EXPERIMENT MANUAL

PHYSICS DISCOVERY

THAMES & KOSMOS

WARNING — Science Education Set. This set contains chemicals and/or parts that may be harmful if misused. Read cautions on individual containers and in manual carefully. Not to be used by children except under adult supervision.

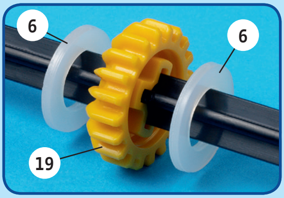
Tip:

You can use this page whenever you need to do a quick check of the parts that you need for the individual experiments.

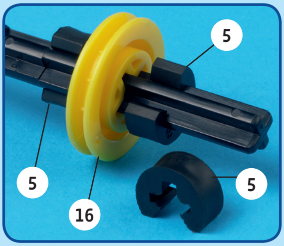
Checklist: Find – Inspect – Check off

✔	No.	Name	Qty.	Item No.
☐	1	Anchor pin	15	702527
☐	2	Joint pin	3	702524
☐	3	Shaft plug	10	702525
☐	4	Shaft pin	1	702526
☐	5	Axle lock	5	702813
☐	6	Washer	6	703242
☐	7	Large frame	2	703239
☐	8	Small frame	2	703232
☐	9	Long rod	4	703235
☐	10	Short rod	2	703233
☐	11	Long axle	2	703234
☐	12	Medium axle	6	703238
☐	13	Short axle	3	703236
☐	14	Large pulley wheel	2	702516
☐	15	Medium pulley wheel	2	702518
☐	16	Small pulley wheel	5	702519
☐	17	Large gear wheel	3	702506
☐	18	Medium gear wheel	2	702505
☐	19	Small gear wheel	4	702504
☐	20	Base plate	1	703237
☐	21	Crankpin	1	702599
☐	22	Connection bridge	2	703231
☐	23	Shovel blade	8	703240
☐	24	Rubber band (long)	1	703241
☐	25	Wooden ball	8	703243
☐	26	Cord (white)	1	703244
☐	27	Elastic cord	1	703245
☐	28	Wheels with tires	2	703230
☐	29	Tire rings for medium pulley wheel	2	703251
☐	30	Tire rings for small pulley wheel	2	703250
☐	31	Anchor pin lever	1	702590
☐	32	Die-cut cardboard sheet	1	703365
☐	33	“Sail” cutout sheet	1	710983

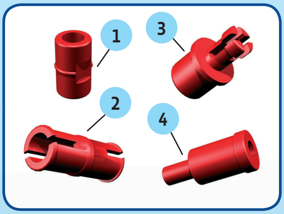
If you are missing any parts, please contact Thames & Kosmos customer service.



Washers (6) and gear wheel (19)



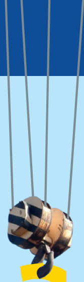
Axle lock (5) and small pulley wheel (16)



Additional things you will need:

Tape, glue, scissors, ruler, paper clips, measuring tape, pen, paper, letter, hole punch, heavy book, empty plastic bottle (16-ounce, or half-liter), pitcher, water, hair dryer

Any materials not contained in the kit are marked in *italic script* in the “You will need” boxes.



Dear parents

Physics is an extremely exciting and pivotal science, and it isn't really all that hard to understand. It's actually a lot of fun to investigate the physical phenomena we encounter on a daily basis, to figure them out, and to put them to use.

This experiment kit is designed to help bring the fascinating world of physics a little bit closer to your child. With its multipurpose materials and easy-to-grasp examples, it will provide a first look into the world of physical measurements and laws — and thus also contribute to a better understanding of what your child will be learning in school.

The individual experimental setups are assembled step by step out of pieces with variably interconnecting parts. The assembly will take a little patience and practice at first. It will be ideal if you can help your child until he or she is familiar with all the connection systems.

We wish your child a lot of fun discovering and learning!

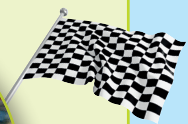
WARNING! Not appropriate for use by children under 3 years of age. There is a danger of suffocation due to the possibility of swallowing or inhaling small parts. The kit contains some small parts, such as anchor pins, washers, and small balls, so it is absolutely essential that you keep it out of the reach of young children. There is a risk of strangulation if cords are wrapped around the neck.

Save the packaging and instructions, as they contain important information.

NEED HELP?

If you find that any of the assembly images are too small to follow, go to www.thamesandkosmos.com/support/pd for larger images.

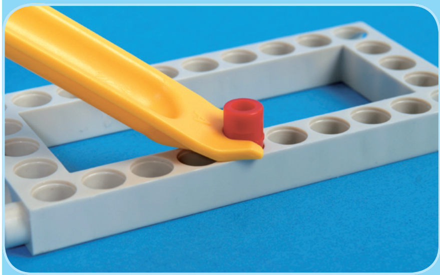
CONTENTS



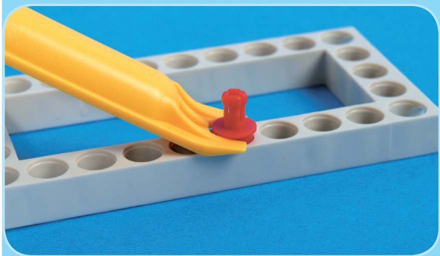
CHECK IT OUT

You will find supplemental information on pages 11, 27 to 29, 38 to 40, and 48.

How to use the anchor pin lever

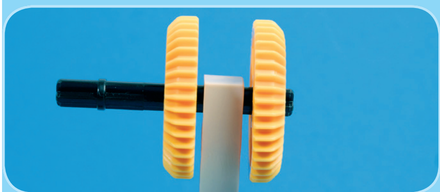


You can easily remove the little red anchor pins (1) with the narrow end of the anchor pin lever (31).



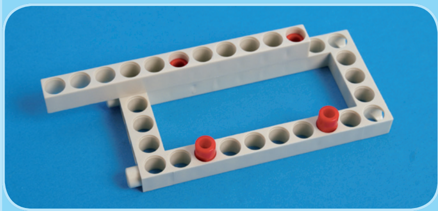
The shaft plugs (3) can be lifted out of the assembly parts with the wide end of the anchor pin lever (31).

Mounting gears and pulleys



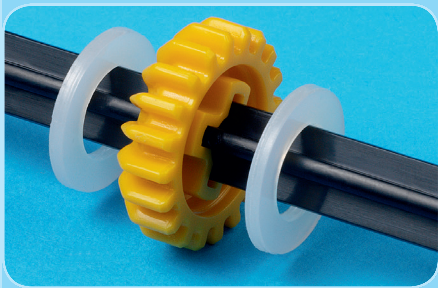
If gears or pulley wheels are pushed too tightly against other components, they will not turn easily. Leaving a gap of about 1 mm between the gear or pulley and the component will solve this problem.

Connecting frames and rods

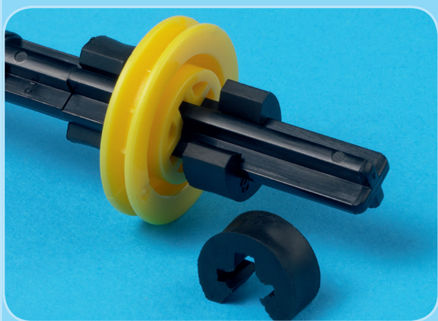


Frames (7, 8) and rods (9, 10) are connected together with the help of anchor pins (1).

