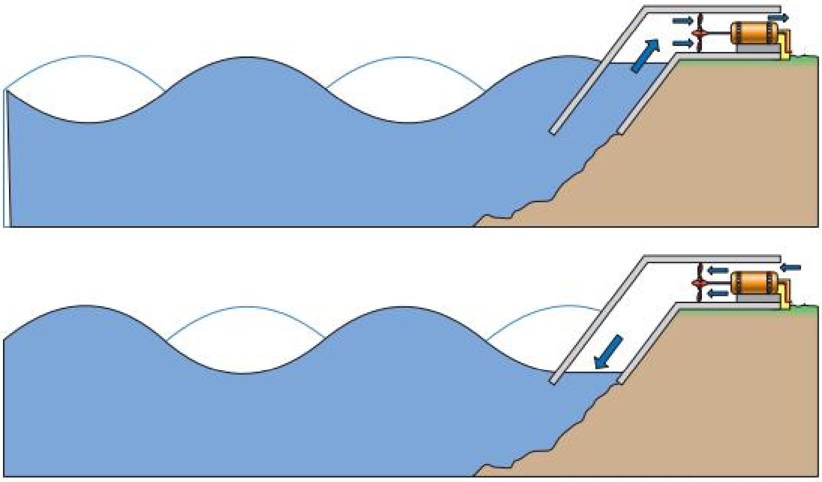
To find out how much power a machine generates, we have to factor in time. You can even measure and evaluate the power output of an athlete. If you need half an hour to move ten kilometers on a bicycle, your power output is greater than if you have to push the pedals for a whole hour to go the same distance. **Power** is work in a certain period of time, or:

Power = Work / Time

Power is measured in: $\frac{\text{Joules}}{\text{Seconds}}$ = Watts

Let's get back to practical matters and measure the power of our wind-power plant. Try to find a friend to help you to make sure that the rotor turns well in the wind and to rotate the "windmill" out of the wind if you want it to stop. As you can see, the wind power plant has a reduction gear unit that converts the high rotation speed of the propeller blades by one ninth — in other words, it increases the torque. That is easy to confirm: it's a simple matter to use our little finger to slow down the rotation of the propeller's shaft, but not so simple to do that at the spool at the rear. There, the rotation is slower but therefore also stronger. The slow rotation speed of the spool will actually come in handy, because we will need to suspend a respectable weight from it and have a few seconds of "winding time" for our power test.

In the Bristol Canal (England), windmill-like rotors have been used since 2003 to capture ocean currents. They produce electricity with the aid of rotors as well.

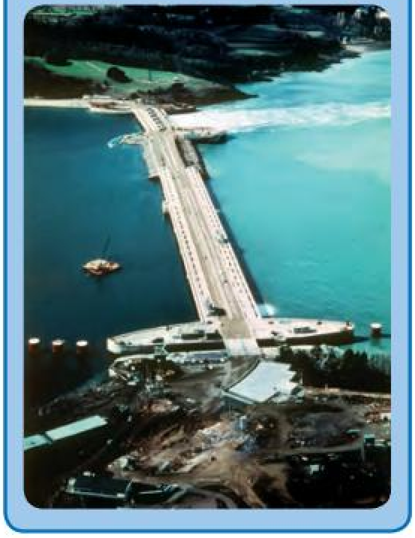


On Pico Island in the Azores and Islay Island in Scotland, the energy of ocean waves is used. As they rise, the waves compress air in a cylinder which has an underwater opening to the sea. The air pressure turns a turbine. When the wave recedes, air is sucked back through the turbine from outside. A generator creates electricity from the turbine's rotation.

DID YOU KNOW?

The ocean's energy

Even the renewable energy of the ocean can be turned into electricity. The conversion of natural energy is environmentally friendly. Unlike power plants that burn oil, coal, or gas, no harmful exhaust gases are produced. The tidal power plant on the river Rance in French Brittany has been using turbines and generators since 1969 to convert the kinetic energy of the tidal current between ebb and flow into electrical power.



KEYWORD: POWER

Power is a measure of the rate of doing work or transferring energy. Work over time.

Attaching the windmill to the support pole

Testing the braking force

Measuring power

EXPERIMENT 25: WIND-POWER PLANT TEST 2

Step 1: In addition to the wind power plant and the mast, you will need to take the 0 to 7.5 newton force scale, a piece of cord about 3 m long and 1 mm thick, and a 20mm axle connector to your testing site. You will also need a plastic bottle filled with water, with a loop of string tied around its neck. What else? A measuring stick, a pen, and a piece of paper.
Set up your wind-power plant as you did for the first test, tie the string to the crank-hole of the empty spool, and wrap the string about 10 times around the spool's center. The end of the string should be long enough to reach the ground. Then, tie the 20mm axle connector to the end of the string, and attach the force scale to the axle.

Step 2: Place the force scale on the ground so that the string will be able to roll up. Now let the propeller run, and the force scale will rise. When it is halfway up, pull on the scale gently to bring the propeller gradually to a stop. When it has come to a standstill, take the reading off the force scale. Now you know how much power is needed to stop the windmill with this size spool. As you know, you can also hang a correspondingly heavy weight to the end of the string.
Remember: weight is equal to newtons divided by 9.81, or about 10. Let's assume the force scale reads 2 N. That corresponds to a braking weight of 0.2 kg.

Step 3: Now suspend the bottle from the force scale and carefully pour off just enough water until it has a fifth less than the braking weight. In our example, that would be 1.6 N of weight, or about 0.16 kg. With this weight, the windmill can just barely keep working. In other words, it can barely pull the bottle up from the ground. Assuming, of course, that the wind is blowing with the same intensity as before.

Now it's time for the power measurement. First, tie the bottle to the end of the string. The string should now be completely unrolled from the spool. Place the measuring stick with its zero end on the ground. Next, let the propeller run, and the string will start to wind up. Now hold the bottle, supporting it with your hand, and slowly let it go.

Step 4: As soon as the windmill has reached its slower revolution speed and the bottle is being lifted just by wind power, one person should keep an eye on the second hand of his or her watch while the other watches the measuring stick to see how high the lid of the bottle is from the ground. Just before the loop and the [20mm axle connector] have reached the wind- power station, take your two readings again (time and distance) and turn the windmill out of the wind. How many centimeters did the bottle rise and how many seconds did it take? Write it down!

Step 5: Now you're ready to calculate the power. Let's stay with our example of a bottle weighing 1.6 N. Assuming it was pulled up 1.0 m in 10 s, this is how to do the math:

$$\frac{1.6 \times 1.0}{10} = 0.16 \text{ Joule/Second} = 0.16 \text{ Watts}$$

Of course, your windmill can actually do more than that with a good, strong wind.

When Masses Are Moving – Momentum and Impact

Nobody willingly runs head-first into a wall. When it happens, it hurts, and you're sure to get a big bump. The faster your head hits the wall, the worse the blow. There is a law of physics lying at the bottom of this kind of unfortunate accident. It says that the greater the mass of the object and the greater its speed, the greater the impact. What does that mean? There is a force that has acted on a moving body, or else it wouldn't have moved. The mass of a moving body has, so to speak, stored up this force within itself. At any time, it could use that force to "pack a punch." A name a physicist would give to this property of moved mass is impulse or **momentum**. The faster a body moves, the greater the force was, or the longer the force acted on it. Its momentum is correspondingly greater. If two bodies are moving equally fast, but have different mass, then their momentum is also unequally great.

KEYWORD: MOMENTUM

Momentum is the combined effect of the mass and velocity of an object.

The momentum formula is as follows:

momentum (p) = mass (kg) x velocity (m/s)

The unit of measure for momentum is the newton-second (Ns).

If a moving body impacts another body and is thereby stopped, then its velocity drops in an instant to zero. In a split second, its momentum is transformed into an impact, and there is a sudden explosion of force.

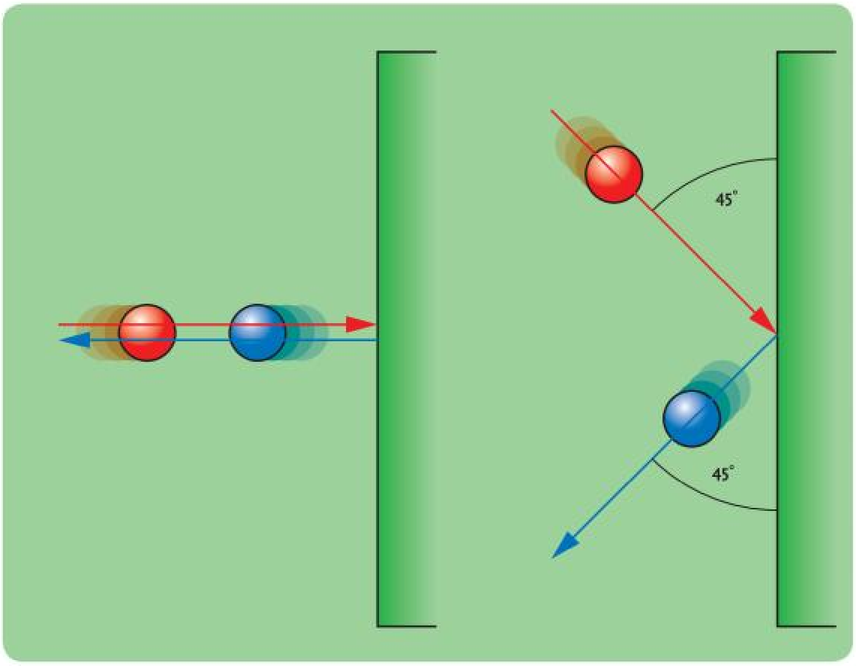
The shorter the braking time — it can often be just thousandths of a second — the greater the force released at the moment of impact. Where does it go? If the colliding bodies are inelastic — in other words if they aren't springy or flexible — then they become deformed, or compressed at the point of contact.

With two colliding cars, there will be dents. That is how they absorb the impact. So the escaping force performs work.

If the bodies are elastic, such as in the case of two balls colliding into each other, then they keep moving for a brief instant at the same speed or remain in one place, deform themselves briefly and then push away from each other and regain their previous shape. Usually, the two bodies are partially elastic, and they become deformed and also bounce off of each other. Here, too, work can be found. If an inelastic body of relatively small mass collides with an inelastic body of relatively very large mass, there is a rebound, with the smaller body bouncing away again. An example is when a small ball hits a wall. If it hits straight on, then it bounces away in the opposite direction. If it hits the wall at an angle, then it bounces off the wall at almost the same angle. This effect is at work in a game of pool (with a small change in direction due to slippage of the smooth balls).

You can construct your own little pool-like game involving inelastic impact, and track the trajectories of the balls. In addition to fixed banks (the edges), it also has two movable banks and even a goal.

You can use the next experiment to study the ways that a ball impacts and bounces off of the banks.



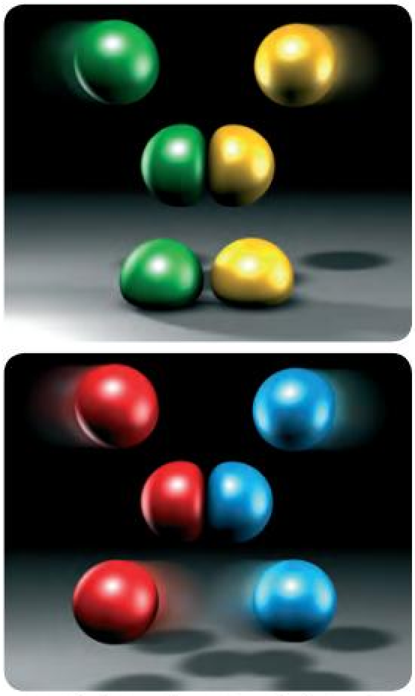
The angle at which a ball bounces off the wall is the same as the angle at which it hits the wall.

DID YOU KNOW?

The law of conservation of momentum

With momentum, things are similar to the way that energy can neither be destroyed nor created: in an isolated system, total momentum — the sum of the momentums of individual bodies in the system — remains constant. A system is isolated if no external forces act upon it.

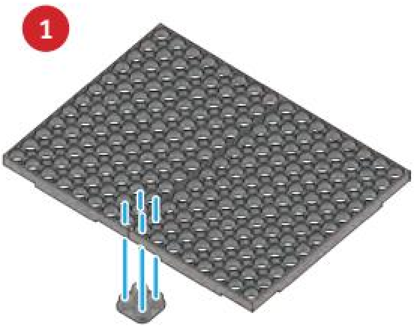
Dents are the result of a change in momentum



Inelastic (above) and elastic (below) impact

WORKSHOP 28 Pinball

1



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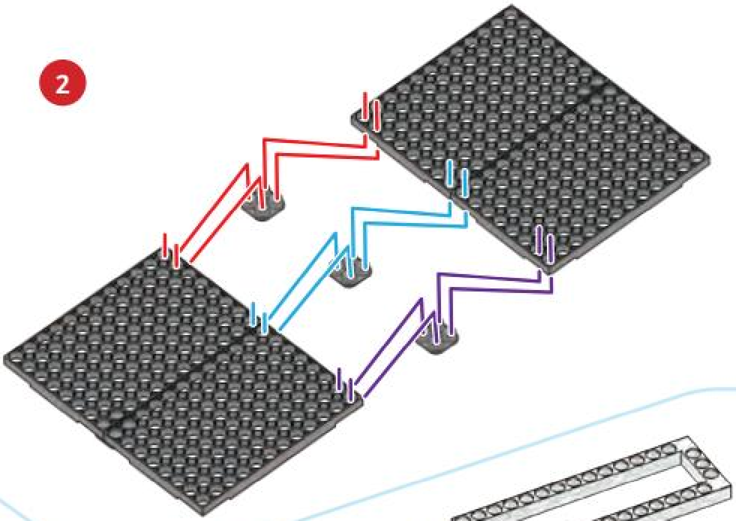

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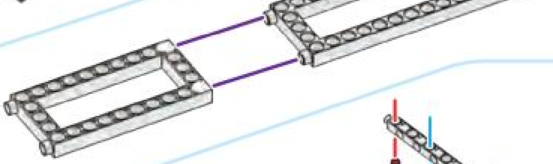

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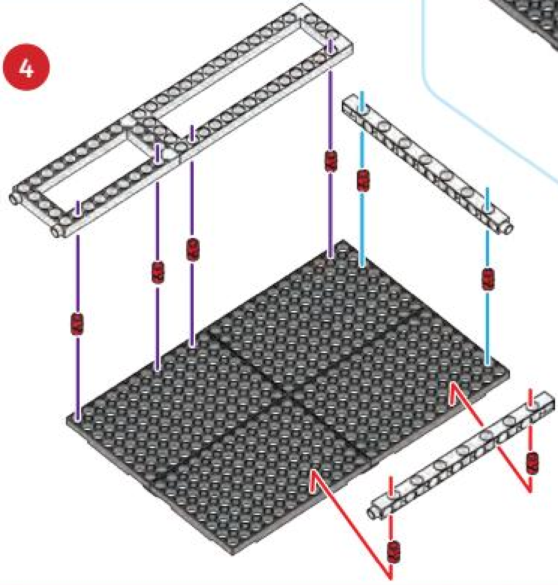

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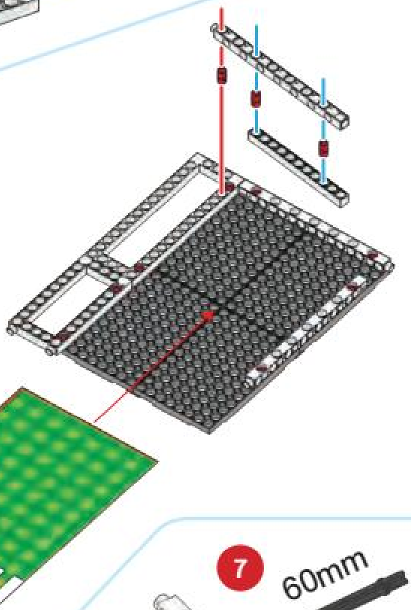
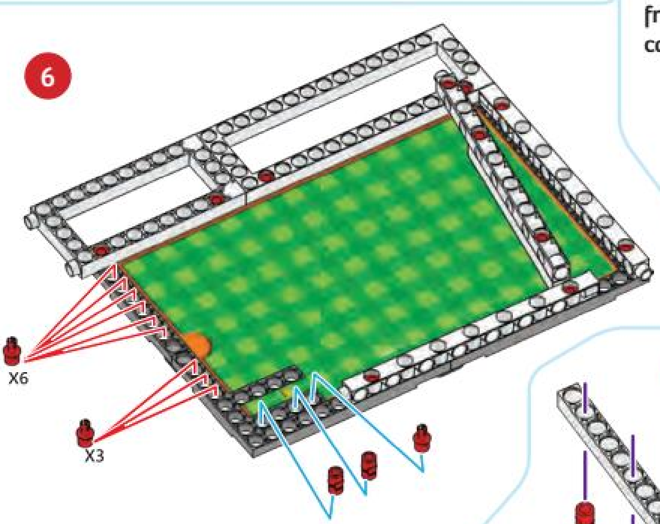


Checkered playing field from the die cut cards.