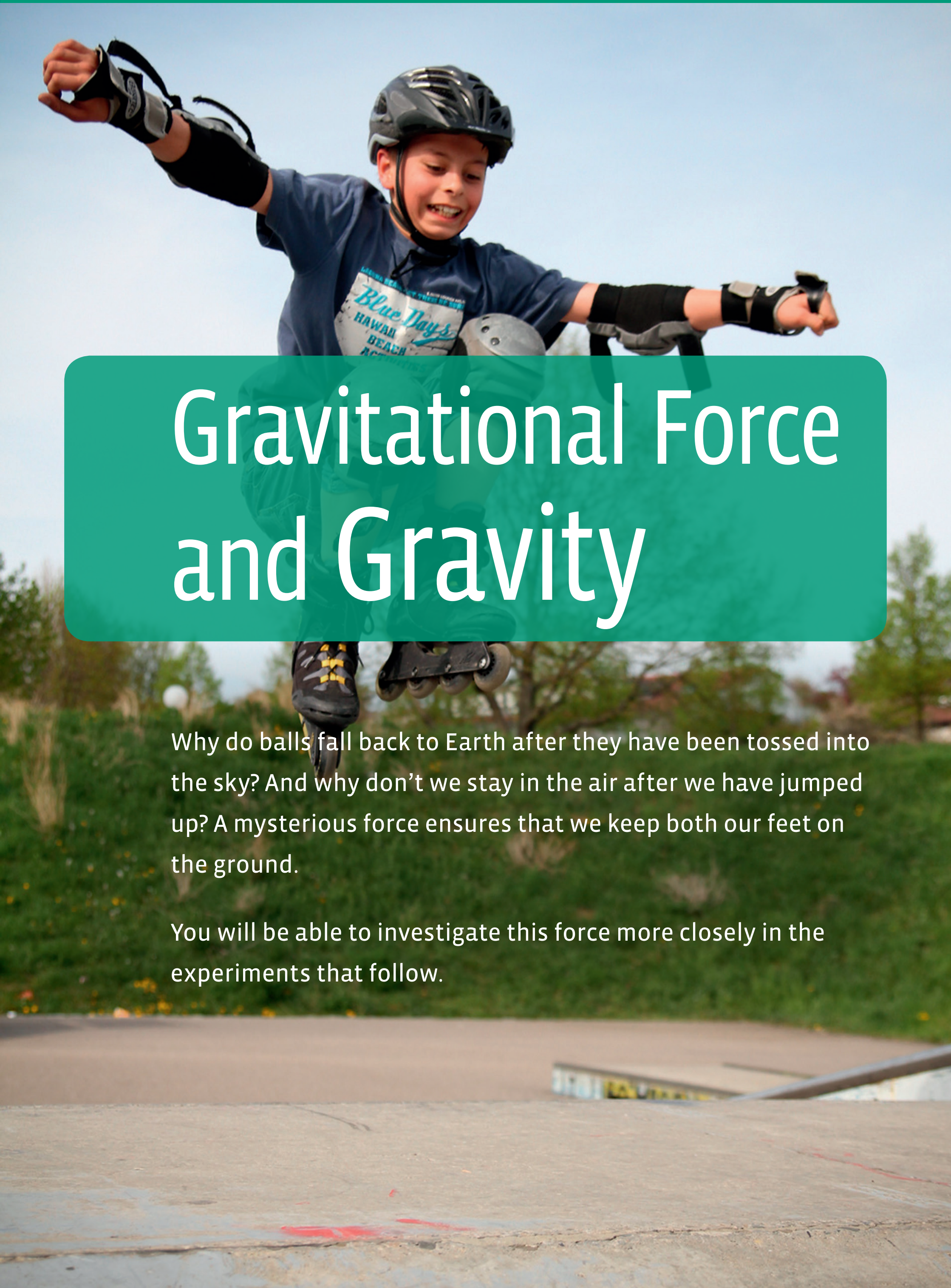
Washers and axle locks



Use the washers to keep gears or pulleys from sliding on the rods or frames.



Attach the axle locks to keep the axles from slipping. You can also install them after assembling the other parts.



Gravitational Force and Gravity

Why do balls fall back to Earth after they have been tossed into the sky? And why don't we stay in the air after we have jumped up? A mysterious force ensures that we keep both our feet on the ground.

You will be able to investigate this force more closely in the experiments that follow.

EXPERIMENT 1

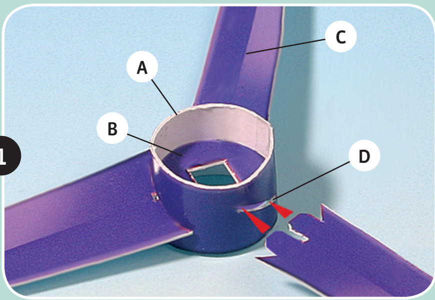
Gravity motor

YOU WILL NEED

- 2 large frames (7)
- 2 small frames (8)
- 2 long rods (9)
- 2 long axles (11)
- 3 medium axles (12)
- 1 axle lock (5)
- 2 large gears (17)
- 1 medium gear (18)
- 3 small gears (19)
- 5 washers (6)
- 4 anchor pins (1)
- 4 small pulley wheels (16)
- 1 connection bridge (22)
- 1 m of cord (26)
- 2 wheels (28)
- 1 joint pin (2)
- 6 "propeller" parts from die-cut sheet (32)
- *tape, glue*
- *scissors, ruler*

These item numbers and the pictures on the first two pages will help you find the right parts.

NEED HELP?
For larger images, go to www.thamesandkosmos.com/support/pd



HERE'S HOW

1. First assemble the propeller. Wrap the strip for the center hub (A) around your finger and attach the abutting ends with tape. (Be careful not to tape over the slits.)

   Gently press the propeller blades along the center line (C). Insert the blades into the hub tube slits from outside (D).

   Place a small drop of glue on each of the blade flaps projecting into the center hole of the hub.

   Then push one disk into the hub tube from above and another from below (B).

2.–7. Now it's the gravitational motor's turn. Assemble it as shown in the illustrations. Cut a 1-m-long piece of cord. Tie the joint pin to one end of it. Tie the other end to the axle between the pulley wheels. Now you can roll up the cord by turning the axle.

8.–9. To keep the apparatus from tipping over, insert the two wheels with an axle onto the connection bridge. Then mount the propeller and secure it in place with an axle lock.

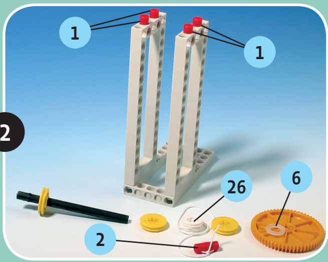
10. Place the motor at the edge of the table and give a strong downward pull on the cord.

→ WHAT'S HAPPENING?

The propeller turns when you give a strong tug on the cord.

EXPERIMENT 1

2



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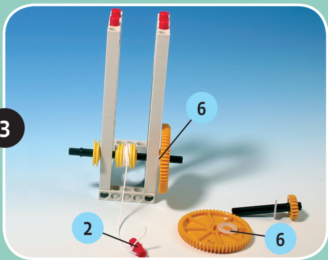

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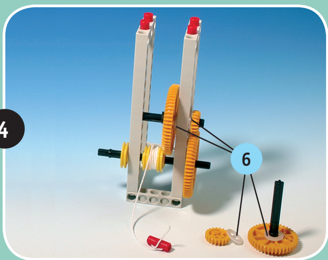

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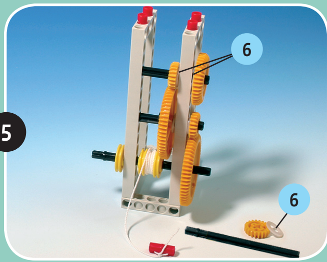

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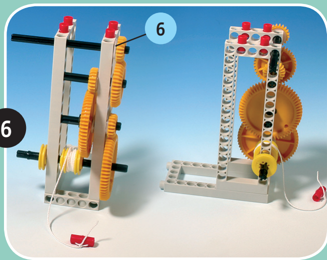

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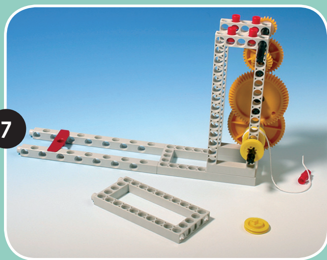

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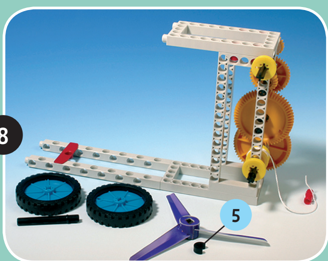

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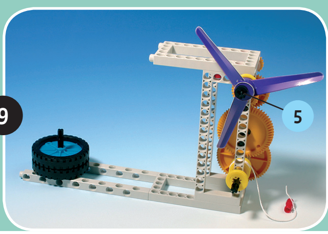

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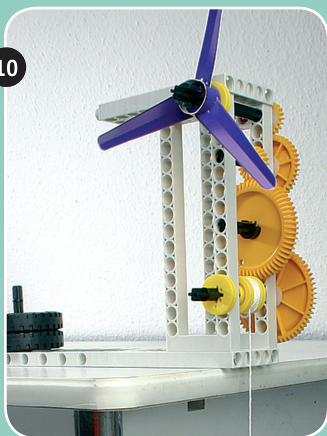


EXPERIMENT 2

Gravity motor in action

YOU WILL NEED

→ "Gravity motor" from the last experiment
→ 25 cm of cord (26)
→ *empty plastic bottle (16-ounce or half-liter)*
→ *paper clip, water*

HERE'S HOW

1. Take the cord and tie it tightly to the neck of the bottle just beneath the cap, with about 10 cm of cord remaining for one of its ends. Ideally, tie a double or triple knot. The loop should be tight enough that it won't slip off over the rim of the bottle neck.

2. Tie a paper clip to the long end of the cord.

3. Fill the bottle with water and screw on the cap. Now suspend the bottle from the gravity motor.

1

2

3

→ WHAT'S HAPPENING?

The water-filled bottle pulls down on the cord and starts the propeller. So what you've done is replace the force of your arm in Experiment 1 with that of the water-filled bottle. This force, which has taken over the work from you, is called gravity.

EXPERIMENT 3

Catapult shot put

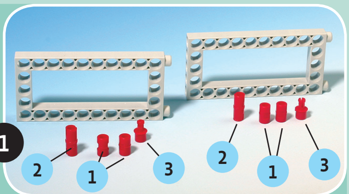
YOU WILL NEED

→ 1 base plate (20)
→ 2 small frames (8)
→ 2 large frames (7)
→ 2 joint pins (2)
→ 2 short rods (10)
→ 4 anchor pins (1)
→ 2 medium axles (12)
→ 1 long axle (11)
→ 1 small gear (19)
→ 4 shaft plugs (3)
→ 1 rubber band (24)
→ 2 “catapult” die-cut parts (32)
→ wooden balls (25)
→ *measuring tape*
→ *paper, pen*

NEED HELP? For larger images, go to www.thamesandkosmos.com/support/pd

HERE’S HOW

1.–9. Assemble the catapult as shown.

1


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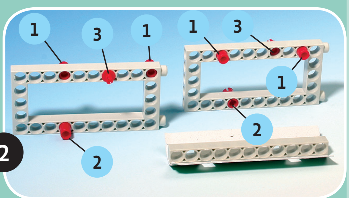

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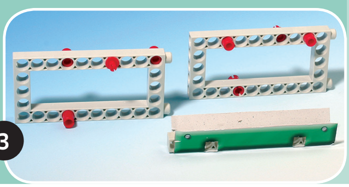

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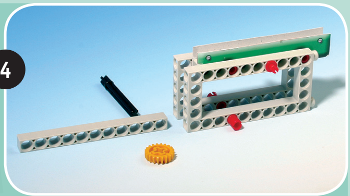

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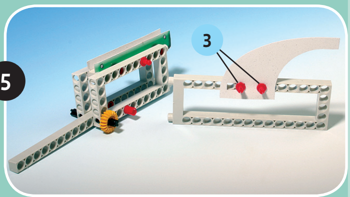

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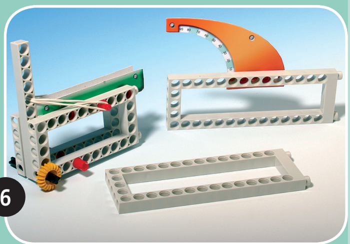

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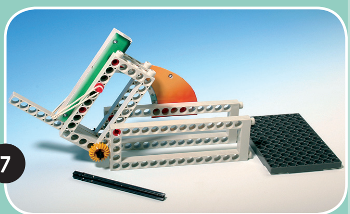

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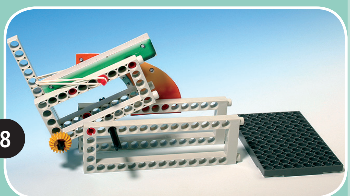

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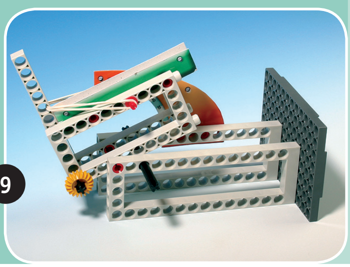


Catapult shot put

Caution!
Do not aim for the eyes or face.

HERE'S HOW IT CONTINUES

10. Find an open area on the floor, and get your measuring tape, paper, and pen ready.

Set the shooting angle with the long axle (B). The angle will change depending on which holes of the large frame you insert the axle through. Read off the angle you have set it to by looking through the frame hole designated with an (A).

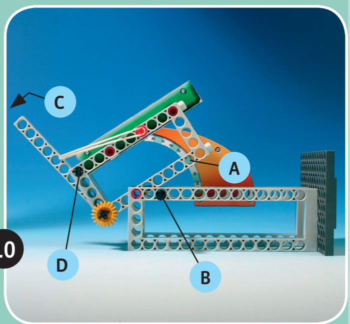
Pull back the catapult (C) and secure it with the medium axle (D).

11. To make sure the ball has an unobstructed path, you may have to bend the edges of the cardboard guide track a little to the outside.

Place the ball in the track. Use one hand to hold the catapult tight at the rear end. With your other hand, carefully remove the safety axle (D). Be careful not to jiggle when you shoot!

Try different shooting angles and compare the shooting distances.
At which angle does the ball fly the farthest?

10



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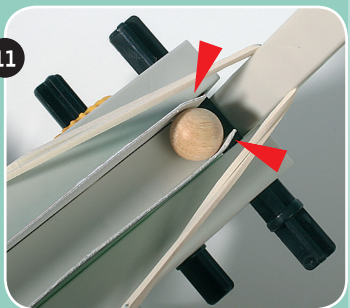


→ WHAT'S HAPPENING?

You can see that the shooting angle makes a difference in how far the ball flies. But however far it flies, it always returns to the ground.

CHECK IT OUT

→ GRAVITY

Gravity is often used for things like powering pendulum clocks or for elevator counterweights, and for generating electricity in hydropower plants.

KEYWORD: GRAVITATIONAL FORCE

There is a mutual force of attraction that exists between any two objects. This is known as gravitational attraction.

When the mass of one object is attracted by the mass of another, the object acquires weight. That's why the word gravity literally means "weight."

On Earth, gravity exerts a force on all objects that pulls them toward its center — that is, downward. That is why you always land on the ground again after hopping or jumping into the air.

↑ Throwing balls:

When you throw a ball, sooner or later gravity will force it to come down to Earth again. The length of its flight path depends mostly on its weight, the starting angle, and your strength.

Gravity comes into play as soon as the ball leaves your hand. As long as the applied forward- and upward-directed force overcomes gravity, the ball will rise. Once it reaches it highest point, gravity forces it on a downward path.

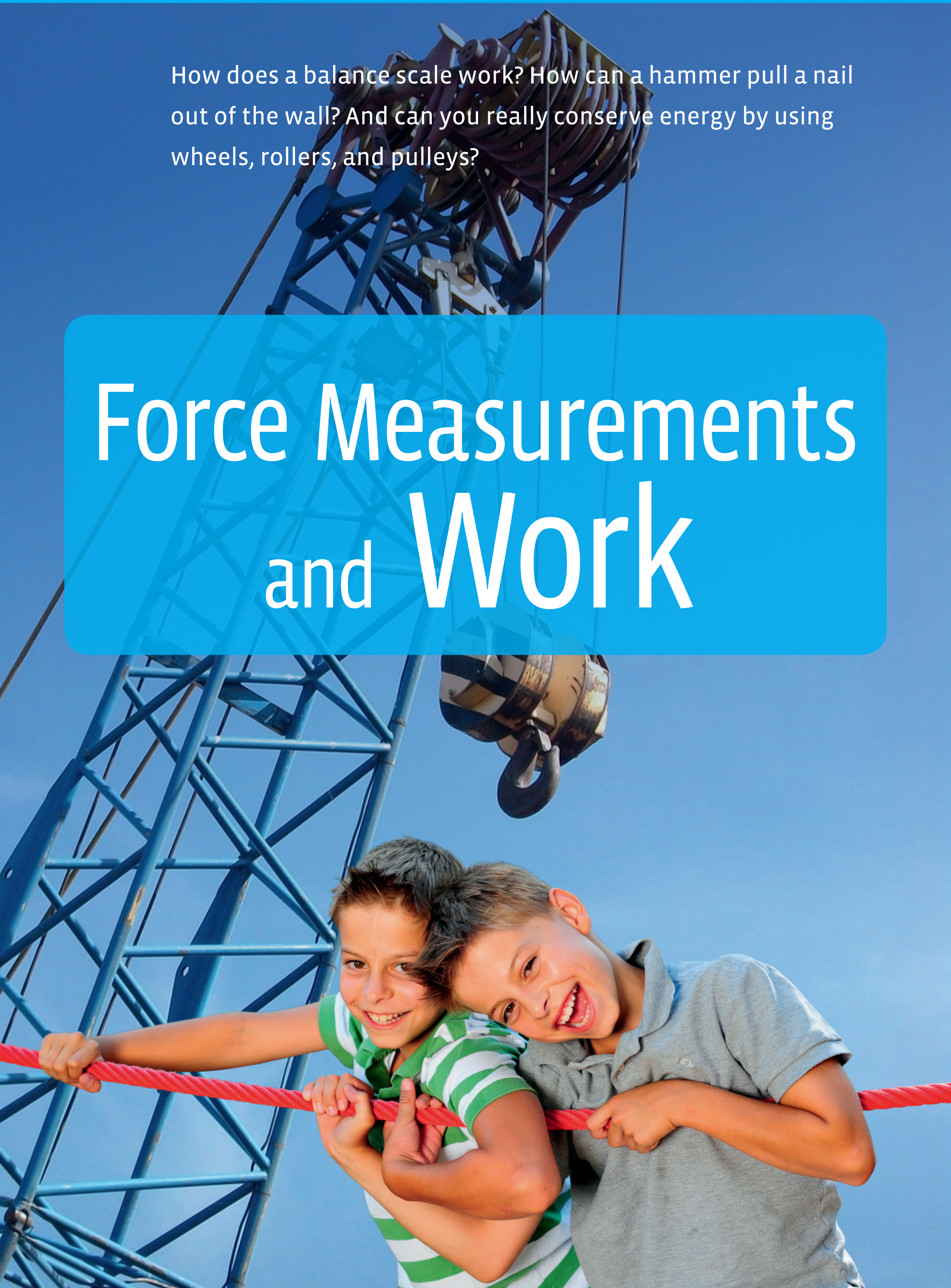
From the throwing point upward to the peak of the flight path, the ball requires the same amount of time as it needs to get from the peak to the landing point (assuming both end points are at the same height). In terms of physics, the ascent is just a descent in reverse.

Note

Mass is indicated in kilograms (kg). The mass of an object always remains the same, even if the force of gravity acting on it changes. That may not happen on the earth, but it certainly will happen to an astronaut in space. Since there's no gravity there, the astronaut has no weight — but he still has mass!

How does a balance scale work? How can a hammer pull a nail out of the wall? And can you really conserve energy by using wheels, rollers, and pulleys?

Force Measurements and Work



EXPERIMENT 4

Balance scale

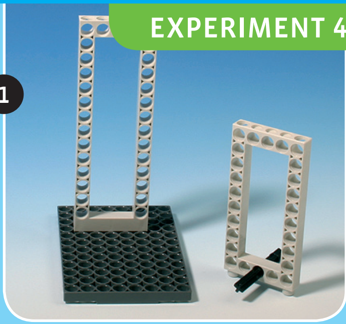
YOU WILL NEED

→ 2 large frames (7)
→ 1 base plate (20)
→ 2 small frames (8)
→ 2 connection bridges (22)
→ 2 long rods (9)
→ 2 short rods (10)
→ 1 medium axle (12)
→ 2 joint pins (2)
→ 2 shaft plugs (3)
→ 2 washers (6)
→ 2 anchor pins (1)
→ 2 large gears (17)
→ 1 axle lock (5)
→ 1 "balance scale pointer" part from die-cut sheet (32)
→ *letter*

HERE'S HOW

1.–7. Collect all your parts and assemble the balance scale step by step.