6



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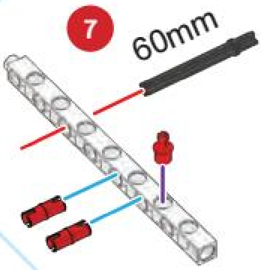

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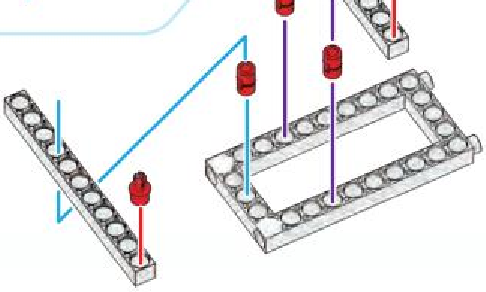

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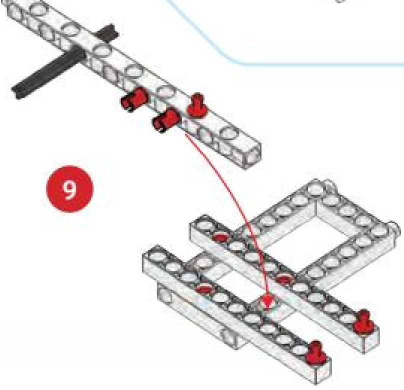

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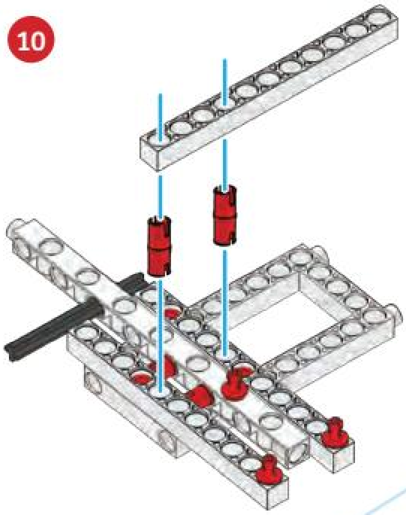

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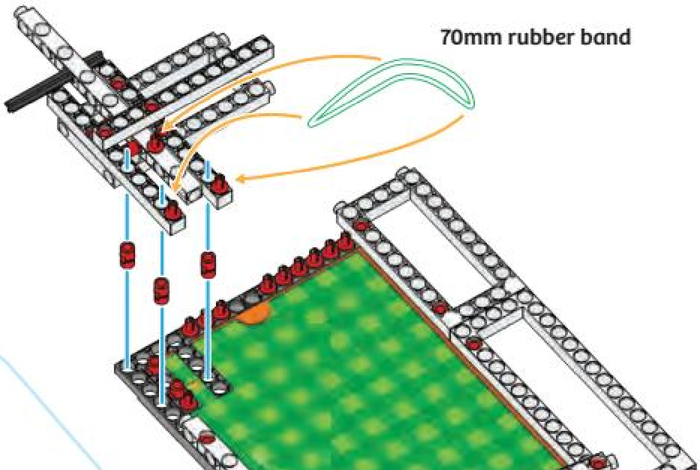

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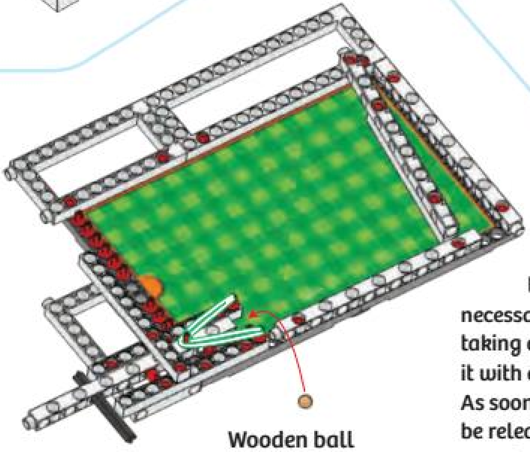
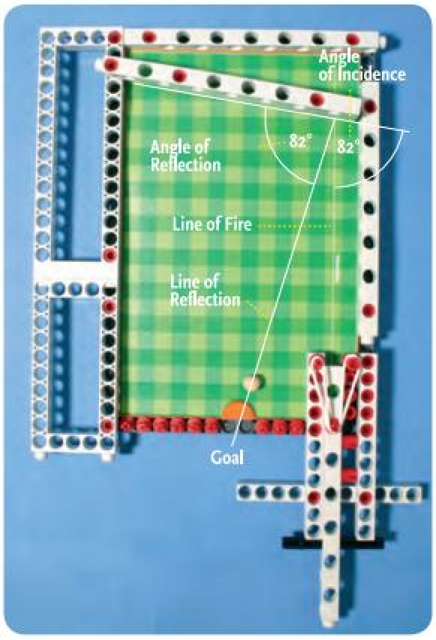


The moveable rod is used to alter the course of the ball. The 70mm rubber band provides the tension necessary for shooting. When you pull it back in preparation for taking a shot, do not pull it too far, or it might get stuck. Secure it with a medium axle. Now, place a ball in the shooting groove. As soon as you pull the axle out of the bolt- hole, the bolt will be released and the ball will shoot out of the groove. Before you shoot, press the moveable rod against the playing surface! Otherwise, the playing field may slip.

Now try Experiment 26.



This is how we determine the trajectory of the shot to the goal.

EXPERIMENT 26: THE TRAJECTORY OF THE PINBALL

For this experiment, you will need your protractor. Lay a piece of paper down over the playing field. First, try an experiment without the moveable rod. The ball bounces back to the place where it came from. Now place the rear moveable rod on its 20mm axle connector and select an angle setting of your choosing. Next, take a pencil and draw a line along the rod through the shooting line, so you have a record of its position on the paper. Take a shot (don't forget to press the rod against the surface) and take note of the spot where the ball hits the edge of the field after hitting the moveable rod first. Draw a line from there to the place where the line you drew along the rod crosses the shooting line. In that way, you have determined the trajectory of the ball. Measure the angle between that trajectory and the moveable rod.

Now try a different angle setting for the moveable rod and determine the trajectory again. What do all the trajectories have in common? The angle at which the ball hits the moveable rod is (almost) the same as that at which it bounces off the rod. So you can actually determine the trajectory in advance that will result in the ball going into the goal. Measure the angle of the moveable rods to the field edge and memorize the position of the rod with the help of the squares. Then, you'll have a good chance of winning in this game. The procedure with two rods is similar, only a little more time-consuming. Note: The more firmly you press the rod down when you shoot, the better the ricochet and the more precise the result.

If you collide an inelastic body against a similar immovable body, then it will bounce back. That's how it is with this ball game. But if the body collides with a moveable body, then they will both move on with a common velocity. If several

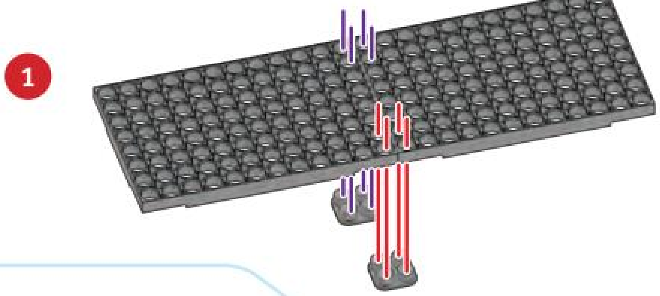
equally heavy bodies are lined up close together, and another body collides with the row straight on, then the momentum is passed on from the first one to the last. With this kind of continuous momentum, the final one will leave the row, while the other stay behind quite neatly. Give it a try with your bowling alley.

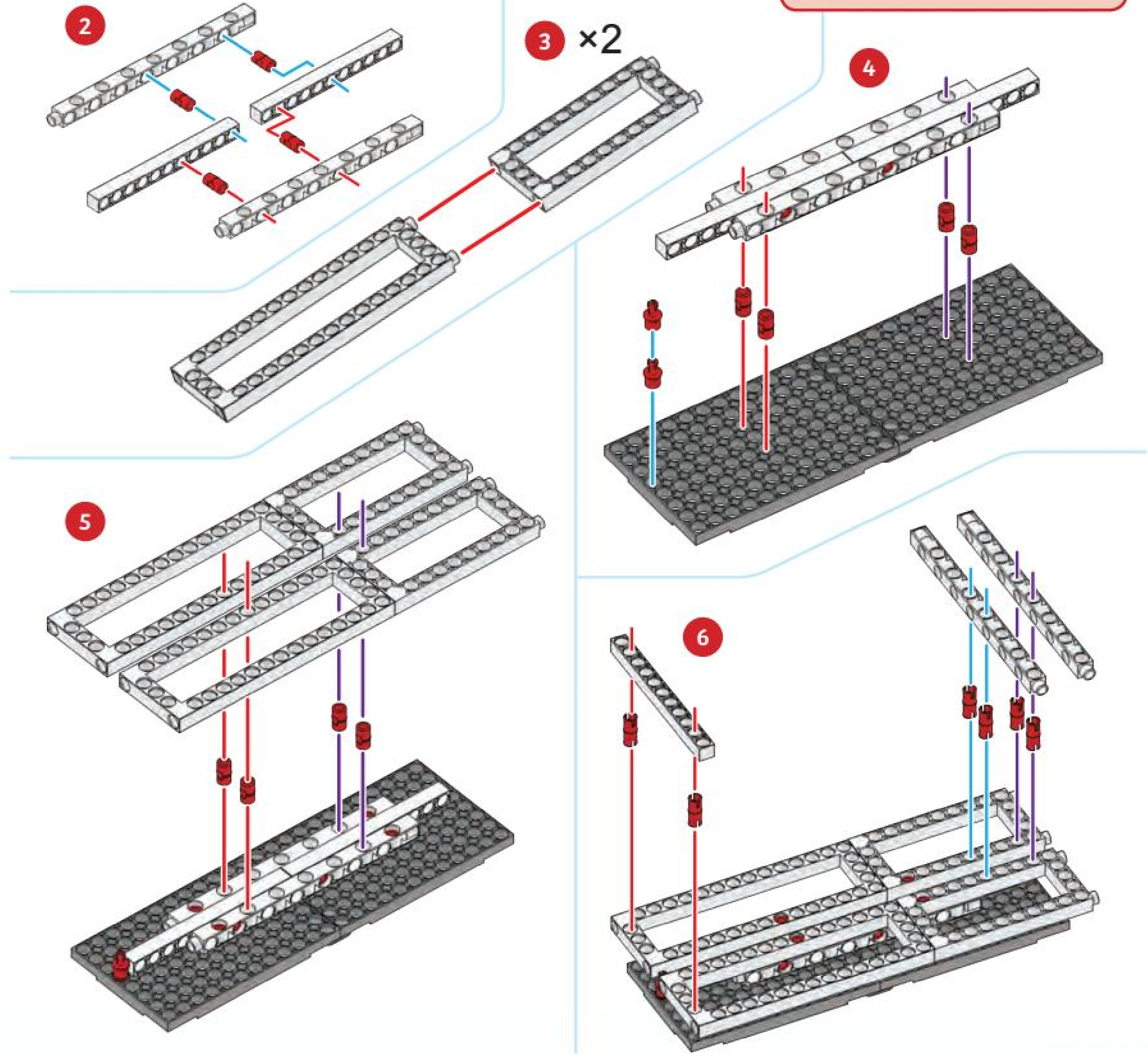
GAME

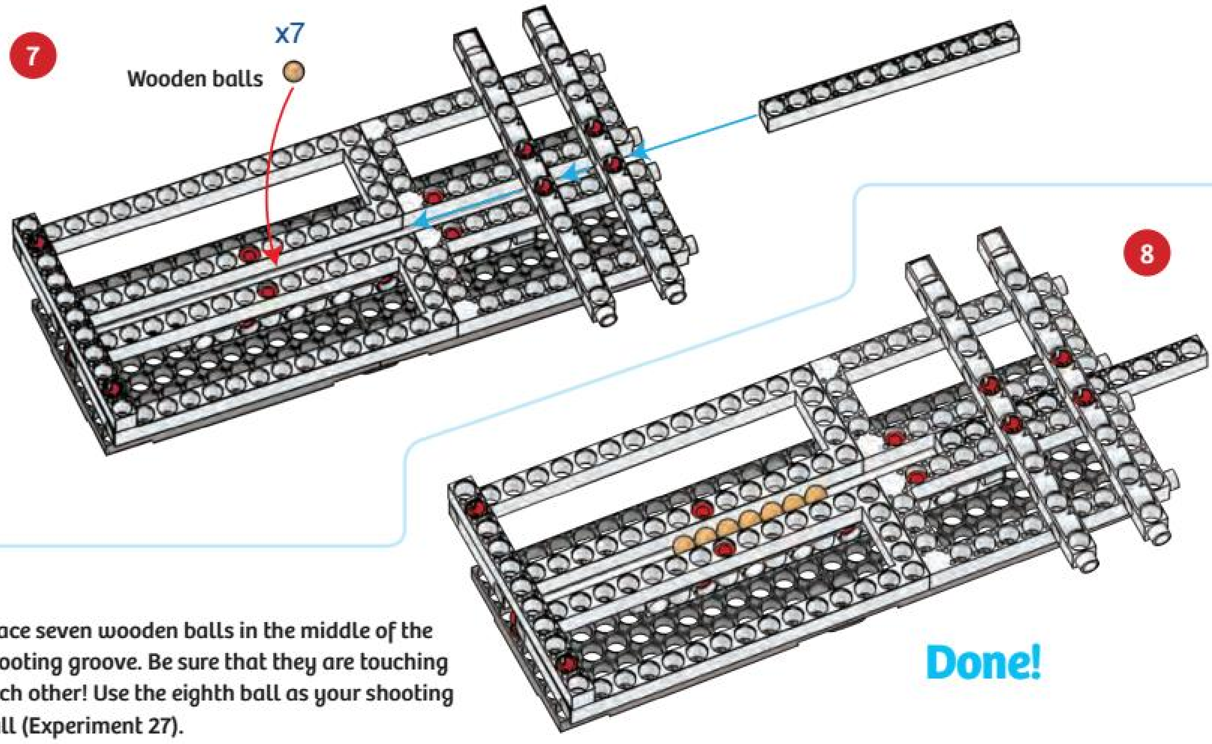
Pinball

You can play games with your pinball machine. You can make up your own rules, or follow these rules: the object is to shoot the ball into the goal via the moveable rod(s). Each player gets three shots. The players can decide together whether to use one or two moveable rods. Other rules can be used, too. If you have studied the path of the ball carefully in advance, you can greatly increase your chances of winning.

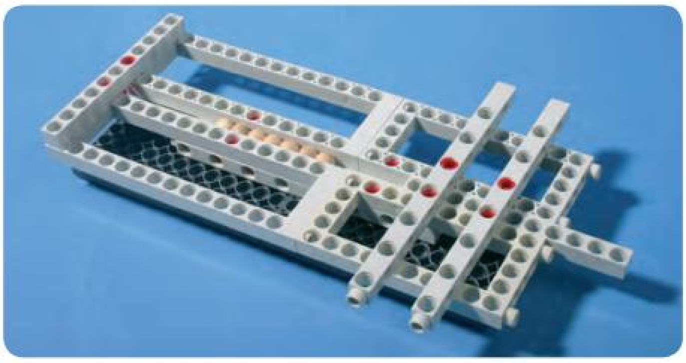
WORKSHOP 29: BOWLING ALLEY







Place seven wooden balls in the middle of the shooting groove. Be sure that they are touching each other! Use the eighth ball as your shooting ball (Experiment 27).



Continuous momentum: six balls receive the blow, but just one must go.

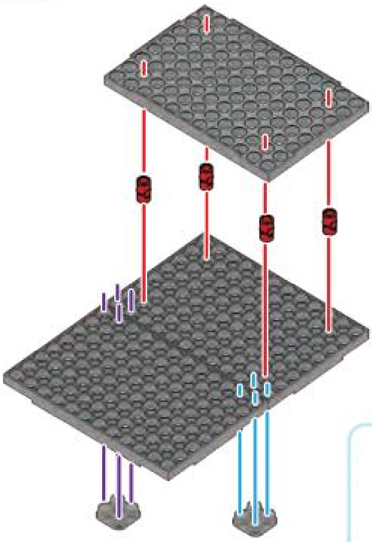
EXPERIMENT 27: MOMENTUM PROPAGATES ITSELF

Push the shot bolt to the rear of your bowling alley device. Place seven balls in the center of the groove and the eighth directly in front of the shot bolt. Be sure that the seven balls are touching each other, or the impact will not be transferred properly. Hold the apparatus to the table surface with one hand and use your other hand's index finger to flick the shot bolt from the rear, so the ball hits the row of seven. One ball at the end of the row will roll away. The kinetic energy of the shot ball, its momentum, moved through the row of balls to the final ball. There, the momentum is transformed into work. Try it with two and then three balls instead of just one shot ball. They will also have to be lined up tightly together at the start. With each shot, the number of balls that roll away from the end will equal the number of balls that you shot with the shot bolt.

Impacts show their effects everywhere, such as in boxing, when a plane lands, when a dot-matrix printer inks the paper, and when a hammer hits a nail. Hammers offer us excellent examples of impact. A hammer's basic principle can be found inside many machines: in jackhammers and percussion drills as well as in hammer mills at quarries or steel mills. A hammer mill is a grinder or crusher in which materials are broken up by hammers. You can build your own simple hammer mill model too.

WORKSHOP 30 Electric Hammer Mill

1



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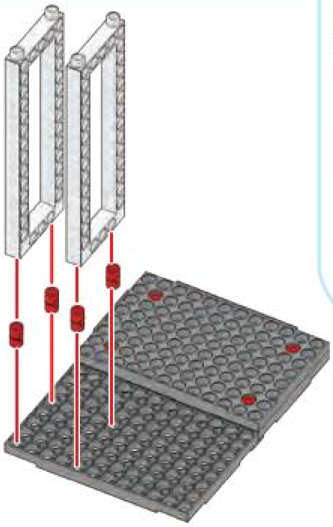

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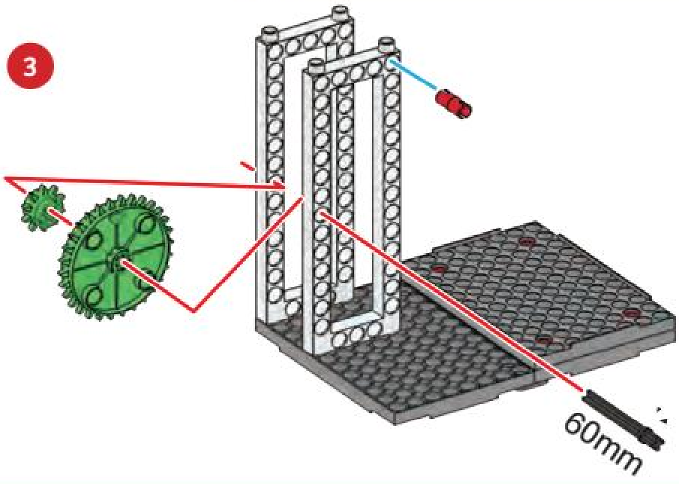

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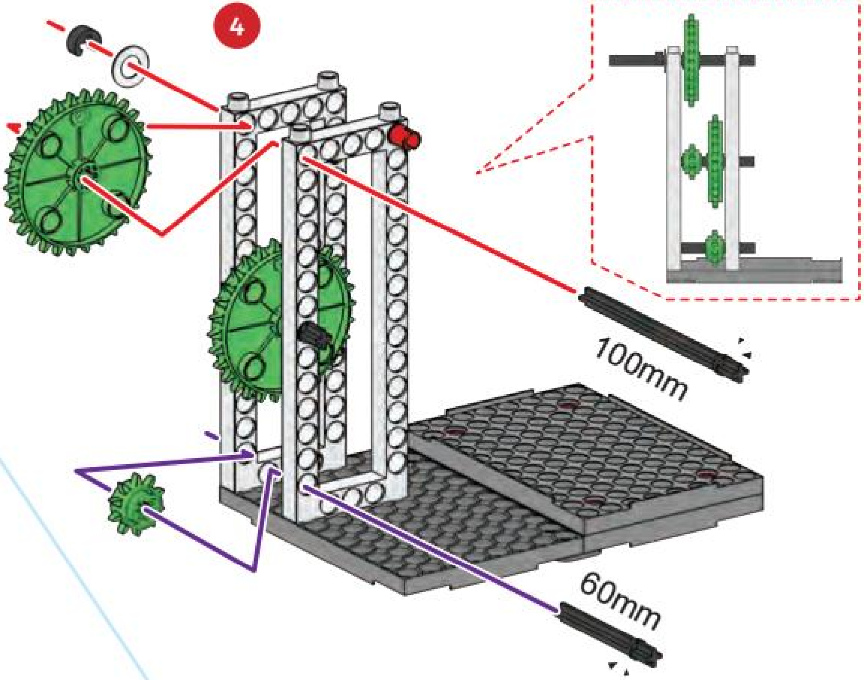

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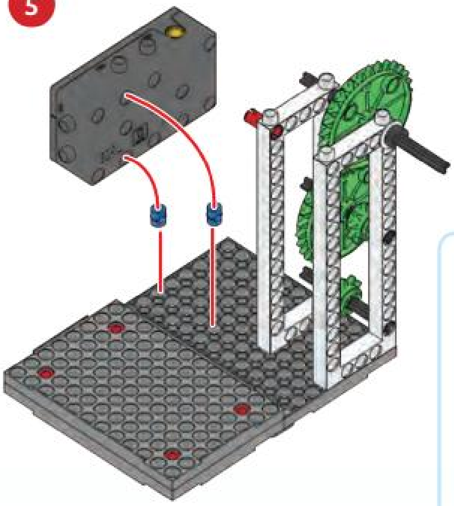

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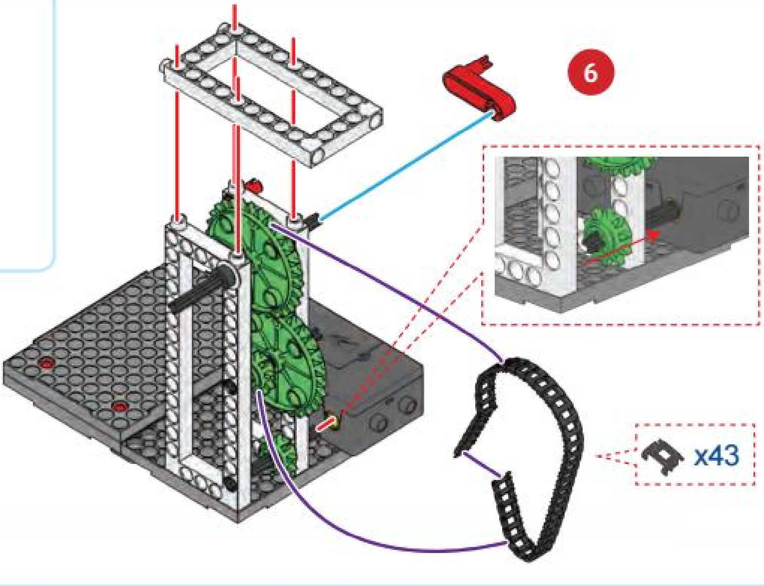

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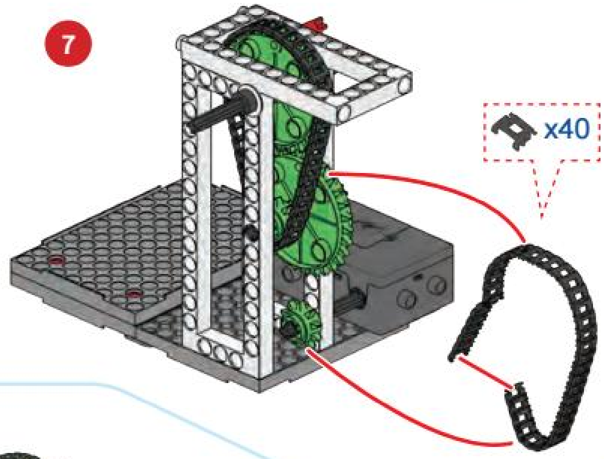

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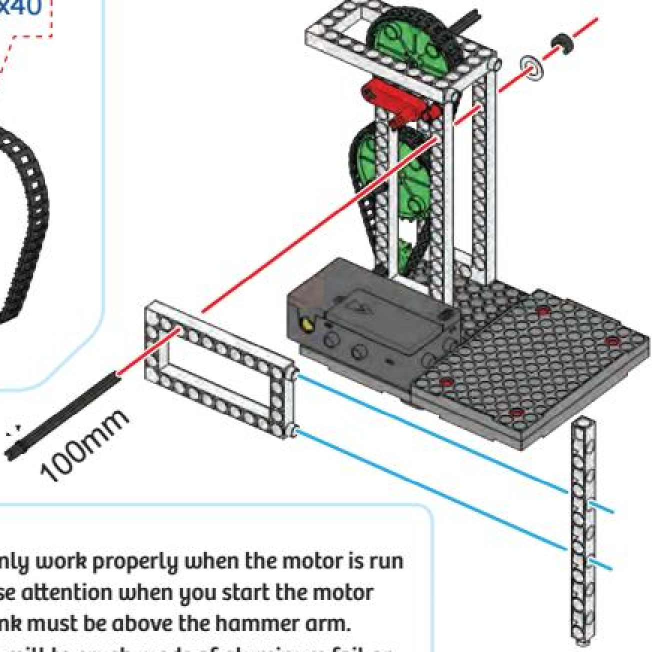

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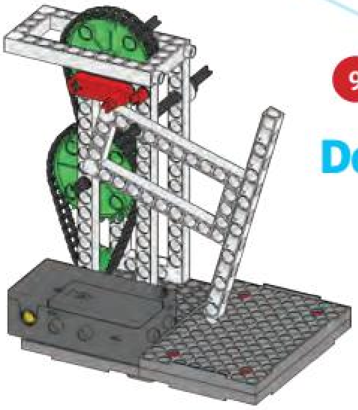
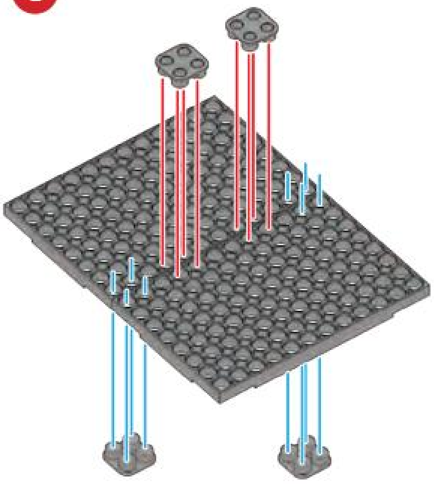


Done!

Note that the mill will only work properly when the motor is run in one direction. Pay close attention when you start the motor for the first time: the crank must be above the hammer arm. You can use the hammer mill to crush wads of aluminum foil or aluminum tealight votive candle cups.

WORKSHOP 31: IMPACT GAUGE

1



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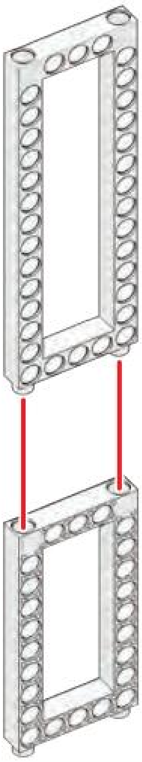

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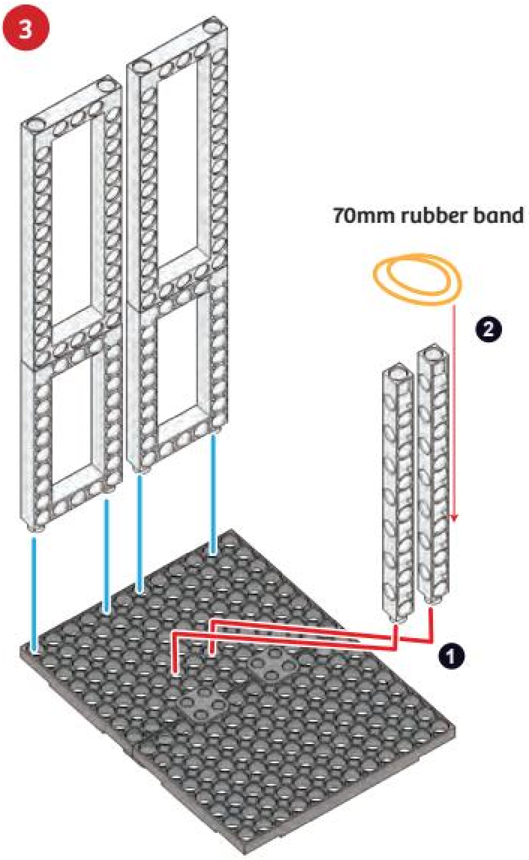
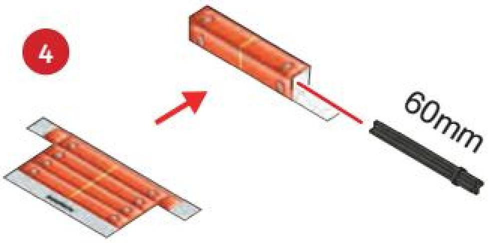


Find the scale, the fall chute cover, and the sleeve for the falling object in the die cut cards.

4



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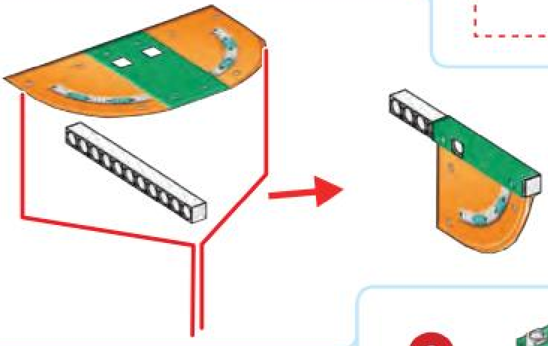

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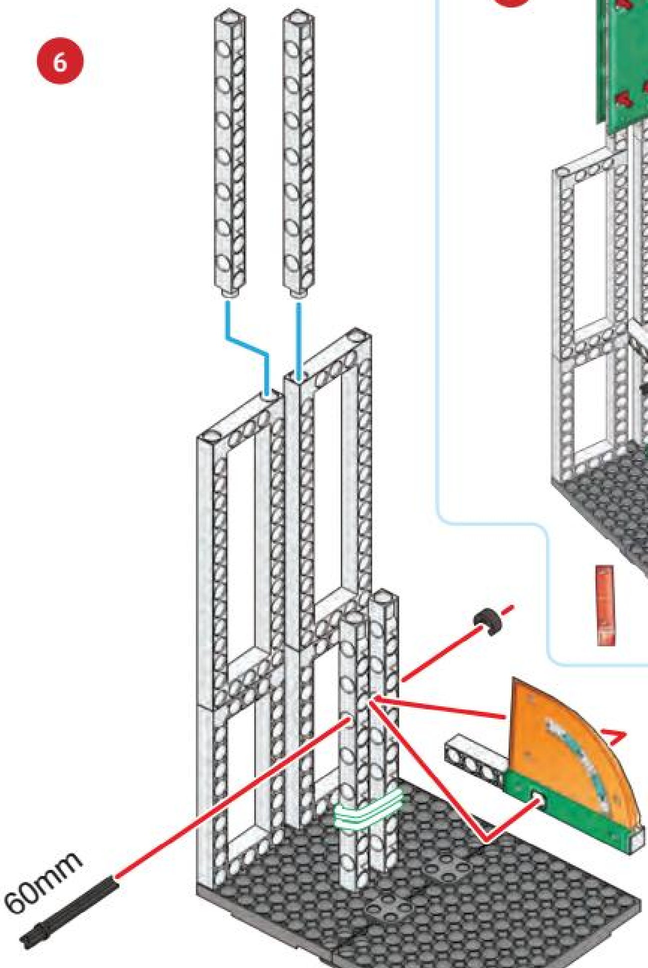

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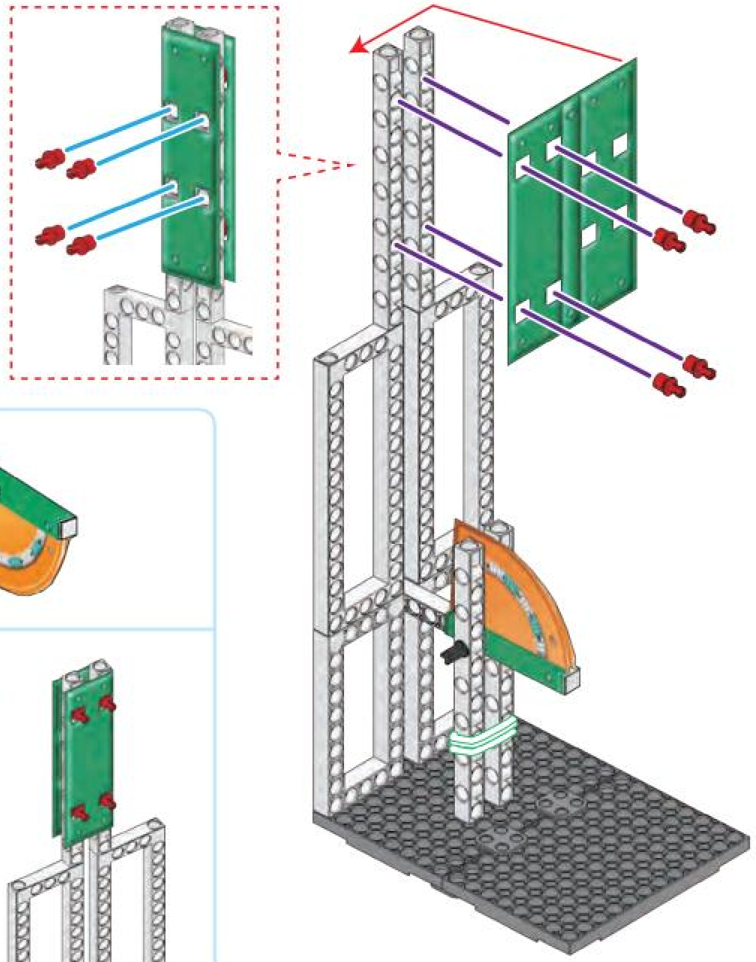

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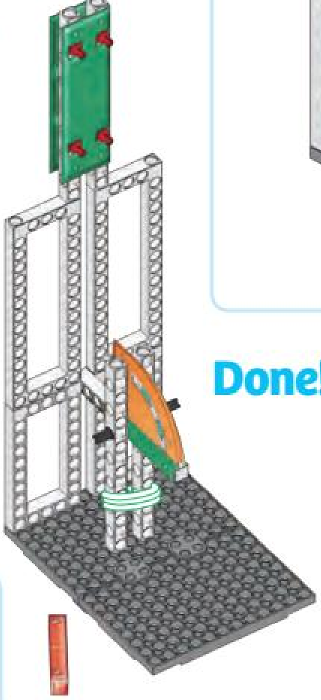
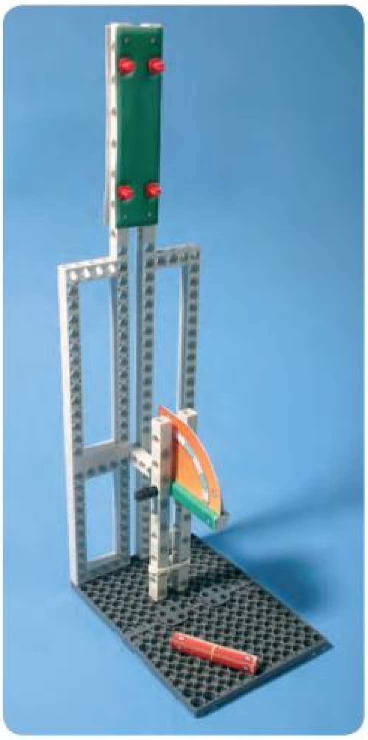


Done!

The impact gauge shows the work performed by a free-falling object. The chute is a little wider at the top than at the bottom, so the indicator rod can move freely. You will find all other information in Experiment 28.



You know that momentum and impact become greater as the speed of an object increases. The impact can be transformed into work when it deforms or moves an object. We can test this with a device that measures impacts at different falling heights and different speeds. The upper falling height in our device is exactly double the lower one. The small rod with the gauge attached to it is clamped tightly between two long rods with a rubber band, so that it rubs against them. The falling object knocks it out of its zero position. The measurement on the gauge approximates the work performed in the impact.

EXPERIMENT 28: BIG FALL, BIG BANG

The device must stand vertically, or else the object won't hit the gauge rod. For our falling objects, we can use a small and a medium-sized axle. The medium one is twice as heavy as the small one. Now push a medium axle, thick end first, into the sleeve, close it well, and hold it in the chute, with its center at the upper end of the chute. Now drop it. It should hit the end of the gauge rod between the two frames. Take note of the impact number on the gauge. Now push the small axle into the sleeve. Make sure that it slides all the way to the bottom of the sleeve — tap the sleeve against the tabletop if necessary. Reset the gauge rod, drop the object, and note the impact. Now remove both of the long upper rods along with the fall chute cover. Drop each axle, inside the sleeve, from the lower height. This time, the sleeve's center should be at the upper edge of the large frame at the start of each drop. Again, note the impact reading.

Shock Absorbers Intercept Impacts

What do the different impact readings tell you? With each axle, its impact from a greater height is greater than its impact from a lower height. The medium axle, which is twice as heavy as the smaller one, makes less of an impact from the lower height than the lighter one does when dropped from double the height. When it comes to impacts, speed plays a major role, and at the end of the longer drop distance the object's speed is more than twice its speed at the end of the shorter drop distance.

Impacts are not always welcome. That goes for bumps on the head, but also for many machines. Imagine a car with no springs — each tiny bump in the road would make us bounce into the air. Fortunately, a car not only has air-filled tires and springs in the seats, it intercepts the biggest impacts with springs, or suspension coils, on its axles. But if you left the job of intercepting impacts to the springs alone, a drive would quickly become a very jolting experience, like a bouncy castle at an amusement park. The car would bounce up and down and back and forth as if it were riding waves — which would be particularly dangerous around curves. That is why **shock absorbers** were invented, to "swallow up" the rocking motion. You will find the instructions for a shock absorber (or oscillation absorber) on the next page.

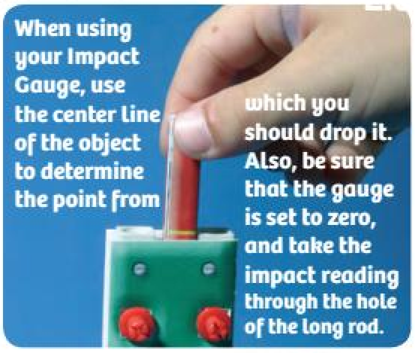
EXPERIMENT 29: WATER COUNTERACTS SWINGING

Assemble the device as shown on pages 88-89. Hold the empty device (without the cup) from the bottom with both hands and make the batteries bounce up and down by moving the device once. The batteries will continue to jiggle a while and then finally stop. Now push the cup under the spool (the pulley) and fill it up with water. Repeat the experiment. This time, the swinging motion quickly stops. Why? The inert water plays an energy-robbing role as it pumps to and fro between the narrow space between the side of the cup and the spool.

Swinging Bodies

In a collision, a moving object releases its kinetic energy, which transforms itself into work through deformation or warping, or into new movement. The suspension of a car transforms kinetic energy into potential energy with its springs. The car sways up and down and, when changing speeds, a little bit back and forth as well. You can find swinging or oscillating movements everywhere in nature and technology: ocean waves, a heartbeat, electrical waves, and acoustic waves in sounds, for example. But what do all these movements have in common? An oscillating body changes its state to a specific rhythm — its location, its speed, its pressure, or its electrical charge.