1



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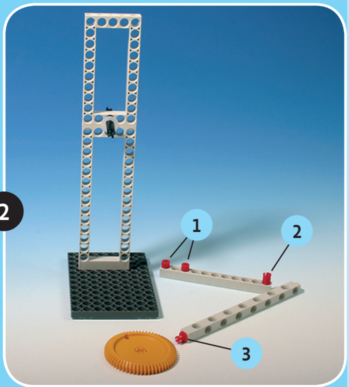

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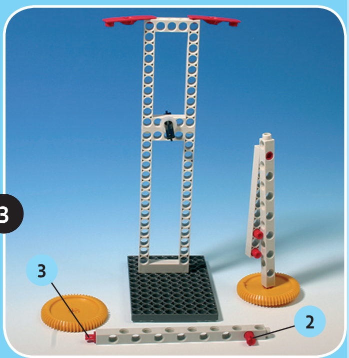


4

EXPERIMENT 4

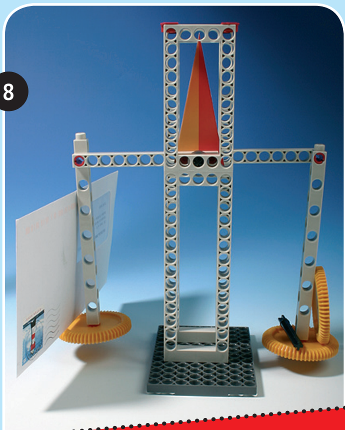
Balance scale

HERE'S HOW IT CONTINUES

Push the axle lock that is mounted on the axle firmly against the bar (Figure 6). Be sure that the tip of the pointer points upward.

8. Now you can use the balance scale as a letter scale as well.

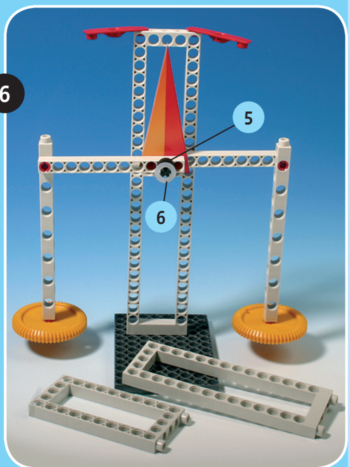
   Use the large gear (11 g), the long axle (3 g), and the short axle (1 g) as counterweights.
   How much does your letter weigh?

8


→ WHAT'S HAPPENING?

Once you have brought your scale into balance, meaning that the tip of the pointer is positioned straight up in the center hole of the frame, you can add up all the counterweights that you suspended from the opposite arm to calculate how much your letter weighs.

5


6


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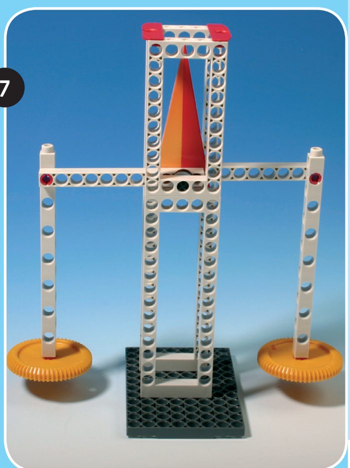


EXPERIMENT 5

Practical force meter

YOU WILL NEED

→ *1 long rod (9)*
→ *1 joint pin (2)*
→ *2 shaft plugs (3)*
→ *1 rubber band (24)*
→ *1 washer (6)*
→ *1 "force meter" part from die-cut sheet (32)*
→ *bottle prepared as in Experiment 2, water*

HERE'S HOW

1.–2. Assemble the force meter as shown in the illustrations. Place the rubber band over the joint pin.

What happens when you pull on the washer?

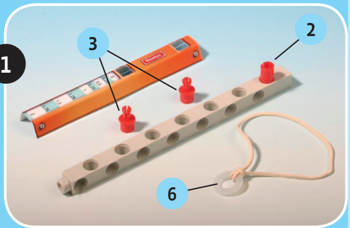
3. Fill the bottle about a quarter of the way with water.

Suspend the bottle from the force meter with a paper clip.

Now you can read the weight of the bottle on the force meter's scale. It will be indicated in newtons (N).

You will also need your force meter for the experiments with fixed and movable pulleys (Experiments 8 to 10).

1



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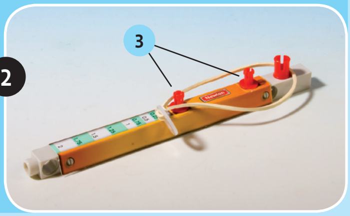

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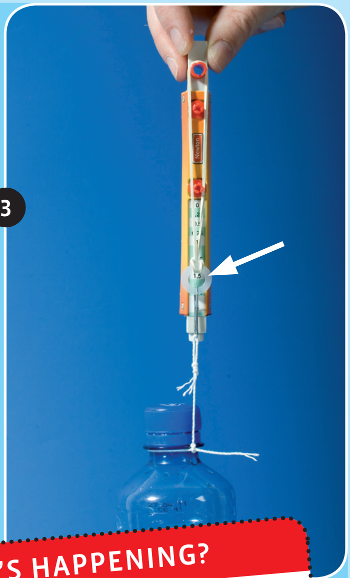


→ WHAT'S HAPPENING?

The farther you try to pull the washer away from the joint pin, you more force you have to apply — as you can see by reading the scale. But your force meter can also measure the weight of the bottle.

Powerful anchor pin lever

YOU WILL NEED

→ 1 base plate (20)
→ 1 anchor pin (1)
→ 1 anchor pin lever (31)

HERE'S HOW

1. Push an anchor pin into one of the holes of your base plate.

2. First try to pull the anchor pin out with your fingers.

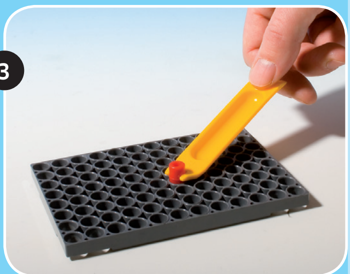
3. Now try it with the anchor pin lever.

What do you notice?

1

2

3



→ WHAT'S HAPPENING?

A lever, such as your anchor pin lever, is a tool for transferring force. If you push down on one end of it, you lift a load upward (or, in this case: pull the anchor pin out of the base plate). When you do that, you need to expend less force than you would without the lever. In the process, the path that the lever follows when you push down on it is a lot longer than the path the anchor pin takes as it is lifted up.

EXPERIMENT 7

Measuring force on an inclined plane

NEED HELP?
For larger images, go to www.thamesandkos-mos.com/support/pd

YOU WILL NEED

→ 1 base plate (20)
→ 2 small frames (8)
→ 2 large frames (7)
→ 1 long rod (9)
→ 1 short rod (10)
→ 2 long axles (11)
→ 2 medium axles (12)
→ 2 axle locks (5)
→ 1 large gear (17)
→ 1 small pulley (16)
→ 2 wheels with tires (28)
→ 6 anchor pins (1)
→ 8 shaft plugs (3)
→ 2 washers (6)
→ 1 rubber band (24)
→ 30 cm of cord (26)
→ 2 "inclined plane" die-cut part (32)
→ 1 "catapult" die-cut part (32)
→ *ruler, scissors*

HERE'S HOW

1.–6. Assemble the inclined plane with force meter as shown in the illustrations.

Tie the rubber band to one end of the cord, and make a loop at the other end.

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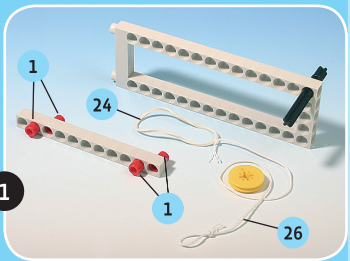

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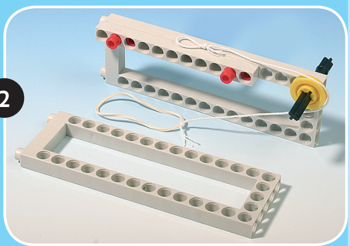

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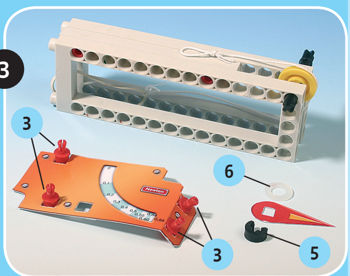

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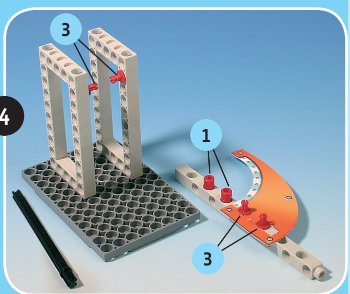
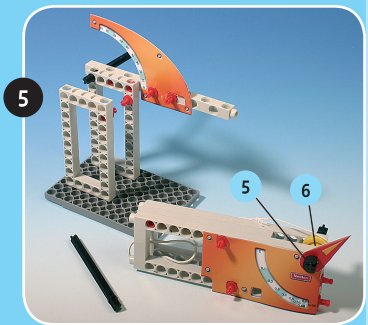
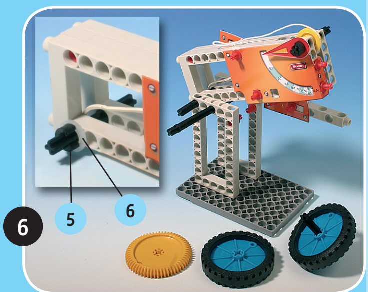
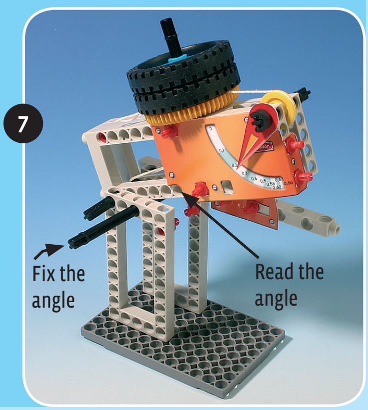


EXPERIMENT 7

Measuring force on an inclined plane







HERE'S HOW IT CONTINUES

7. First, set the plane in a horizontal position. Now you'll be adding the load: the large gear plus two wheels with tires. Clamp the cord between the wheels and the gear. Pull it far enough through that the load is positioned directly in front of the pulley.

   Set the pointer to "0."

   Raise up the plane and fix it in this position with the axle.

   What does the pointer indicate now?

   You can read the angle setting by looking through the hole in the frame.

   What do you notice when you adjust the angle to a steeper or flatter position?

   What happens when you push the weights suspended from the cord further toward the back?

→ WHAT'S HAPPENING?

The downhill force increases as the angle increases.

EXPERIMENT 8

Load hoist with fixed pulley

YOU WILL NEED

→ 2 small frames (8)
→ 1 large frame (7)
→ 1 medium axle (12)
→ 1 small pulley (16)
→ 1 joint pin (2)
→ 2 washers (6)
→ 50 cm of cord (26)
→ “force meter” from Experiment 5
→ *heavy book*
→ *bottle from Experiment 2*
→ *water, pitcher*
→ *ruler, scissors*
→ *paper clip*

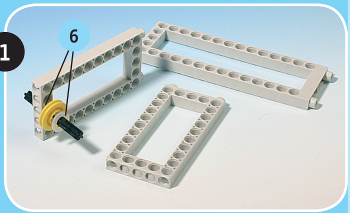
HERE’S HOW

1.–2. Assemble the load hoist.

3. Hang it over the edge of a table and anchor it with the heavy book.

4. Take the bottle from Experiment 2, open it, and get a pitcher of water ready.

1



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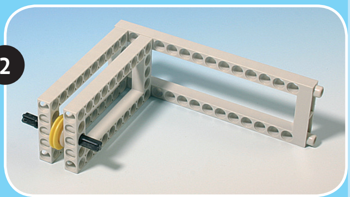


3

4

EXPERIMENT 8

Load hoist with fixed pulley

HERE'S HOW IT CONTINUES

5. Suspend the bottle from the force meter from Experiment 5. Pour water from the pitcher into the bottle until the force meter reads 1.5 N.

6. Cut a piece of cord 50 cm in length. Tie the joint pin to one end and hang the bottle from that end. Guide the other end of the cord through the pulley and hang it on the ring of the force meter with the help of a paper clip.

7. Lift the bottle with the force meter as shown in the illustration.

What is the force reading?

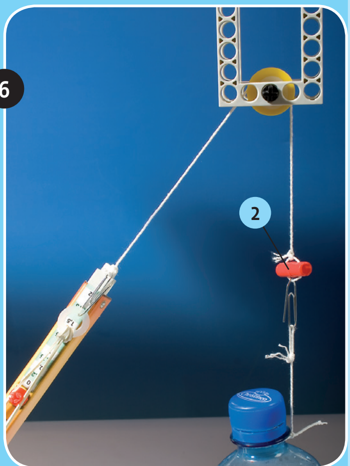
You will need the load hoist again in Experiment 10, and the bottle with water in it in Experiments 9 and 10.

→ WHAT'S HAPPENING?

The force needed to lift the bottle with the load hoist starts by increasing by about 0.25 N. When you stop pulling with your hand and the bottle hangs relatively loosely again, the newton gauge drops to 1.5 N, just as in the force meter measurement in Experiment 5. So this "fixed pulley" won't really save you any application of force. Still, it makes your work easier, since it lets you pull on the cord in the most comfortable direction.

5

6



7

EXPERIMENT 9

The movable pulley

YOU WILL NEED

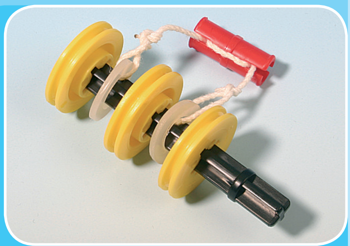
→ 1 large frame (7)
→ 3 small pulleys (16)
→ 1 medium axle (12)
→ 2 washers (6)
→ 1 shaft plug (3)
→ 1 joint pin (2)
→ 2 x 20 cm of cord (26)
→ "force meter" from Experiment 5
→ *water-filled bottle from Experiment 8*
→ *heavy book*
→ *paper clip*

HERE'S HOW

1. Cut two 20-cm-long sections of cord. Tie pulleys to both ends of one of the cords. Then slide the three small pulley wheels onto the medium axle, separated by the two washers attached to the cord.

   Then attach the joint pin by wrapping the cord around it as shown in the illustration.

2. Take the water-filled bottle from Experiment 8 and hang it to the movable pulley with the paper clip.



1

2

The movable pulley

HERE'S HOW IT CONTINUES

3. Insert a shaft plug into the large frame. Place the frame at the edge of a table and anchor it with a book.

   Attach a paper clip to the second piece of cord and make a loop to hang it between the force meter and the shaft plug. Let the cord run through the middle pulley.

   What reading does the force meter show?

   You will need the movable pulley and the filled bottle again in Experiment 10.

3

→ WHAT'S HAPPENING?

The force meter reads 0.75 N. To lift the bottle vertically, you need just half as much force as with the fixed pulley on the last experiment's load hoist.

EXPERIMENT 10

Block and tackle

YOU WILL NEED

→ 1 shaft plug (3)
→ “force meter” from Experiment 5
→ 50 cm of cord (26)
→ “load hoist” from Experiment 8
→ “movable pulley” from Experiment 9
→ *water-filled bottle from Experiment 9*
→ *heavy book*

Tip

In this experiment, you will have to be sure that the cords are always running correctly through the pulley wheels. Ask a friend for help — for example, to hold the force meter steady while you thread the cord through the other components.

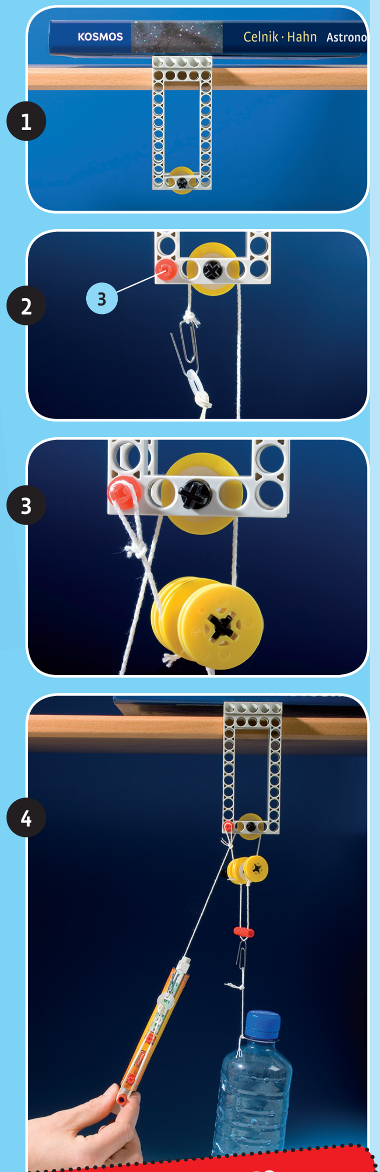
HERE’S HOW

1. Use a thick book to anchor the load hoist from Experiment 8 at the edge of a table.

2. Insert the shaft plug into the frame. Attach the 50-cm-long cord to the force meter ring with the help of a paper clip. Guide the cord from the left side through the load hoist pulley.

3. Next, guide the cord over the middle pulley of the movable pulley and make a loop at its end to attach the shaft plug.

4. Now use the paper clip to attach the water-filled bottle to the movable pulley.
   What force meter reading do you get when you pull the bottle up?



→ WHAT’S HAPPENING?

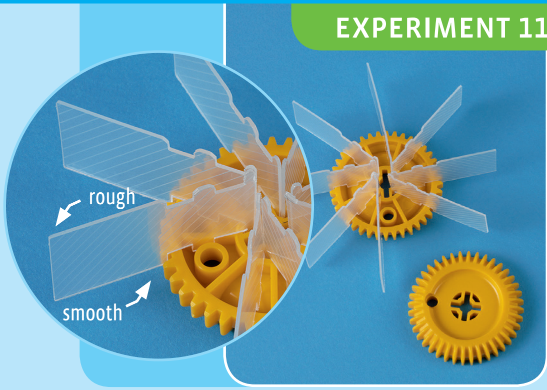
If you combine the movable pulley (Exp. 9) and the fixed pulley (Exp. 8) into a block and tackle, you also combine their advantages: The pulling direction is comfortable, and you get a gain in force.