Ear-shattering Impact: the pneumatic jack-hammer



When using your Impact Gauge, use the center line of the object to determine the point from which you should drop it. Also, be sure that the gauge is set to zero, and take the impact reading through the hole of the long rod.

Shock absorber on the axle of a car

WORKSHOP 32 Oscillation Absorber

YOU WILL ALSO NEED

- *2 C batteries or similar-sized objects*
- *tape*
- *cup of water*

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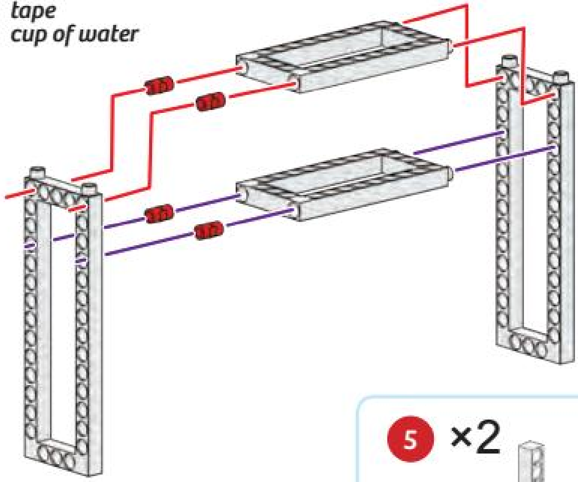

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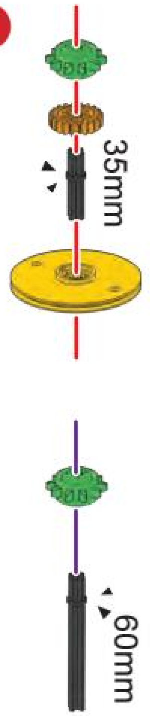

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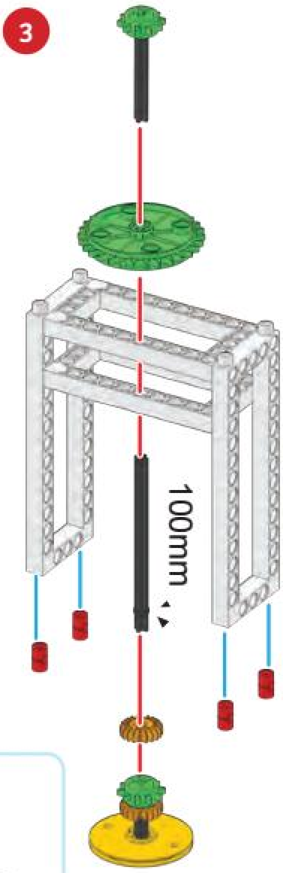

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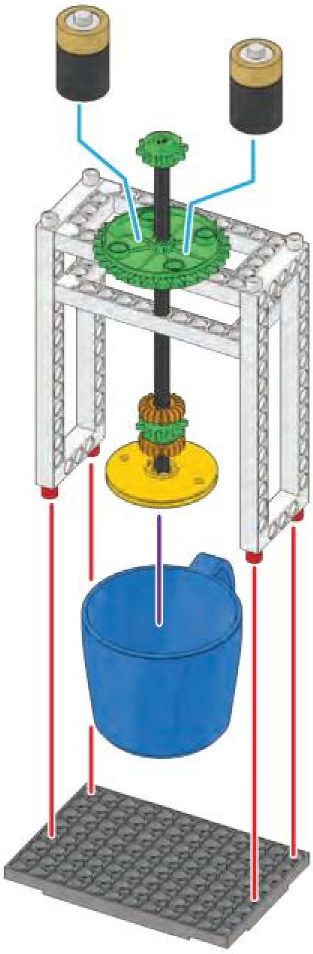
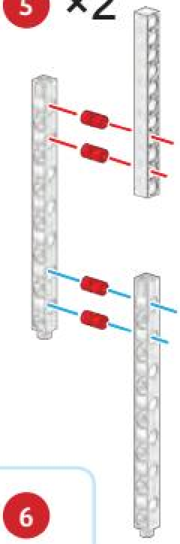
Use C batteries or similar-sized objects for weight. Secure them with tape.



The batteries act as weights, while the water-filled cup with the spool made of pulleys and gears acts as the oscillation absorber.

5 ×2



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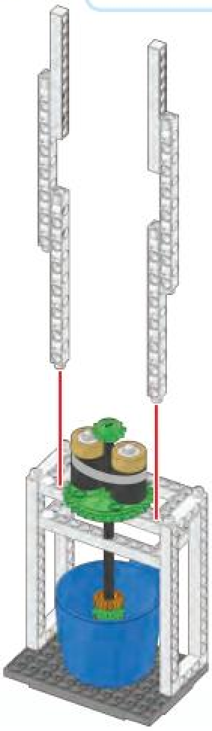
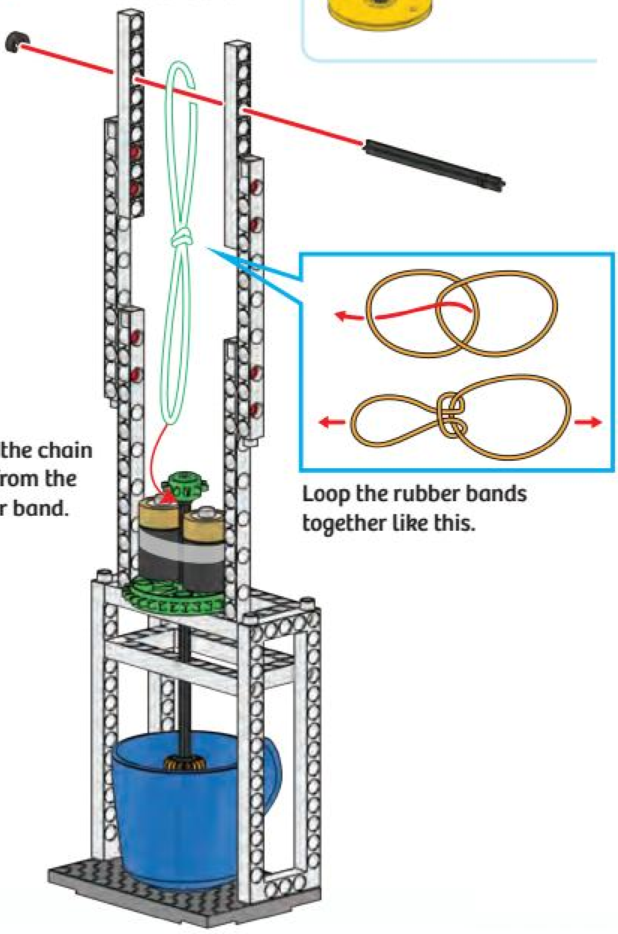


7 ×2

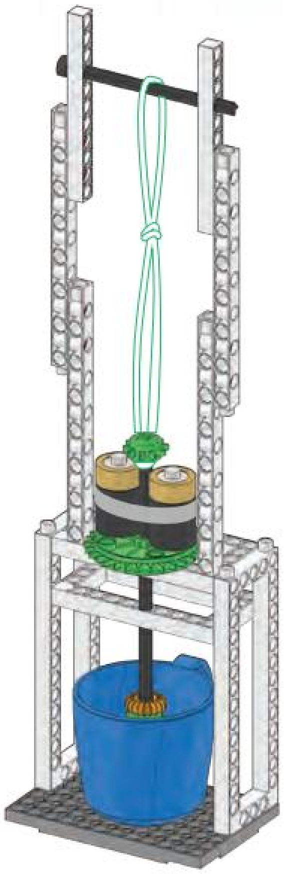
100mm rubber band

Hang the chain gear from the rubber band.



Loop the rubber bands together like this.

8



For the spring suspension, loop two rubber bands together. If they have already gotten a little stretched out, mount the large axle from which they will hang one hole higher. It is very important that the vertical axle with the battery holder hang from the top horizontal axle in such a way that vertical axle can swing equally far up and down.

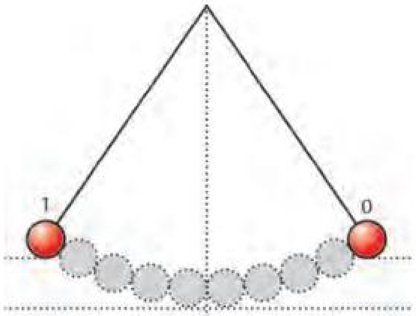
Done!

Now try Experiment 29.

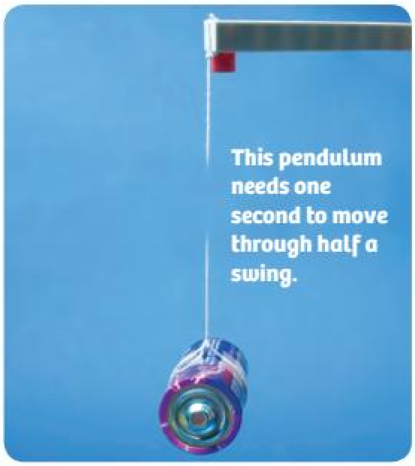
Oscillating Energy

A **pendulum** is an oscillating body, too. It changes its energy state in a steady beat between potential and kinetic energy. The time it takes to make one back-and-forth motion is called its **periodic time**, or simply its **period**.

The useful thing about the swings of a pendulum is that the periodic time is not dependent on the mass of the body. A pendulum of a certain length always needs the same amount of time for a period, even when the amplitude becomes smaller or the mass changes. That is why pendulums lend themselves very well to measurements of time — in other words, to clocks. The periodic time of a pendulum depends on its length and on acceleration due to gravity. Long pendulums swing slowly, short pendulums swing quickly. If a pendulum is exactly 99.4 cm from the suspension point to the center of mass of the pendulum weight, it needs very close to one second to travel the distance from 0 to 1, in other words for a half swing. It's easy to make a pendulum like that from the illustration at the lower left.



Energy change in rhythm. At turning points 0 and 1, the pendulum possesses potential energy, while it has kinetic energy on the curved path between those points.



This pendulum needs one second to move through half a swing.

EXPERIMENT 30: THE SECOND PENDULUM

Attach the **battery** with tape to the **string** as shown in the picture, then lead the other end of the string through the hole of the **rod**, pull the string through to leave a length of 99.4 cm exactly, and secure it with an **long peg** or **20mm axle connector.** Take the measurement from the head (positive pole) of the battery to where the string goes through the hole of the rod. To start, make the battery swing about 30° to each side. Observe it for a minute to see if the swing of the pendulum is synchronized with the second hand of your watch. If not, you'll have to alter the length of the string. The weight may have stretched it a little.

If a pendulum is to be used to determine the timing of a clock, it needs a source of power, because various forces of friction would otherwise bring it to a stop. The drive mechanism of the clock likewise needs the pendulum, so that it releases its energy in a specific timing rhythm.

A centuries-old technology for pendulum clocks is the crown wheel (or escape 8 wheel) and long peg. The long peg sits with the pendulum on an axle, and the drive rotation comes from the crown wheel. Without the long peg, the wheel would rotate quickly, and the driving energy of the wind-upspring would be rapidly used up. But the long peg seesaws back and forth against the teeth of the wheel, so it only lets ones tooth slip by with each swing of the pendulum. That is where the familiar ticking sound comes from. Here are instructions for a clock mechanism that just runs for one minute and indicates the time by making second marks on a sheet of paper. Study it well and take your time when assembling it.

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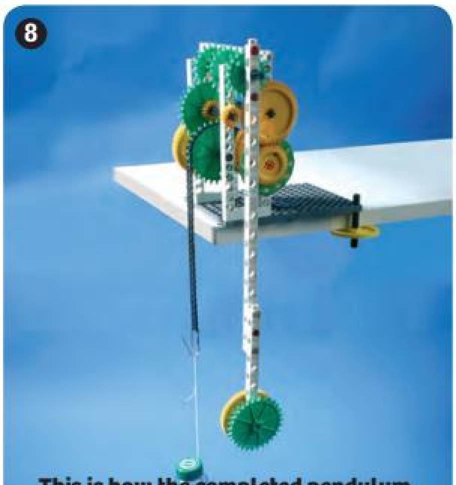

This is how the completed pendulum clock should look. To hang the drive weight, use a paper clip. You may have to give the pendulum another push.

EXPERIMENT 31: SETTING THE TIME

If you have assembled your clock, you will be able to study the way it works. The pendulum's period lasts about one second. To adjust the clock, or to get it to run with the right timing, compare its beat for about a minute with the second hand of your watch. If the length of the period is too long or short, shorten or lengthen the distance between the pendulum's center of gravity and the axle. To do that, move the pendulum weight (the 30T chain gear) by one hole.

WORKSHOP 33: PENDULUM CLOCK

This model is very challenging. Do your best to figure it out!

YOU WILL ALSO NEED

- *a paper clip*

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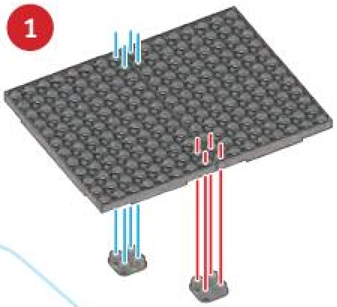

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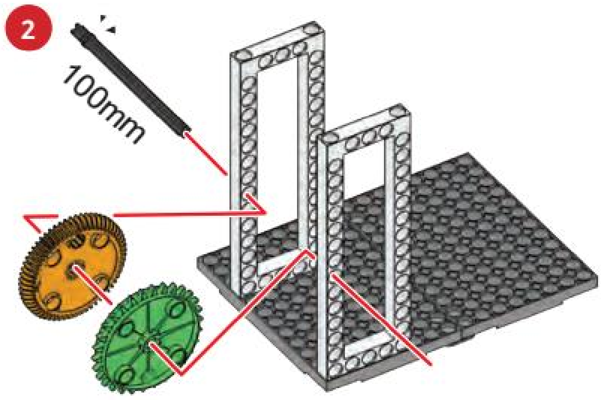

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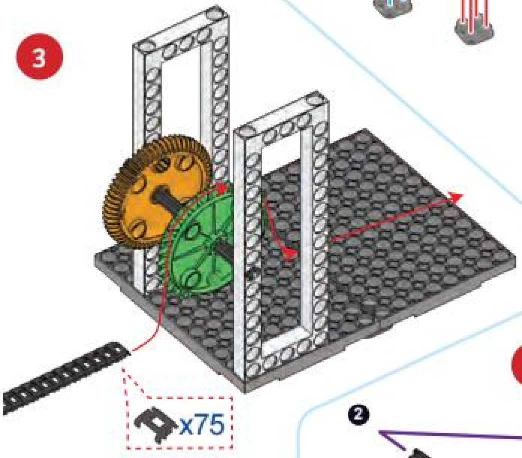

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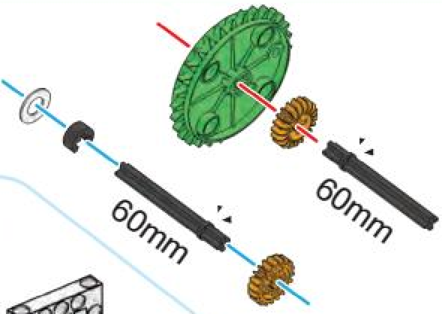

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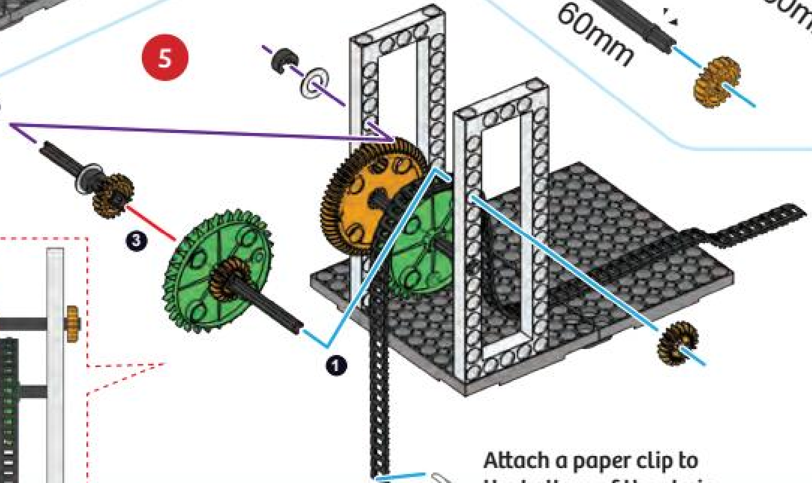
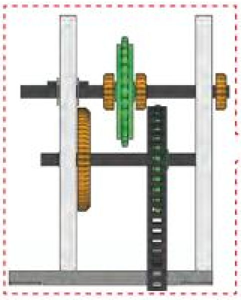
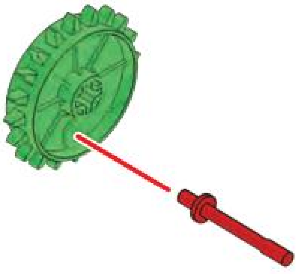


Front view



Attach a paper clip to the bottom of the chain.

6 ×2



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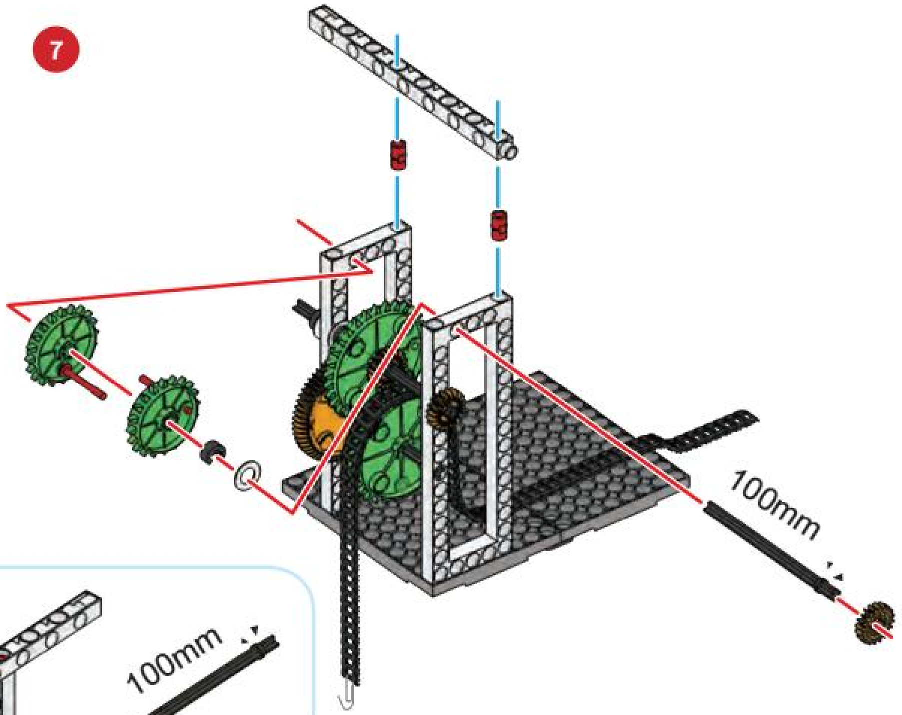

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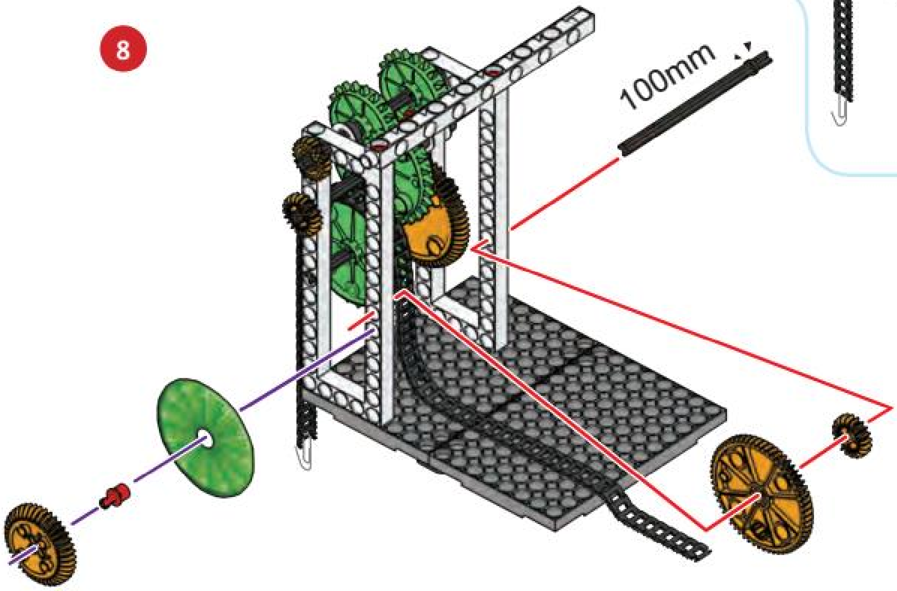

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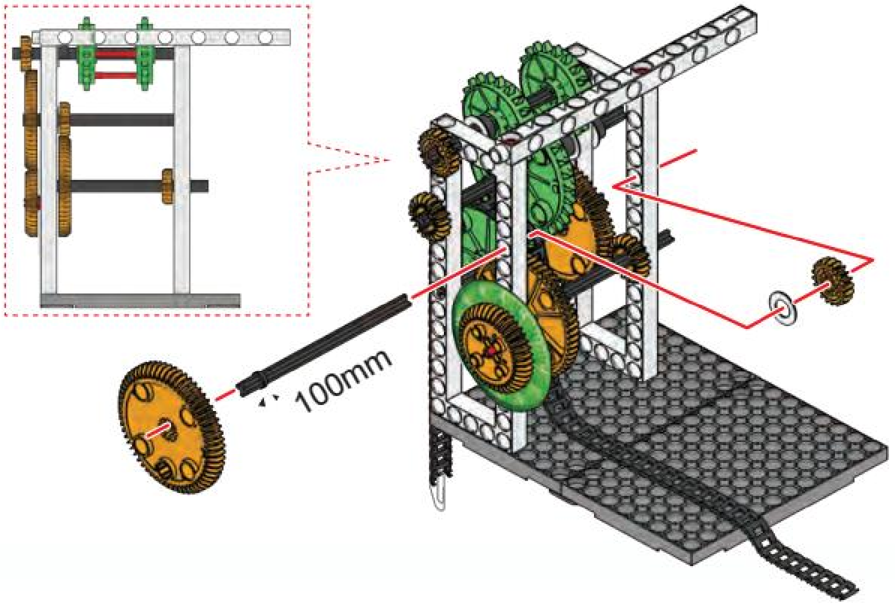

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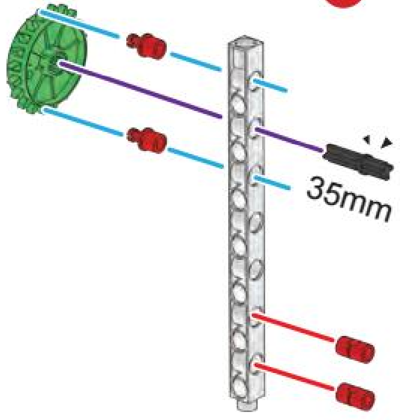

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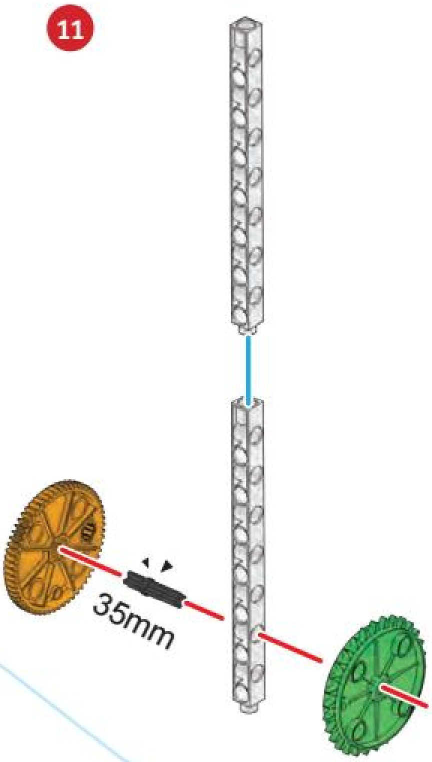

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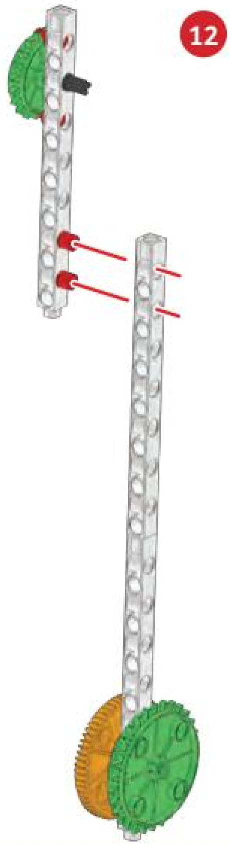

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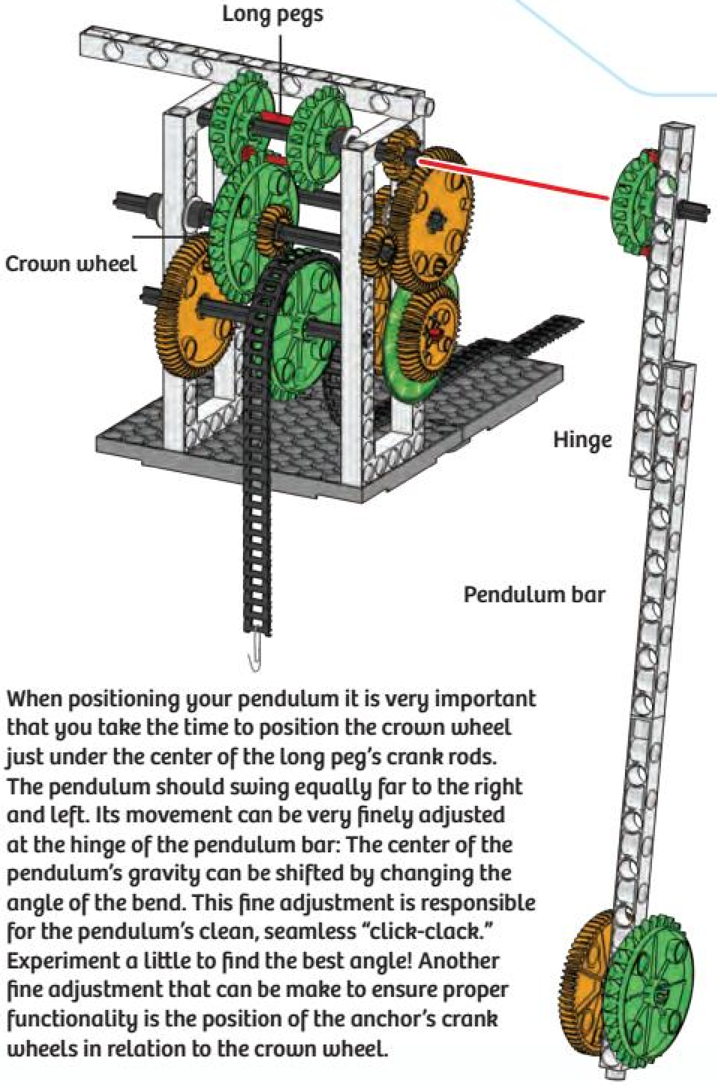

When positioning your pendulum it is very important that you take the time to position the crown wheel just under the center of the long peg's crank rods. The pendulum should swing equally far to the right and left. Its movement can be very finely adjusted at the hinge of the pendulum bar: The center of the pendulum's gravity can be shifted by changing the angle of the bend. This fine adjustment is responsible for the pendulum's clean, seamless "click-clack." Experiment a little to find the best angle! Another fine adjustment that can be make to ensure proper functionality is the position of the anchor's crank wheels in relation to the crown wheel.

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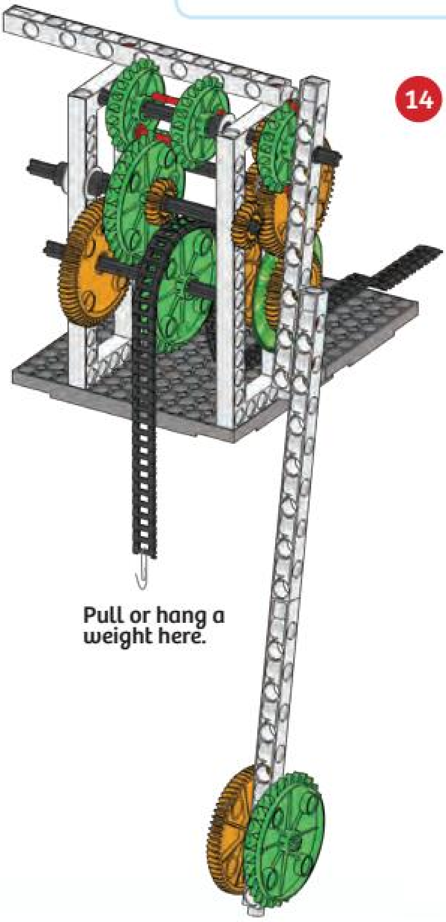


Turning Forces

Up until now, we have investigated the laws of physics pertaining to bodies moving linearly, or in a straight line. With a lot of machines, though, from a pencil sharpener to a coffee mill to a Formula One racecar, we are dealing with **rotating** or turning movements. In principle, the same regularities apply, albeit in a "twisted" sort of way.

Angular Velocity and Angular Acceleration

It starts with **velocity**. Remember that velocity is distance passed in time, or meters per second. How can you measure this relationship with a wheel, a fixed, circular body that rotates around a central point? Which part of the wheel should you choose to determine rotation speed? And how about with wheels of different sizes that rotate equally fast?

If you want to compare the rotation of different-sized bodies, you have to indicate the time they take to make a complete turn. A circle is divided into 360 angle degrees (abbreviated with the degree symbol: ∞). With one revolution, the body moves through 360∞, with half a revolution 180∞, and so on. The faster the body turns, the more degrees it passes through in a second. That is why the rotation speed of a body is also called its **angular velocity**. Of course, not only circular bodies can rotate around an axis — square or angular ones can too. And it's equally possible for the center of rotation to lie inside the body or outside of it.

Now that you know what angular velocity is, it's a similar matter to determine acceleration during rotation. You just have to determine how angular velocity changes in a specified period of time. This is called **angular acceleration**.

Taking Turns: Centripetal Force and Centrifugal Force

Now we will focus on the forces at work in rotation. As you know, bodies are inert. They do not want to change their state of motion. If you want to get them moving from a resting position, you have to contend with their inertia — which has to be overcome with force. That's exactly how it is with bodies in motion, too: they want to retain their direction and their speed. Only with extra force can you make them "change their minds."

If a body is moving on a circular path, there has to be a force that prevents it from taking a straight path. That force is called **centripetal force**. It's a force that accelerates the body in the direction of the center of rotation. But if a body could move in an unconstrained manner, it would break away in accordance with its inertia and fly off in a straight line. So it is always pushing itself away from the center of rotation. The force that it produces in its constant desire to fly off the circle is called **centrifugal force**. Centripetal and centrifugal force are equally great and work in opposite directions. They are therefore in balance. Like all mechanical forces, they are measured in newtons (N). You can make the effect of centrifugal force visible without much difficulty.

EXPERIMENT 32: PEBBLES IN FLIGHT

Lay your bicycle on the ground so that its front wheel can spin freely. Find a good-sized rock and place it on the side of the tire. (It should be flat and not too thick, so that it doesn't touch the fork.) Let the wheel turn slowly at first and then gradually faster. Up to a certain revolution speed, the rock will stick to the tire. Then the centrifugal force overcomes the force of friction and the rock flies off in a straight path — in fact, at a **tangent**, which is a line that shares a common point with the circle and is the closest linear approximation of the circle's curve at that point.

DID YOU KNOW?

What is RPM?

There is another name for the speed of rotation: **revolution speed**. It indicates how many complete turns a body makes in a certain period of time. With engines, it is common to indicate the number of revolutions per minute. When, for example, an automobile engine has a median rotation rate of 3,000 revolutions in a minute, one writes: 3,000 rpm.
In many cars, next to the driving speed indicated on the speedometer, you can see the engine's revolutions per minute, indicated on the tachometer.

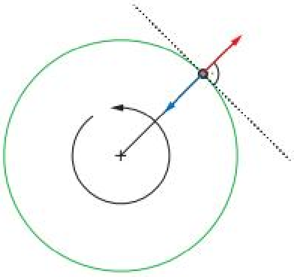
KEYWORD: ANGULAR VELOCITY

Angular velocity is the rate of change of the angular* position of a body with respect to time.

KEYWORD: ANGULAR ACCELERATION

Angular acceleration is the rate of change of the angular velocity of a body with respect to time.

(*angular meaning position on a circle)



The centrifugal force indicated in red, which acts on the rotating (black) body, is just as great as the opposing centripetal force, shown in blue.

KEYWORD: CENTRIPETAL FORCE

Centripetal force, "center-seeking force," is a constant force acting on a body in circular motion, pushing it toward the center of the circular path. Balances centrifugal force.

KEYWORD: CENTRIFUGAL FORCE

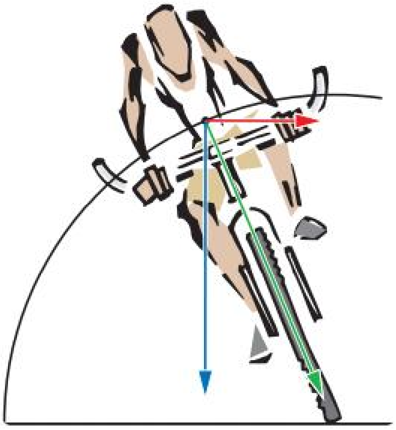
Centrifugal force, "center-fleeing force," is a constant force acting on a body in circular motion, pushing it away from the center of the circular path. Balances centripetal force.

The hammer thrower needs (centripetal) force to keep the hammer in its orbit. When the hammer is released, centrifugal force rips it out of its circular path. The faster the athlete turns with it before releasing it, the farther the hammer flies in a straight line.

For calculating tangents, there are three things that are important: the mass of the body, the angular velocity, and the radius of the circular path. Centrifugal force (and its opposing force) increases with the mass of the body and with its angular velocity. But it also increases with the radius of the circular path on which the body moves. You may have experienced centrifugal force as a child, as you flew through the air on a circular swing ride at an amusement park. Attached securely by its chains, the swing chair can't fly away, but it can move out and — against the force of gravity — up as well.

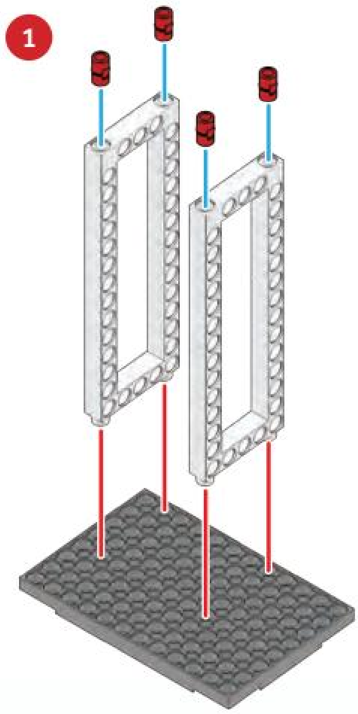
You also experience centrifugal force with your own body when you lean into a curve while riding your bicycle, so that you don't get thrown off. At a certain angle, gravitational force (blue) and centrifugal force (red) are in balance. Both pull at the center of gravity of the rider and the bike around the center of rotation, which is the spot where the tires are touching the road. Both forces result in the force (green) that is directed toward the road in the direction of the tilt.

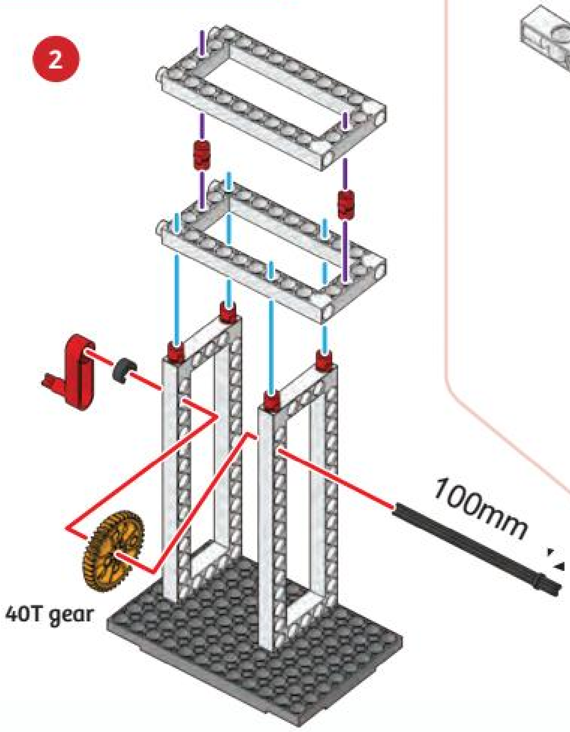
We can make centrifugal force visible with the help of a small device. The rotating body sits on top of the turning axle.