EXPERIMENT 11

Water wheel crane

YOU WILL NEED

→ 1 base plate (20)
→ 2 small frames (8)
→ 2 large frames (7)
→ 2 long axles (11)
→ 1 medium axle (12)
→ 1 short axle (13)
→ 4 small gears (19)
→ 2 medium gears (18)
→ 2 large gears (17)
→ 8 shovel blades (23)
→ 2 short rods (10)
→ 3 long rods (9)
→ 3 small pulleys (16)
→ 1 medium pulley (15)
→ 1 joint pin (2)
→ 12 anchor pins (1)
→ 2 wheels (28)
→ 6 washers (6)
→ 70 cm of cord (26)
→ *ruler, scissors*
→ *stream of water straight from the tap*



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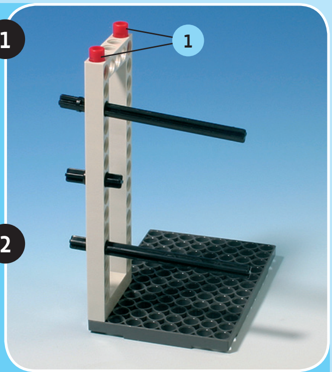
HERE'S HOW

1. First assemble the paddle wheel. Be sure that the rough surfaces of the blades always point in the same direction. Mount the second wheel.

2.–6. Now assemble the water wheel crane. Place the shovel blade on the lower axle. Tie the cord tightly to the upper axle between the two pulleys and roll it up.

1



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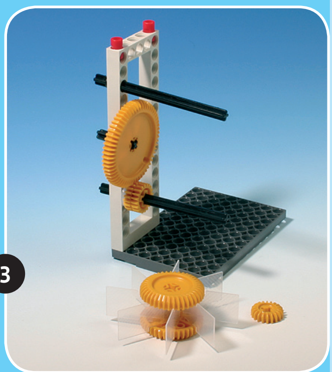

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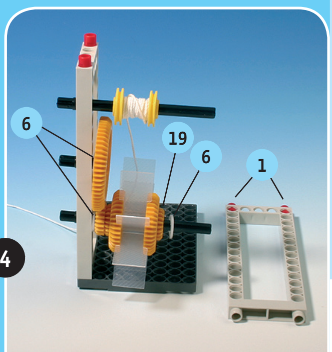


4

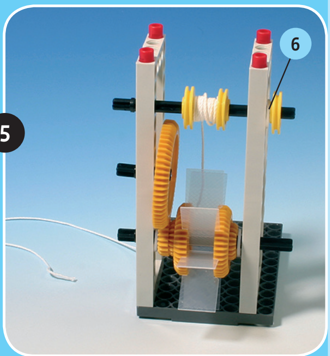
EXPERIMENT 11

HERE'S HOW IT CONTINUES

7. Guide the cord through the upper frame.

8.–11. Now construct the crane arm with the small pulley and guide the cord over the pulley toward the front.

5



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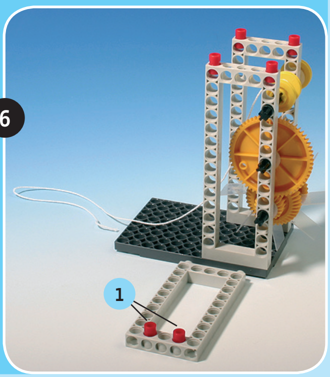

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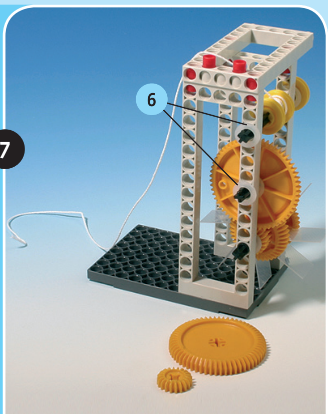

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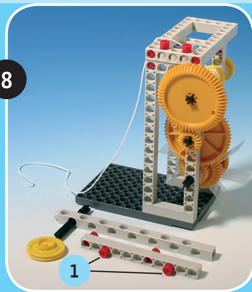

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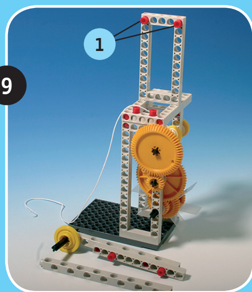

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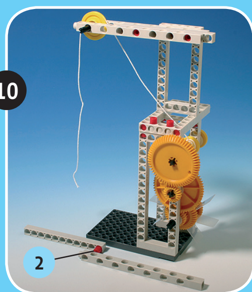

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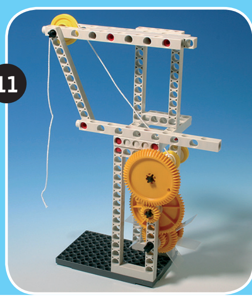


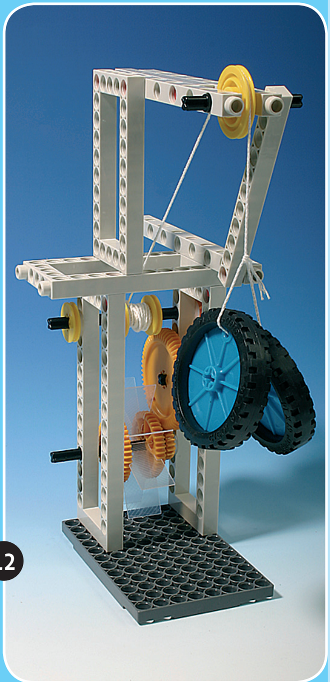
Water wheel crane

HERE'S HOW IT CONTINUES

12. Now you can hang a load — in this case, the two wheels — from the cord.

13. Set the water wheel crane in the sink and let a strong stream of water fall onto the water wheel. Careful of the spray!

    If you have a yard, you can try using your water wheel crane outside. Take the garden hose and aim it onto the water wheel from above.



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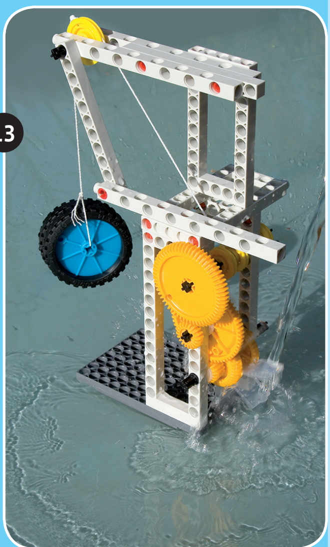


13

→ WHAT'S HAPPENING?

As the force of the water turns the water wheel, the two wheels are gradually lifted up.

CHECK IT OUT

NO ACCELERATION WITHOUT FORCE:

OTHER FORCES BESIDES GRAVITY CAN CAUSE AN OBJECT TO ACCELERATE — THE FORCE OF YOUR LEG, FOR EXAMPLE, WHEN YOU KICK A BALL. → → →

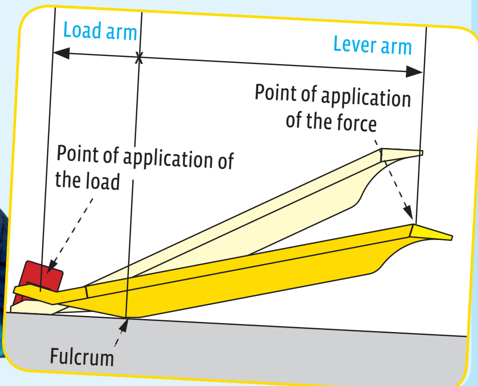
Note

The newton (N) is used as the unit of force.

LEVERAGE FORCES:

You can find a lot of levers in everyday life, both out in the open and behind the scenes — in a doorbell, in the accelerator pedal of a car, in a pair of pliers. Your arms and legs are levers too, of course.

A lever is a rigid body that can be rotated around an axis, or fulcrum. It doesn't have to be any particular shape, but usually it will be rod-shaped. A lever is something that lets you apply less force than you would otherwise need. The end of the lever on which the force (or effort) is exerted is called the lever arm, and the end that lifts the load is called the load arm. A one-armed lever has both the lever arm and the load arm at the same end, and the fulcrum at the other end.



Your arms and legs are levers too.

Mechanics

These experiments are designed to teach you the mechanical laws that form the basis of physics. The word "mechanics" comes from the ancient Greek word *mechane*, meaning tool or machine.

Machines have existed for thousands of years. The first ones were quite simple. Stone Age people living over 10,000 years ago had no doors. So how could they close off their cave entrances to protect themselves against predators?

They would cut sturdy branches with their stone axes, which they used as levers to move heavy "door stones" into the mouth of their caves. To do this, they made use of two tools: the wedge (axe) and the lever (branch). Things like this are known as simple machines.

The ancient Egyptians also used simple machines 4,500 years ago to carry three-ton stone blocks 150 meters up to the top of the Great Pyramid of Giza. They did this by using inclined planes — sloping ramps made of stone blocks or earth — up which they dragged the heavy blocks over wooden rollers.

Note

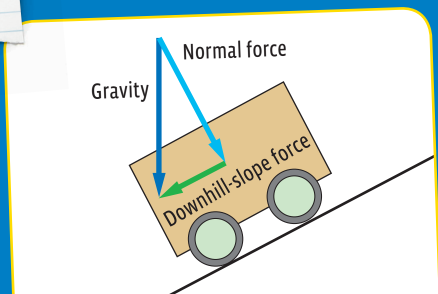
The "Golden Rule of Mechanics": The less force you need, the more distance you need.

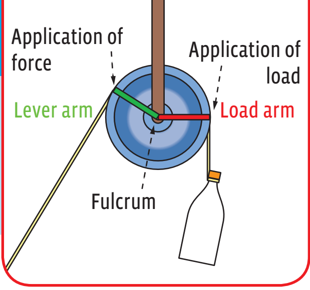
THE INCLINED PLANE

You are probably already familiar with inclined planes, from times when your bicycle path slopes uphill and you suddenly have to expend more effort pushing on the pedals. When that happens, what you're doing is fighting against the downhill force of the inclined plane.

There are two other forces at work on a sloping path as well, though: gravity (your weight and the weight of your bike), and the normal force acting at a right angle to the path of movement.

On the other hand, you can use an inclined plane to save a lot of force – relative to pulling a load straight up. When you do that, of course, there is an increase in the distance you have to move the object.





THE FIXED PULLEY

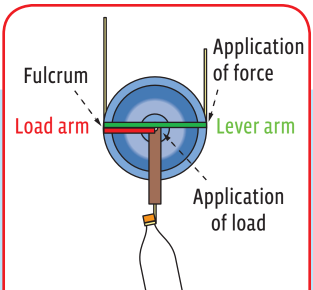
The fixed pulley is a two-armed lever that rotates around a fulcrum as it does its work. Its load arm and lever arm are equally long, so you can't save any effort with the fixed pulley.

Nevertheless, a fixed pulley can make your work easier because it lets you pull on the rope in the direction that is most comfortable for you.

MOVEABLE PULLEY AND BLOCK AND TACKLE

A movable pulley works like a one-armed lever for pulling a load up into the air. The load hangs from two sections of line, so twice as much line passes over the pulley and you only need to expend half the effort to move the object twice the distance.

If you combine a fixed and a movable pulley into a block and tackle, you also combine their advantages: optimal pulling direction and effort savings. The more pulleys you have in the block and tackle, the less effort you need to expend.



CHECK IT OUT

WORK

Machines make work easier. But what exactly is meant by work? Here's an example: You have two boxes in front of you, one weighing 50 kg and the other weighing 20 kg. You want to push them 3 meters across the floor to the elevator.

Even though you put all your effort into it, you can't budge the heavy one from the spot. So you try the lighter one and you do manage to move it. You would probably say that the heavier one was "more work" than the smaller one.

In terms of physics, though, that isn't quite right. Work is only performed when a force moves an object over a certain distance. The unit of measure for work is the newton meter (Nm).

So you actually performed zero work with the heavy box. On the other hand, you used your force to move the lighter one 3 meters. Let's assume you applied a force of 60 N. In that case, you accomplished 3 m x 60 N = 180 Nm of work.

Note

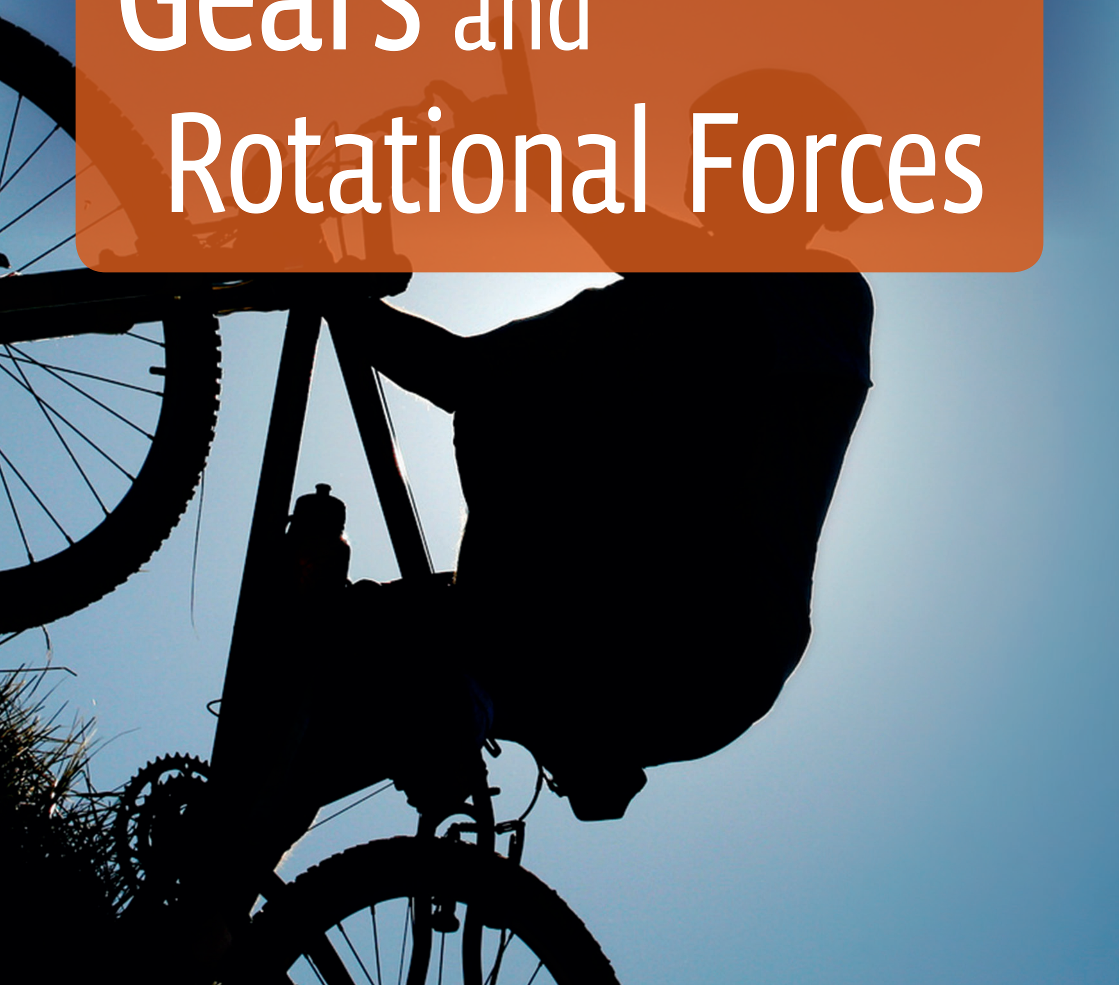
Work is the product of force and distance. The formula is:

Work = Force x Distance

Why do your bicycle wheels turn when you push on the pedals, and why are you pushed outward from the center when you ride a carousel?

All this and more will become clear to you once you perform the four experiments in this section.

Gears and Rotational Forces



EXPERIMENT 12

Bicycle

YOU WILL NEED

→ 2 large frames (7)
→ 1 short rod (10)
→ 3 medium axles (12)
→ 3 axle locks (5)
→ 5 washers (6)
→ 2 joint pins (2)
→ 2 wheels (28)
→ 1 small pulley (16)
→ 1 medium pulley (15)
→ 1 large pulley (14)
→ 1 rubber band (24)
→ 1 crankpin (21)
→ 1 connection bridge (22)

HERE'S HOW

1.–5. Assemble the bicycle.

Turn the red crankpin.
What happens?

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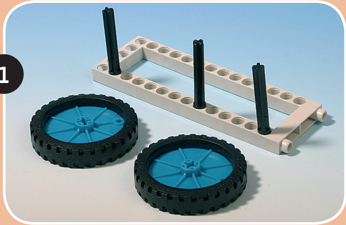

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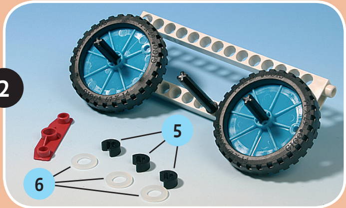

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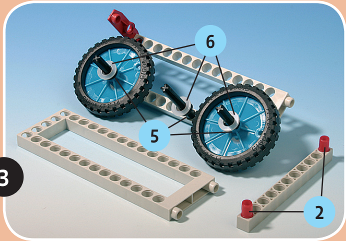

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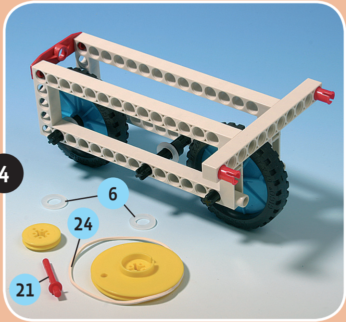

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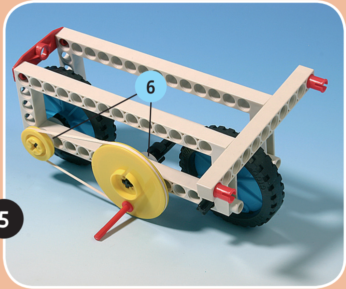

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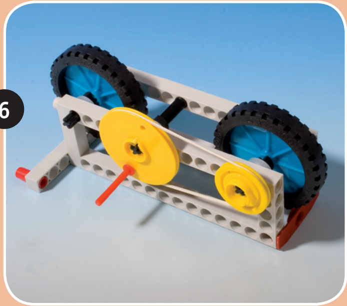
Bicycle

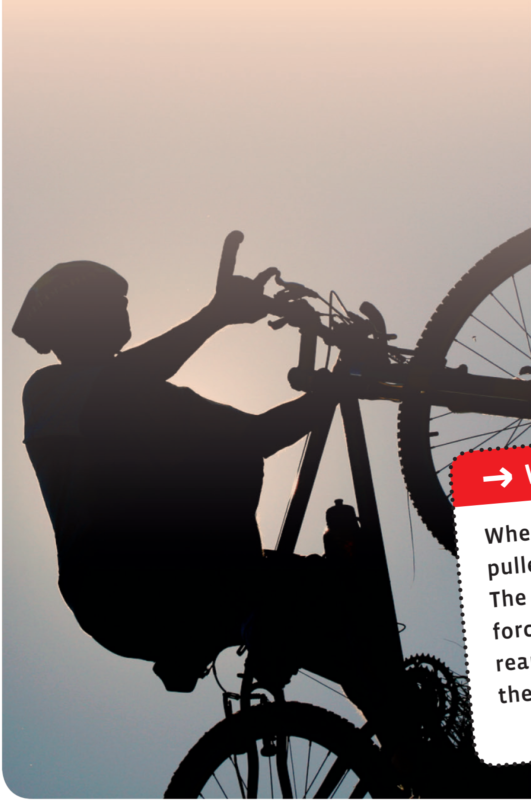
HERE'S HOW IT CONTINUES

6. Turn the bicycle upside down to switch out the small rear pulley for a medium pulley. Turn the crankpin again.

   What do you observe now?