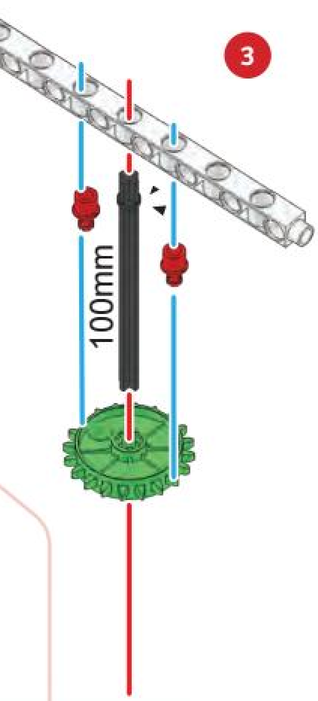


Riding the curve: By shifting his center of gravity, the rider compensates for centrifugal force.

WORKSHOP 34: CENTRIFUGAL FORCE STATION







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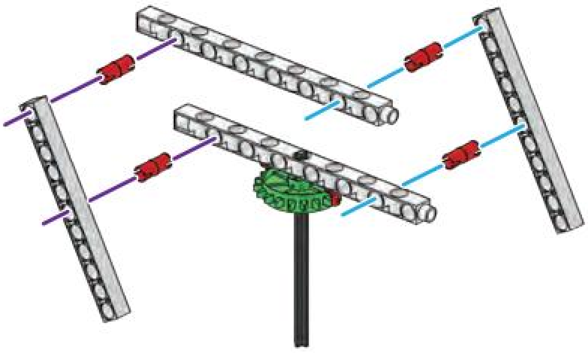

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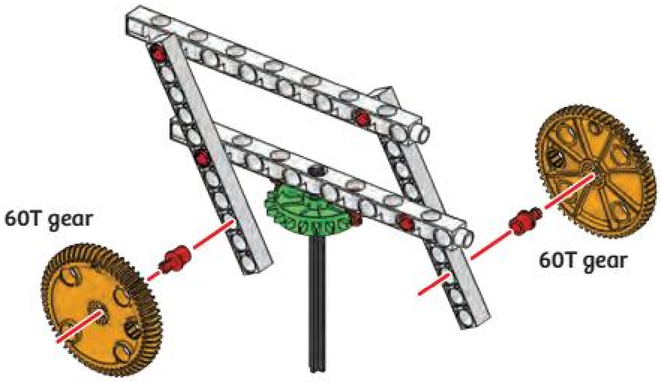

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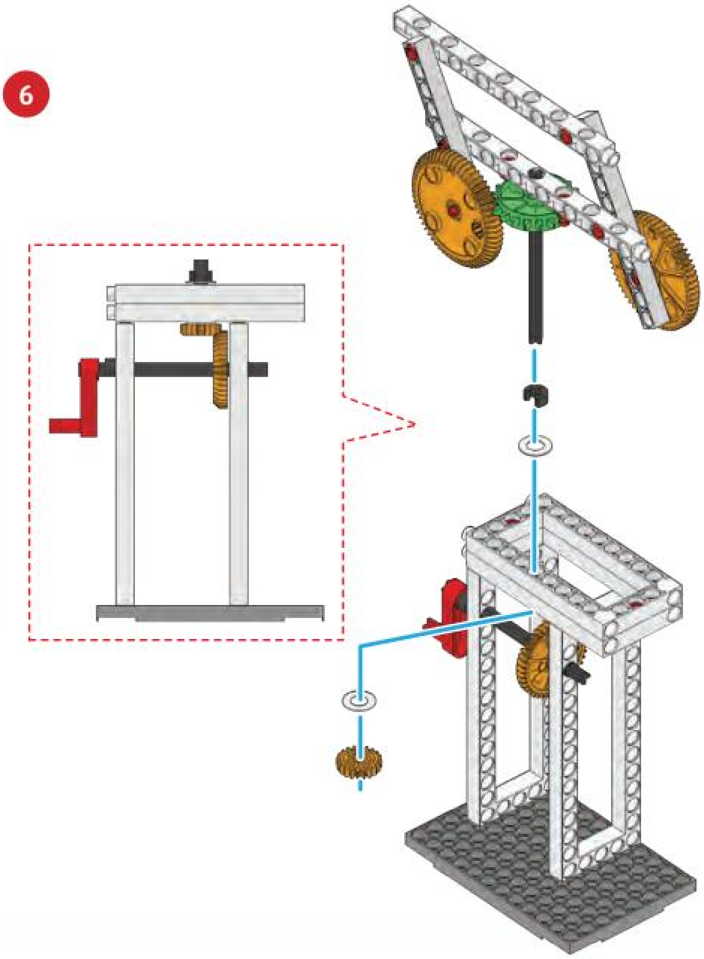

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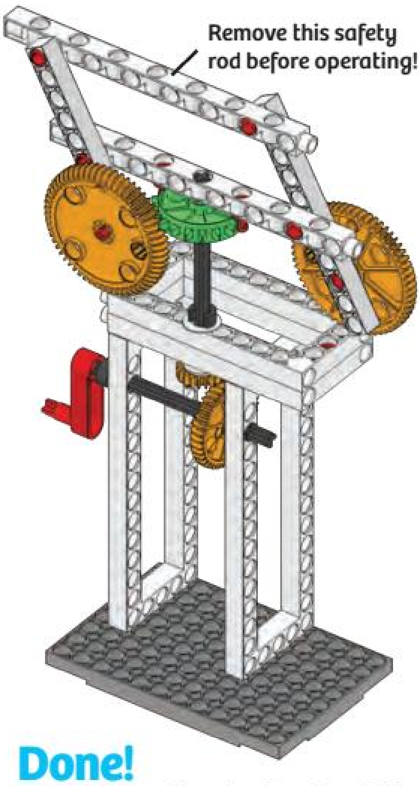
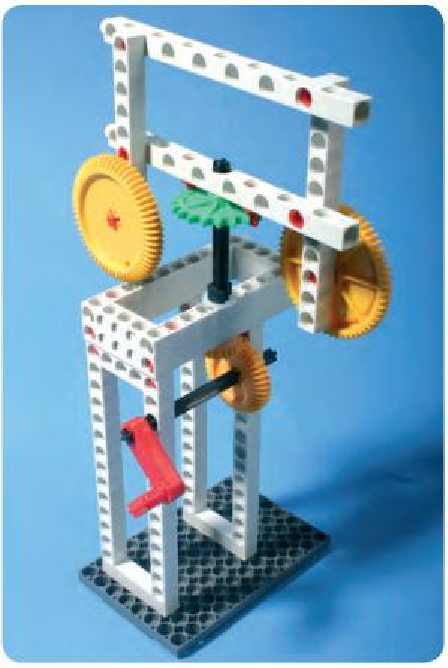
As the rotation speed increases (in other words, as you crank the handle faster), centrifugal force will move the yellow gears outward and upward, just like on a rotating swing ride. First, though, you will have to remove the safety rod at the very top of the model.



Done!

Now try Experiment 33.



The same goes for an amusement park swing ride: the faster it spins, the farther up and out the chairs fly.

EXPERIMENT 33: FORCES IN FLIGHT

Turn the crank to make your centrifugal force station spin. Does something occur to you? There's nothing for the centrifugal force to really work with. Remove the safety rod from the very top and repeat the experiment. The faster you crank the handle, the farther the weights push outward and upward.

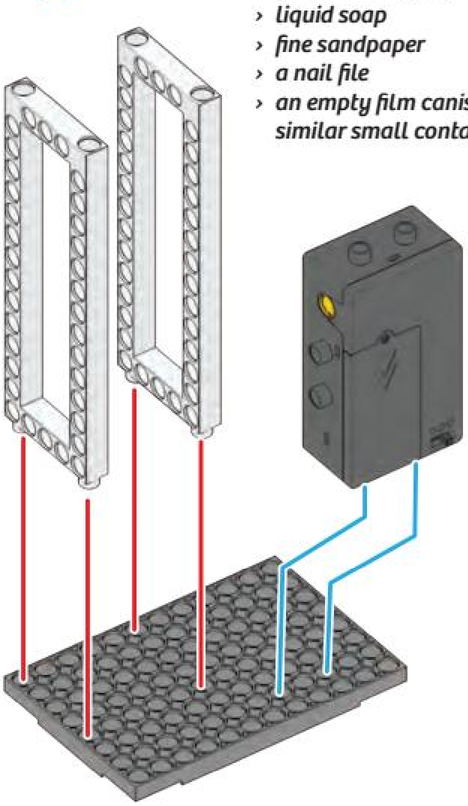
In everyday life, centrifugal force is used in the spin cycle of a washing machine. It releases water particles from the fabric and drives them to the wall of the drum. The holes in the drum allow the water to flow away but not the clothes.

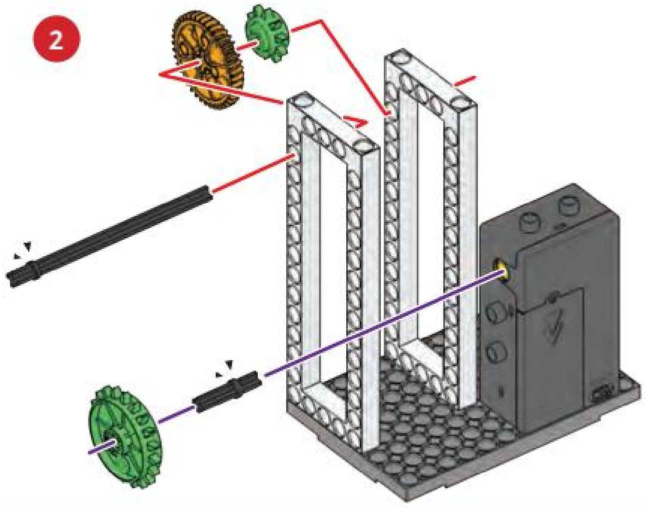
Due to the fact that bodies of different weights also experience different centrifugal forces, one can use centrifugal force to separate particles of different masses that are mixed up together. That is what happens in a **centrifuge**, which is a kind of rotating container whose contents are dissociated from one another by centrifugal force. That is how lighter cream (fat) is separated from heavier milk (protein and water) in a dairy factory, or in an olive oil mill the lighter oil is separated from the remaining components of the crushed olives. We can use our electrically powered centrifuge to observe what happens in a washing machine or an industrial centrifuge. You will also need a light-colored, somewhat translucent film container with a lid, and a good glue (e.g. model glue). You can usually get a film container for free at a camera shop.

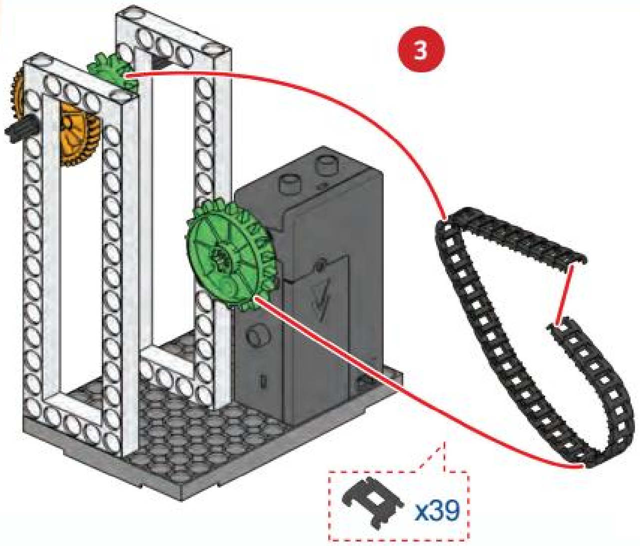
WORKSHOP 35: CENTRIFUGE

YOU WILL ALSO NEED

- *glue (model glue)*
- *liquid soap*
- *fine sandpaper*
- *a nail file*
- *an empty film canister or similar small container*







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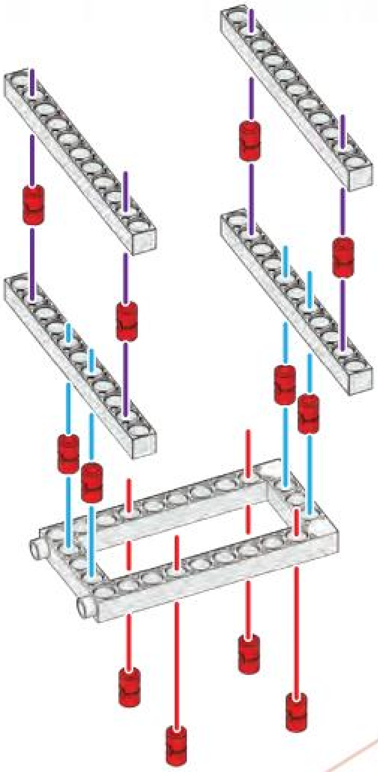

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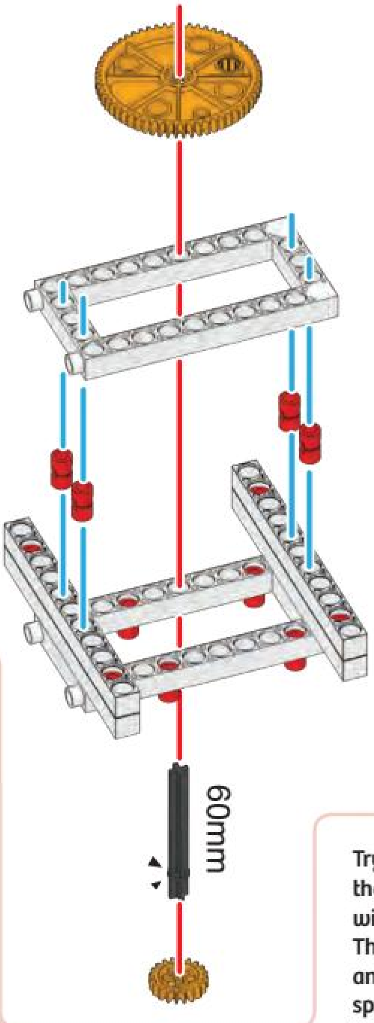

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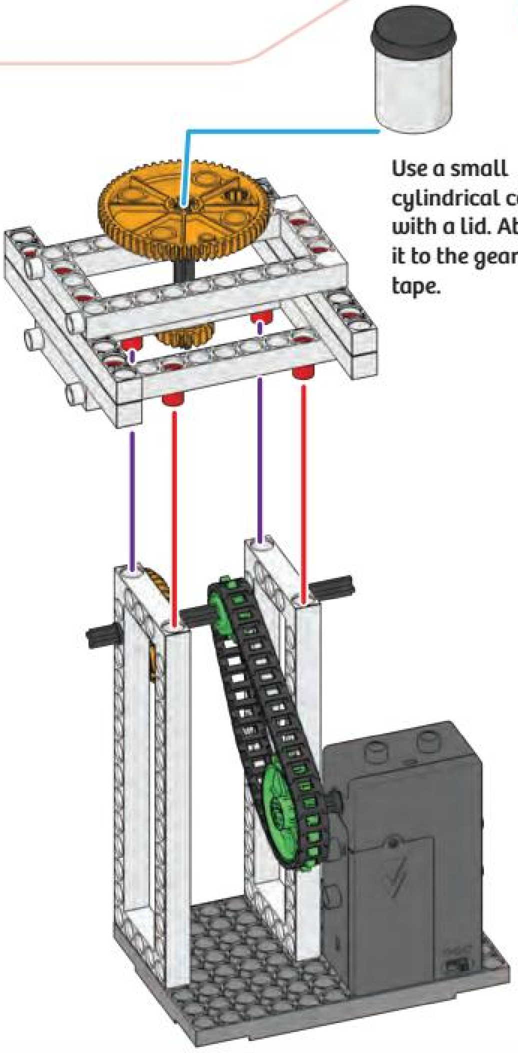

Use a small cylindrical container with a lid. Attach it to the gear with tape.

Try a test run to make sure the container spins nicely without wobbling off-center. That would use up energy and reduce the revolution speed. You may have to adjust the location of the container and try it again.

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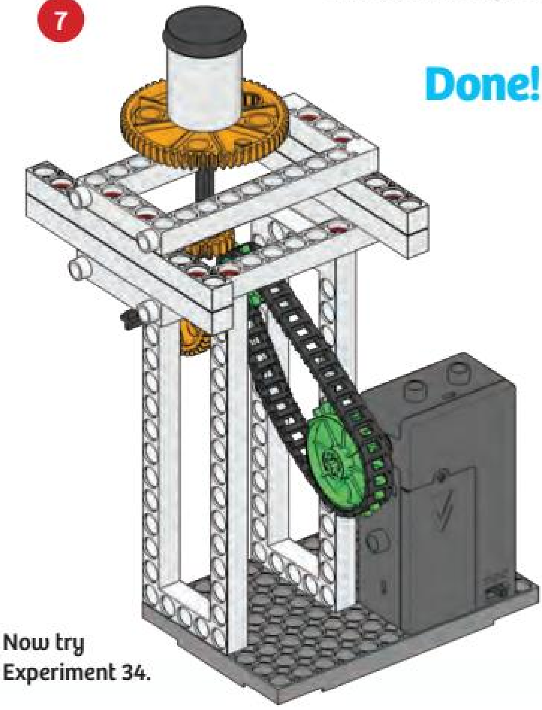


Done!

Now try Experiment 34.

EXPERIMENT 34: SPIN-DRY PRINCIPLE

You can investigate the principle of spin-drying by removing the section with the gear and film container and filling the container with about one centimeter of water. Close it tight, place it back on the shaft of your centrifuge, and switch on the motor. Observe the water in the container, ideally against a light source. You can see it flow up the walls of the container, as it adheres to the container and is pulled around with it. Turn off the motor again and watch what the water does.

The more water there is in the centrifuge, the stronger gravity works to keep some of the water on the bottom. Imagine that the container had tiny wet shreds of material, its sides had lots of little holes, and it had an exterior wall to catch the outward-spinning water — then your experimental setup really would be a miniature spin-drier.

EXPERIMENT 35: CENTRIFUGE PRINCIPLE

For this experiment, we will use our centrifuge again. Unfortunately, most of us can't very easily come by unprocessed vegetable oil or raw milk. So instead, we will take some water and some yellow cooking oil, and half-fill the container with equal amounts of those (over the sink!). Close securely. Before switching on the motor, take the gear-container unit between your thumb and forefinger and shake it well, so the oil and water mix. Now, the oil will be dispersed through the water in big and little bubbles. The term for a liquid like this is an emulsion. (An emulsion usually contains two liquids that will not dissolve in each other, with one floating in the other in small particles.) Now return the unit to its shaft. Switch on the motor and watch! You will see how two little inverted hats take form, one inside the other. The lighter one, made of oil, rotates on the inside, separated from the heavier one made of water.

Imagine that more emulsion was constantly pumped up from the floor of the container and that at the top, inserted through the lid at appropriate locations, two tubes were positioned to carry off the light oil and heavy water — then we would have a mini-centrifuge. There are countless different styles of centrifuges in industrial use. They all, however, obey centrifugal force, from which they get their name.

Centrifugal force can also be used to steer or switch machines automatically. You can see how it works with our example of a **centrifugal switch**. Imagine that one of these sat in a ventilator behind an electric motor that sometimes got a lot and sometimes only a little power from a solar generator. The greatest possible rotation speed has to be attained by the exit shaft with the rotor. You will find the instructions for this automatic centrifugal switch on the next page.

EXPERIMENT 36: CENTRIFUGAL SWITCH

Before starting the motor of your centrifugal switch, check to make sure that all the shafts rotate easily in their bearings. You may have to move the long vertical rod with the exit shaft a little to the left or right, so the gear mesh without jamming. Also test whether the upper shaft moves back by itself after you push it inward.

Start the motor and watch which gear meshes with which. Now slow down the upper shaft on the motor side by holding it carefully between your finger and thumb. It will crunch a little, and then the other gears will intermesh, right?

Who is doing the switching? It isn't you, it's the centrifugal force, which changes as the rotation speed changes. The centrifugal weights push outward and make the pair of belts come together, which then pull the switching axle into a different position.

(Note: If the belt does not seem to be pulling the switching axle inward enough to contact with the inner exit shaft gear there are a few things you can try. First, you can try "squishing" the belt very lightly to take some of the spring out. Second, adjust the location of the gears on the exit shaft, in or out so that they mesh better with the gear on the switching axle. Third, adjust the chain on the motor a bit looser so that it avoids binding. One last thing you can try is changing the motor battery; it may not have enough power left to spin the belt fast enough.)

When it spins, the water wanders outward and up the container walls. Even once the container has stopped, the water returns only gradually to its starting position, because it continues to spin for a few seconds longer.

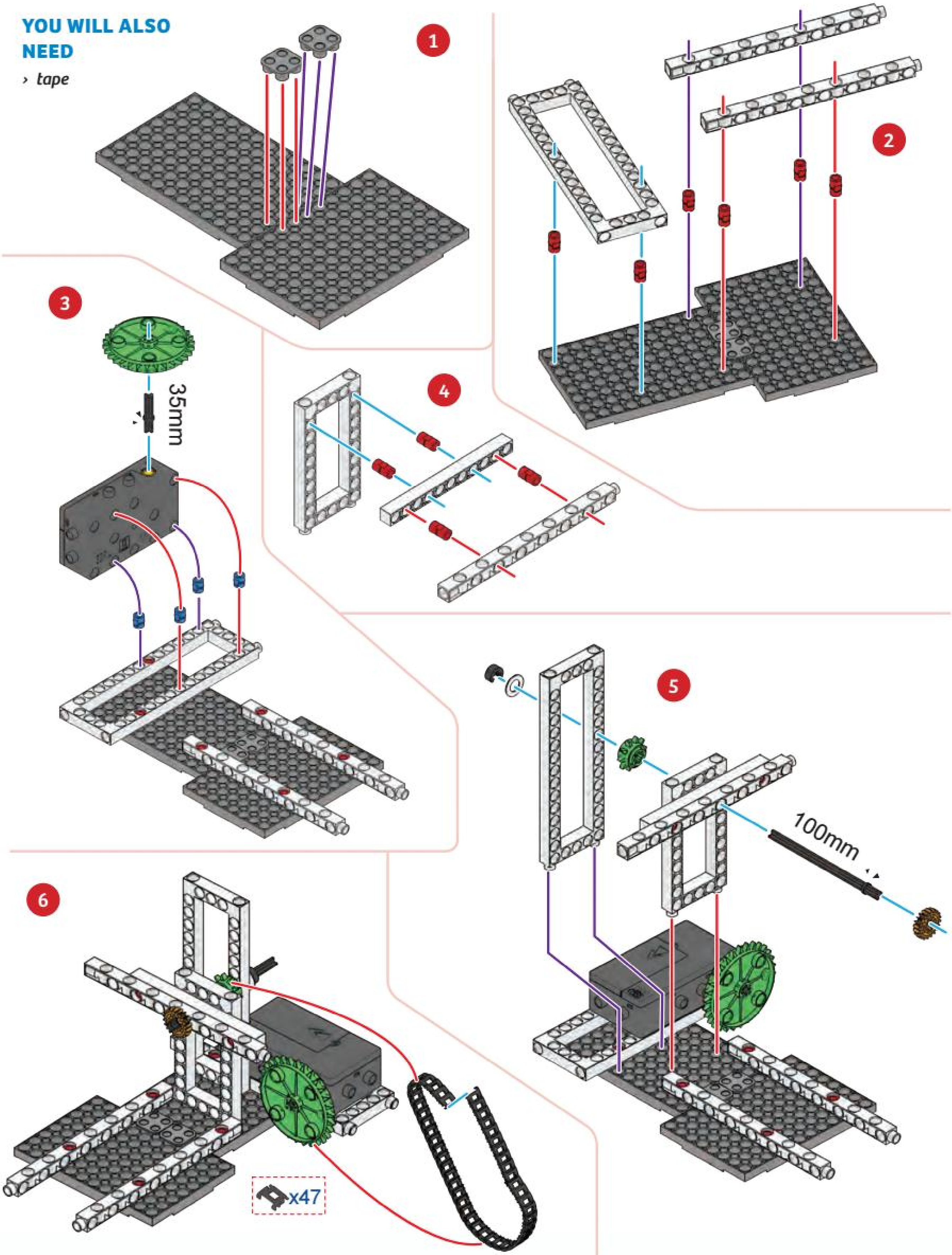
The centrifuge separates water from oil.

The drum of a modern washing machine doesn't just wash, it spins as well.

Automatic Centrifugal Switch WORKSHOP 36

YOU WILL ALSO NEED

- › *tape*



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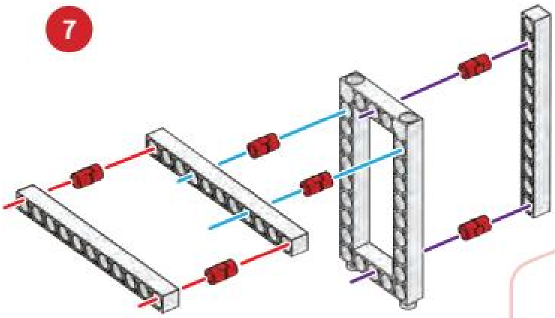

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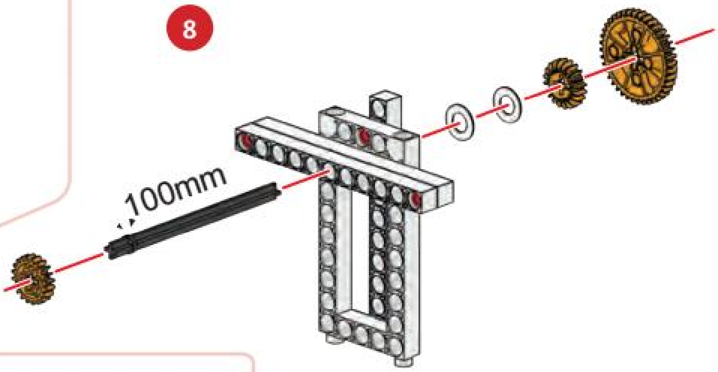

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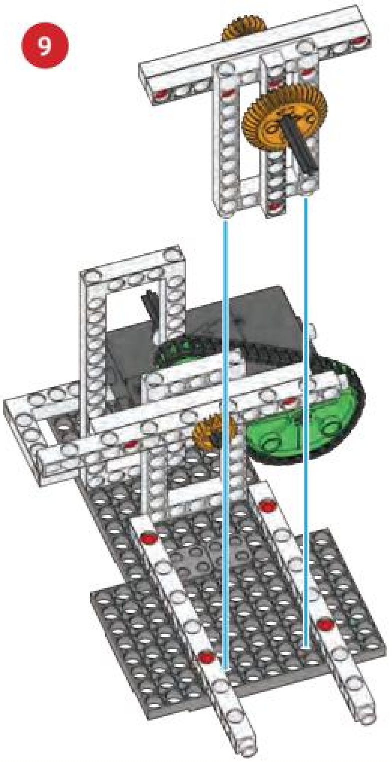

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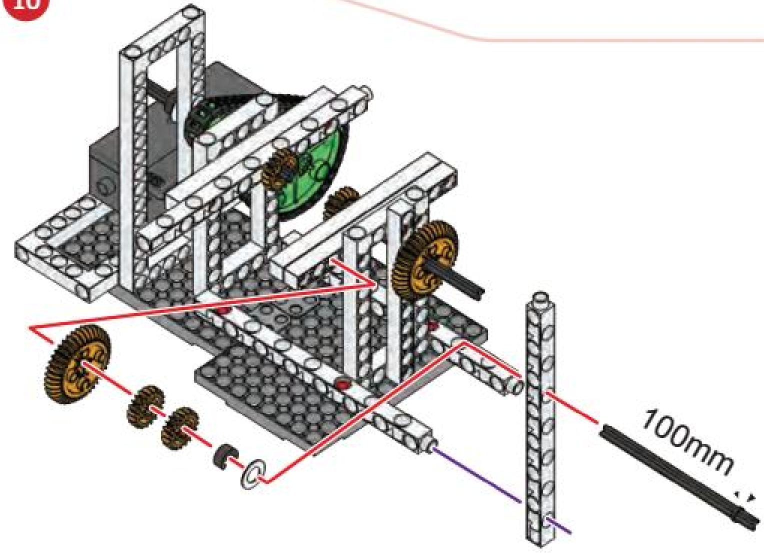

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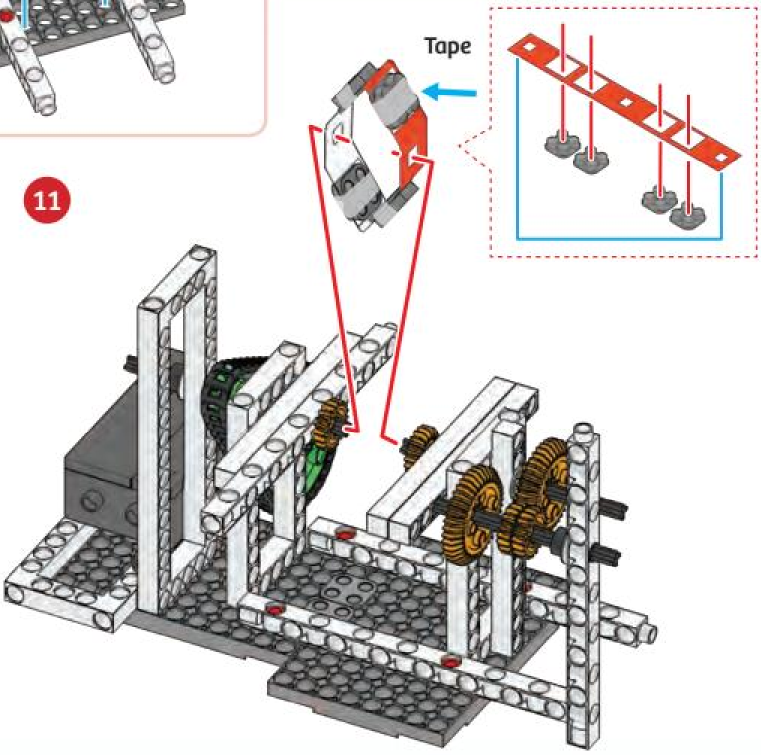
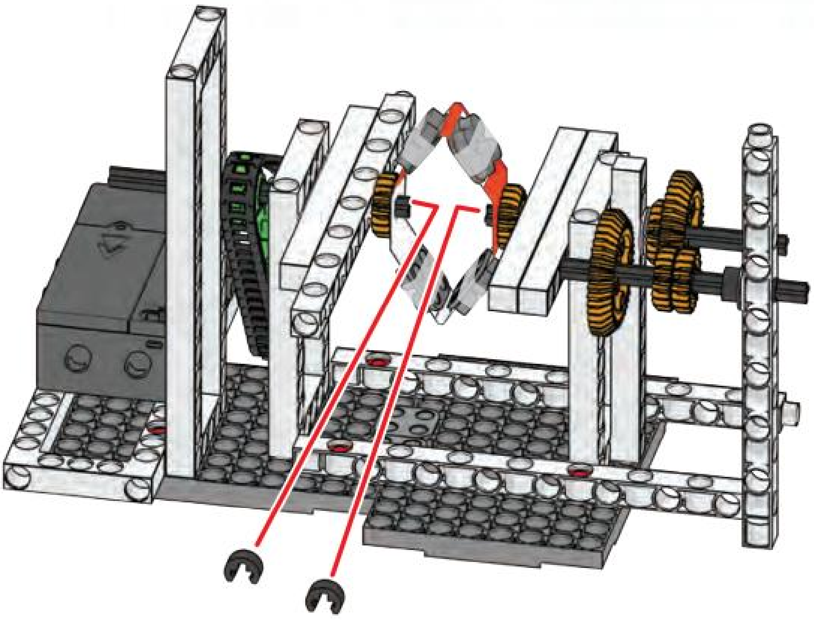


The four base connectors serve as the centrifugal weights. Tape them into the large holes of the belt (from the die cut card).

12



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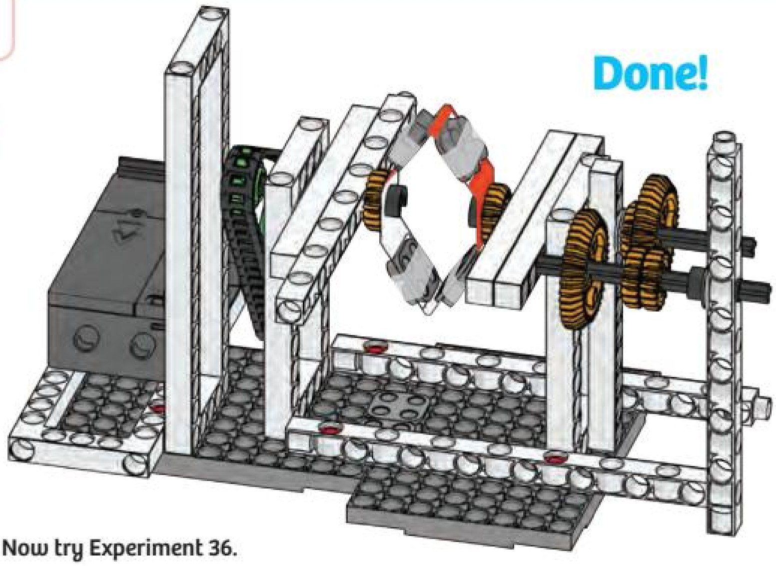


Done!

Now try Experiment 36.

The top on a plate

What Makes the Top Slow Down — the Moment of Inertia

We have learned about velocity and the two important forces of rotation. If the physical factors of rotation are similar to those of linear movement, then what about mass?

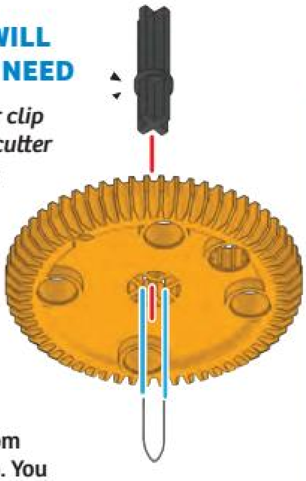
In other words, how does rotation affect the tendency of a body to be inert and heavy? Gravity naturally works on the mass of a rotating body too, and that makes it inert and pulls it towards Earth's center. Now we have to add to that another inertia of its mass, one that comes from its rotation. A rotating body wants to maintain its movement as well, and conversely it acts inert if you want to prod it out of a state of rest into rotation. You are familiar with this kind of inertia from a top: once twirled and loaded with energy, it will continue to spin for a while without any extra help.

To investigate the perseverance of a spinning body once again, we will construct a metal-tipped top. You can either spin this top between your thumb and forefinger, or start it in the classic manner with a pull-cord and rod.

WORKSHOP 37 Spinning Top

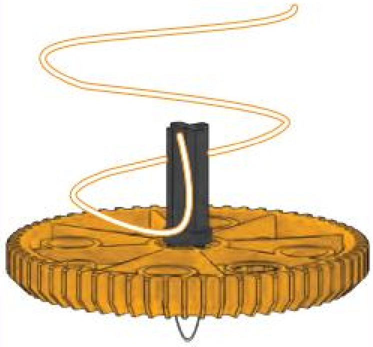
1 **YOU WILL ALSO NEED**

- *paper clip*
- *wire cutter*
- *pliers*



Make a wire tip for your top from a paper clip. You must wear safety goggles when you cut the wire! An adult should help you cut and bend the wire. The tip is pushed over the axle and then the gear wheel is pushed over both.

2 Wrap a 500 mm string around the axle.



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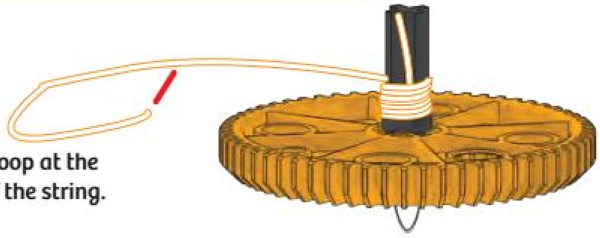
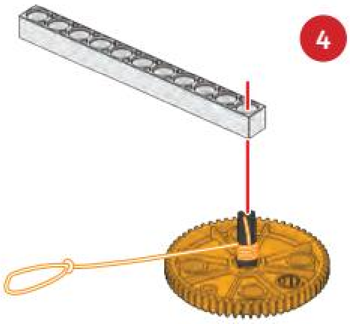


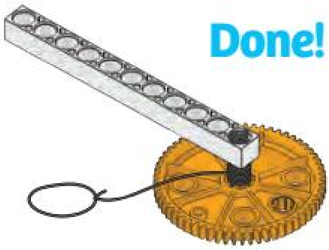
Tie a loop at the end of the string.

4



Done!

5



Before starting, wrap the pull cord tightly around the top's axle, but do not tie a knot (when you start wrapping, hold it with your thumb against the gear). Insert the axle into the last hole of the rod, and hold the rod loosely over the ground. With a powerful yank of the cord, the top begins its whirlwind tour. As soon as it starts, lift the rod out of its way. Of course, you can also twirl your top between your finger and thumb if you like.

EXPERIMENT 37: TOP ON A SLOPING PATH

Practice starting your top a few times so that its axle stays in place as it spins. Then start it on a flat dinner plate and tilt the plate a little to the left and the right. (The top with the metal tip works best for this.) You can see that the top maintains its position; it may wander a little to one side, but it basically tries to keep its axis vertical.

What do these experiments show? The top tries to keep spinning as long as possible. If there were no resistance between the gear and the air and no friction against the surface on which it spins, it would keep spinning indefinitely. That fact is due to the so-called **moment of inertia**. There is one more thing the experiments show: just as the mass of a resting body is stubbornly pulled towards the center of Earth by gravity, it also makes the body obstinate and inert when it spins. It tries to force the body to maintain its position in space.

The top isn't bothered by any movement in or across the direction of its axis. But it resists any attempt to alter its tilt.

The moment of inertia increases with mass, in other words with the weight of a rotating body. Its value also rises with the size of the circle's radius, or the circular path on which the center of mass moves. And last but not least, it depends decisively on the angular velocity, which is, in turn, produced by a force. With circular movements, force and radius are combined in torque (see page 32). The equation is:

$$\textbf{moment of inertia} = \frac{\textbf{torque}}{\textbf{angular acceleration}}$$

DID YOU KNOW?

The top takes a flight

Its "defiant" attitude toward changes in its tilt make the top an excellent sort of watchdog for shifts from horizontal position — specifically, in the gyroscope of an airplane.

The housing of the gyroscope is built rigidly into the cockpit. In its almost friction-free bearing, a high-mass top spins extremely fast, driven by a special electric motor. The top's axis is oriented toward Earth's center, with its position displayed by an instrument indicator. If the airplane shifts to the left or right, the indicator jerks sideways. In fact, of course, it only seems to be doing that. The position of the indicator actually remains the same — just like the top on the plate — and it is the plane that is doing the tilting.

KEYWORD: MOMENT OF INERTIA

Moment of inertia is a measure of a body's resistance to angular acceleration.

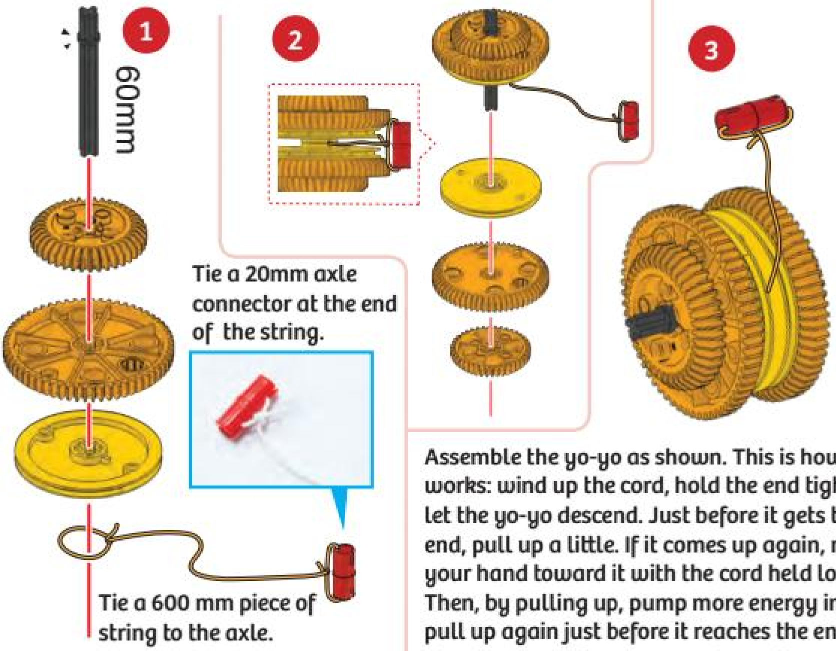
Work and Energy in Rotation

You will recall that with bodies moving in a straight line, we defined work in terms of the product of force and distance: work = force x distance.

With rotating bodies, too, the quantity of work is measured in terms of the change in location undergone by a force. Instead of meters, we indicate the change in location with and angle, and force — as just mentioned — with torque. In rotation, then, work is the product of torque and the angle by which the body turns.

And where do things stand with **rotational energy**, or the capacity of rotating bodies to perform work? Its laws must be similar to those of bodies moving in a straight line as well. Start your high-performance top with the cord again. The harder you pull the cord to get it going, the faster the top spins, right? In other words: the greater the moment of inertia and the angular velocity, the greater the amount of stored rotational energy. The work that you applied at the start is now stored in the body as energy. We'll prove it with a quickly assembled yo-yo.

WORKSHOP 38: WEDGE AND STUCK RACK



Tie a 20mm axle connector at the end of the string.

Tie a 600 mm piece of string to the axle.

Assemble the yo-yo as shown. This is how it works: wind up the cord, hold the end tight, and let the yo-yo descend. Just before it gets to the end, pull up a little. If it comes up again, move your hand toward it with the cord held loosely. Then, by pulling up, pump more energy into it, pull up again just before it reaches the end, etc. The stored rotational energy keeps the yo-yo going.

What's Going on with the Yo-Yo?

Gravity pulls the body of the yo-yo, it unrolls from the cord, rotates (faster and faster, because of gravitational acceleration), and thereby takes up rotational energy. After the cord unrolls, the yo-yo body keeps rotating and climbs back up the cord with the help of the stored rotational energy. But because energy is lost through friction (above all by the rolling and unrolling of the cord), we keep having to add some back in.

In industry, rotational energy is used in **flywheel** energy storage systems. Those usually have a wheel with a heavy metal rim, which is kept constantly rotating by a motor. When the motor is briefly required to provide more energy than it can, the flywheel springs into action and gets it through the critical few seconds of overload. Just like a bicyclist who gives some of his own energy to nudge an exhausted companion over a hill. Or the way your work in this booklet has hopefully made the task of constructing, experimenting, and understanding a little bit easier.

The End

We hope you had a great time building the models, conducting the experiments, and learning the lessons in this kit!

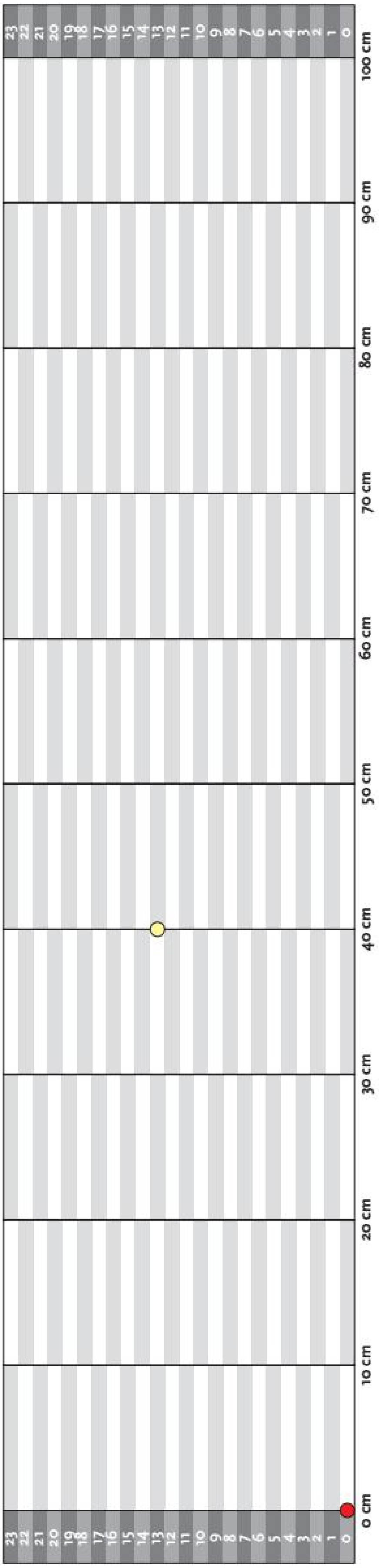
DID YOU KNOW?

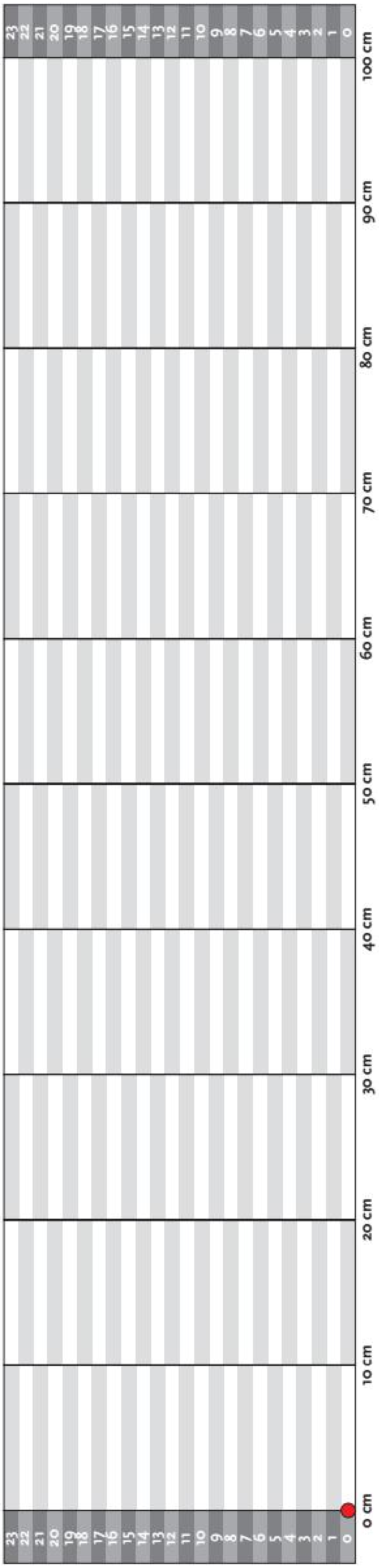
Riding a bike — pure trickery

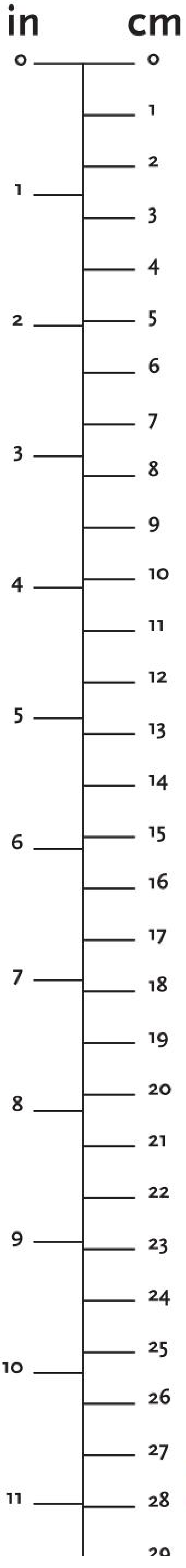
How is it actually possible to keep your balance on a bike? Trying to just stand still on two wheels results in falling. The art of bike riding consists in a balance of centrifugal forces that arise from small curves while riding. Without a steering wheel, then, bike riding would be impossible. With it, we accommodate the curves, without really being conscious of what we're doing. Against the centrifugal force that arises when riding through a curve, our body instinctively angles itself a little too steeply. The body reacts to the sharp angle by shifting its weight to the other side, which leads to another curve in the opposite direction and another corresponding centrifugal force, to which our body reacts...and so on. As we start riding, the curves and our compensating movements are relatively great, but they become smaller as we get going, until we seem to be riding in a perfectly straight line.

The faster the speed, the less we need the steering wheel to balance. Then we're dealing increasingly with a different effect of rotation: the moment of inertia. This rises with the rotation speed of the wheels, and stabilizes the ride. Because of their mass, the wheels fall increasingly into a sort of "top defiance." In other words, they are harder and harder to shift from the direction of their axis.

Here are the flight data charts for Experiment 9. You can enter in the graph data for various drive power settings and shooting angles. As an example, we made an entry shown by a yellow dot: If the number board is positioned at a distance of 40 cm from the shooting apparatus and the ball hits the board at a height of 13, you would make an entry as shown by the yellow dot. You might want to make a few copies of this page, so you can use the charts for a lot of different sets of data.







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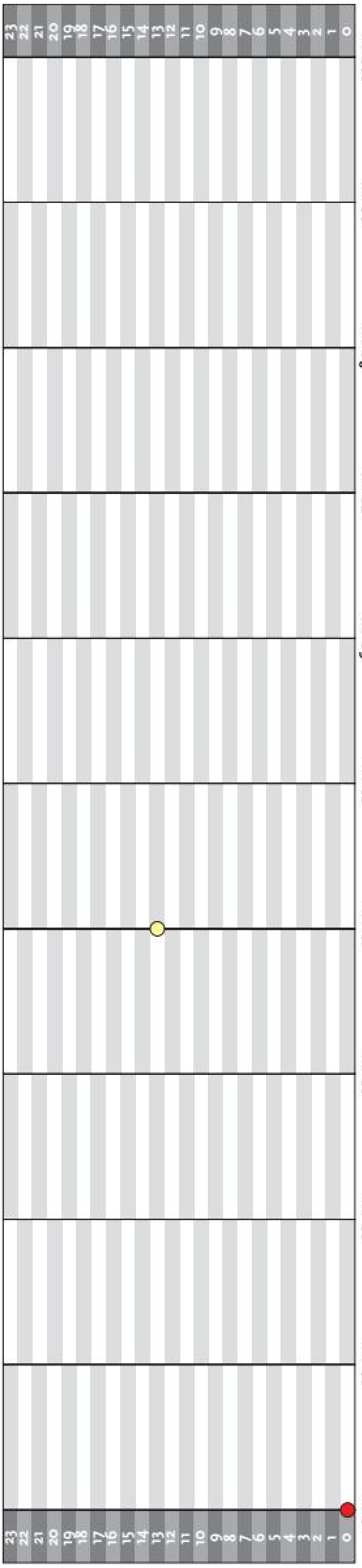

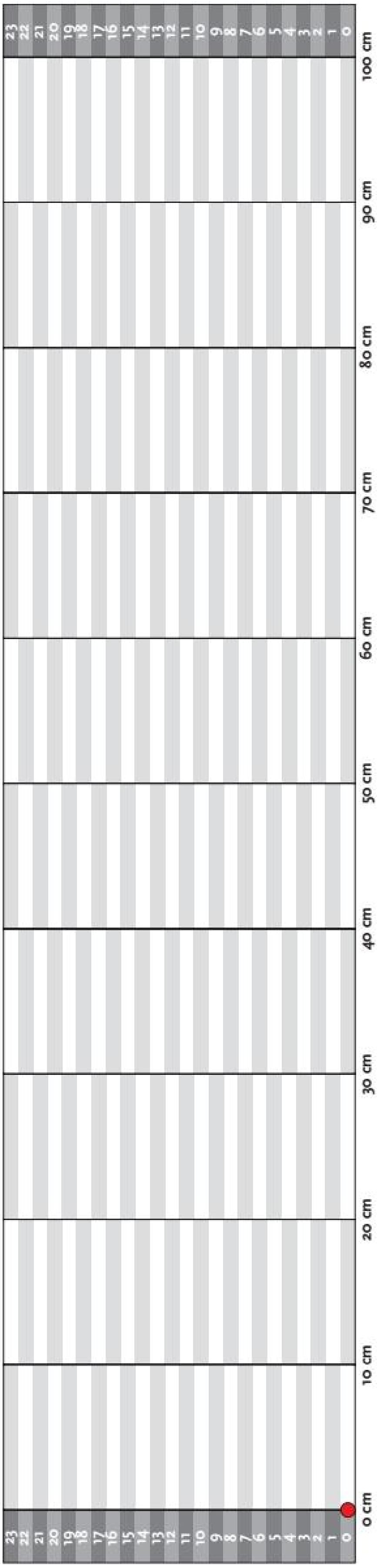

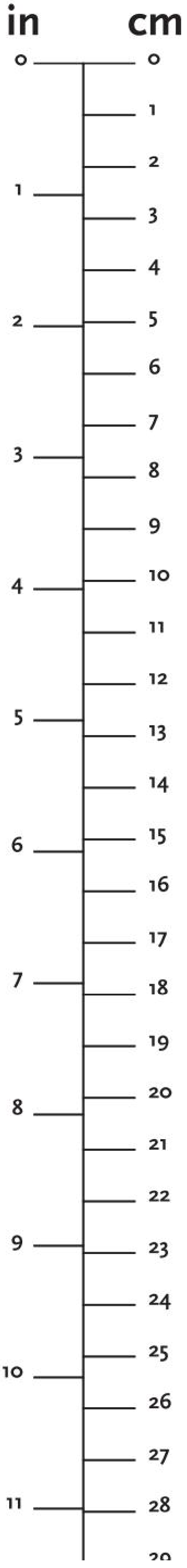

WARNING. Not suitable for children under 3 years. Choking hazard — small parts. Strangulation hazard — long cords. Store the experiment material, particularly the battery-powered motor, and assembled models out of the reach of small children.

WARNING. Only for use by children aged 8 years and older. Instructions for parents or other supervising adults are included and have to be followed. Keep the packaging and instructions as they contain important information.

Warning! Do not aim at eyes or face. Some models are able to launch projectiles. Do not aim the projectiles (balls) toward other people or animals. Make sure people and animals are well out of the potential path of the projectiles.

Caution! The shot put device and pinball models are able to discharge objects other than the balls provided with the toy. Do not use with any other objects. There is a risk of injury.

Safety for Experiments with Batteries

- Wires are not to be inserted into socket-outlets. Never perform experiments using household current! The high voltage can be extremely dangerous or fatal!
- For operation, you will need two AA batteries (1.5-volt) which are not included in the kit due to its limited shelf life.
- The supply terminals are not to be short-circuited. A short circuit can cause the wires to overheat and the batteries to explode.
- Different types of batteries or new and used batteries are not to be mixed.
- Do not mix old and new batteries.
- Do not mix alkaline, standard (carbon-zinc), or rechargeable (nickel-cadmium) batteries.
- Always insert batteries in the right polarity orientation, pressing them gently into the battery compartment.
- Always close battery compartments with the lid.
- Non-rechargeable batteries are not to be recharged. They could explode!
- Rechargeable batteries are only to be charged under adult supervision.
- Rechargeable batteries are to be removed from the toy before being charged.
- Exhausted batteries are to be removed from the toy.
- Dispose of used batteries in accordance with environmental provisions.
- Be sure not to bring batteries into contact with coins, keys, or other metal objects.
- Avoid deforming the batteries.

With all of the experiments that use batteries, have an adult check the experiment or model **before use** to make sure it is assembled properly. Always operate the motorized models under adult supervision.

After you are done experimenting, remove the batteries from the battery compartments. Note the safety information accompanying the individual experiments!

Notes on Disposal of Electrical and Electronic Components

The electronic components of this product are recyclable. For the sake of the environment, do not throw them into the household trash at the end of their lifespan. They must be delivered to a collection location for electronic waste, as indicated by the following symbol:

Please contact your local authorities for the appropriate disposal location.

Dear Parents and Supervising Adults,

Before starting the experiments, read through the instruction manual together with your child and discuss the safety information. Check to make sure the models have been assembled correctly, and assist your child with the experiments.

We hope you and your child have a lot of fun with the experiments!

EXPERIMENTS

STRUCTURAL ENGINEERING BRIDGES & SKYSCRAPERS
#7410
25 Models to build
323 PCS

MECHANICAL ENGINEERING ROBOTIC ARMS
#7411
6 Models to build
204 PCS

CROSSBOWS & CATAPULTS
#7406
10 Models to build
110 PCS

RCM CONSTRUCTION VEHICLES
#7408
8 Models to build
227 PCS

MINI GYRO
#7395
20 Models to build
88 PCS

GECKOBOT
#7409
7 Models to build
176 PCS

SOLAR POWER 2.0
#7303
10 Models to build
120 PCS

WATER POWER
#7323
15 Models to build
165 PCS

WIND TURBINE
#7400
5 Models to build
77 PCS

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