6





→ WHAT'S HAPPENING?

When you rotate the crankpin, both pulleys turn and the bicycle takes off. The chain (rubber band) transfers the force from the pedals (crankpin) to the rear wheel. After changing the pulley, the bicycle goes slower than before.

EXPERIMENT 13

Acceleration transmission system

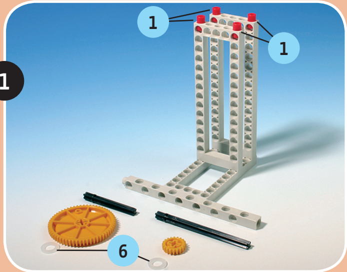
YOU WILL NEED

→ 2 small frames (8)
→ 2 large frames (7)
→ 3 long rods (9)
→ 1 long axle (11)
→ 8 anchor pins (1)
→ 6 washers (6)
→ 3 medium axles (11)
→ 1 large pulley (14)
→ 2 axle locks (5)
→ 1 crankpin (21)
→ 3 large gears (17)
→ 1 short rod (10)
→ 3 small gears (19)
→ “propeller” from Experiment 1

HERE’S HOW

1.–9. Assemble the acceleration transmission system as shown.

1



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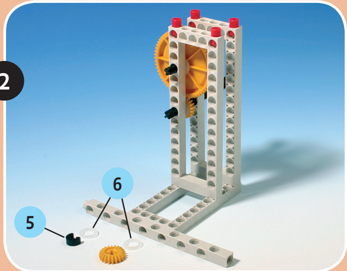

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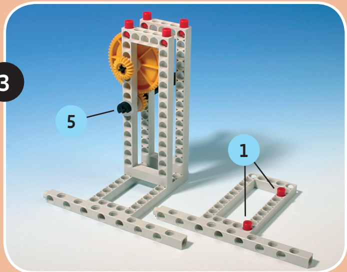

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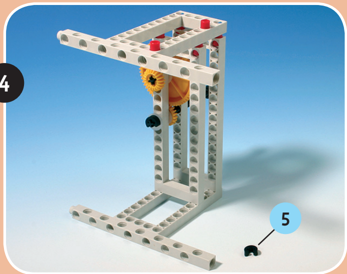

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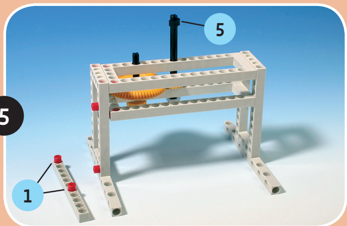

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Acceleration transmission system

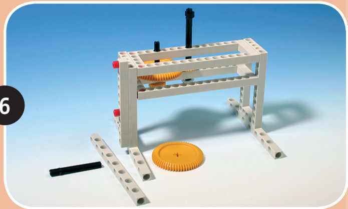
HERE'S HOW IT CONTINUES

Set the propeller on the end of the long axle with its white side up (!). It should sit loosely on the axle lock. If it's too tight, widen its interior until it moves freely.

Ideally, set your device at the edge of a table. Now it's ready to go.

10. Hold one foot of the transmission stand in place with one hand and turn the crank in a counter-clockwise (!) direction with the other.

6



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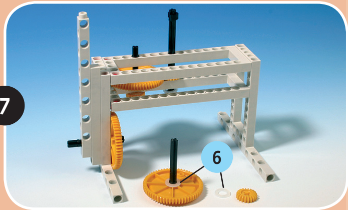

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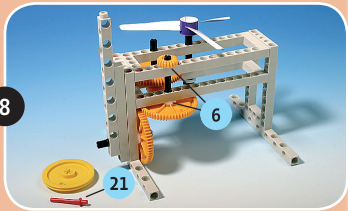

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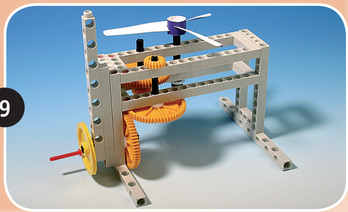

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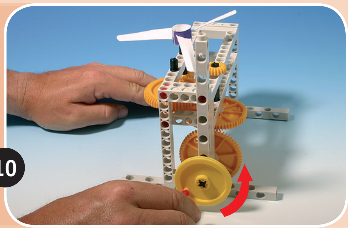


→ WHAT'S HAPPENING?

When you turn the crank in the right direction, the propeller takes off. In our model, the transmission system increases the rotation speed. After all, the propeller only needs a little turning force to start up, but a high rotation rate. It happens in two stages, from a gear with 60 teeth to one with 20 teeth at each stage. One rotation of the large one makes the little one turn three times. So it's a triple transmission ratio (1:3), and it applies twice: 3 x 3 = 9. The end result is that the propeller turns nine times for each turn of the crank wheel.

EXPERIMENT 14

Ball in flight

YOU WILL NEED

→ large gear (17)
→ small axle (13)
→ wooden ball (25)

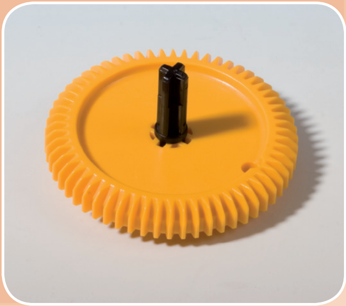
HERE'S HOW

1. Assemble the top out of a large gear wheel and a small axle.

2. Place the ball on it.

3. Give the top a gentle twist and watch what direction the balls flies.

1



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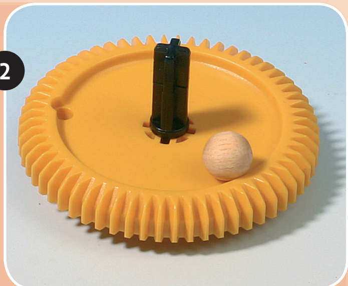


3

→ WHAT'S HAPPENING?

When the gear's groove can no longer hold the ball, it shoots away from the gear.

Centrifugal force movie theater

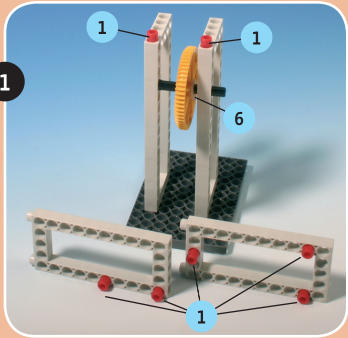
YOU WILL NEED

- → 1 base plate (20)
- → 2 small frames (8)
- → 2 large frames (7)
- → 1 long rod (9)
- → 2 short rods (10)
- → 1 long axle (11)
- → 1 medium axle (12)
- → 2 axle locks (5)
- → 3 large gears (17)
- → 1 medium gear (18)
- → 1 small gear (19)
- → 1 small pulley (16)
- → 1 large pulley (14)
- → 7 anchor pins (1)
- → 1 shaft pin (4)
- → 4 shaft plugs (3)
- → 2 joint pins (2)
- → 1 crankpin (21)
- → 4 washers (6)
- → 2 “centrifugal force machine” die-cut sheet parts (32)
- → *dark background*

HERE’S HOW

1.–6. Assemble the centrifugal force movie theater as shown.

1



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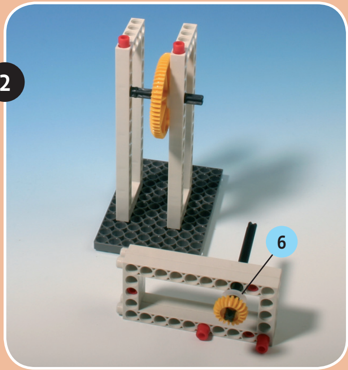

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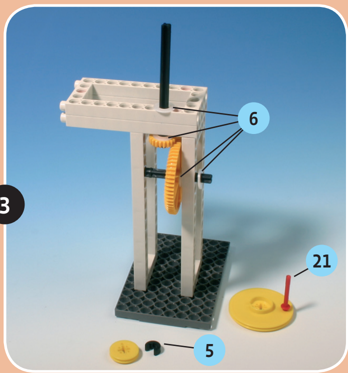

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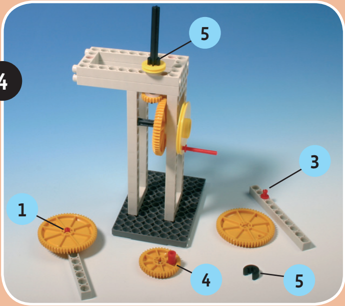
EXPERIMENT 15

4


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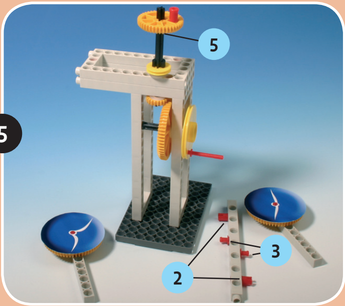

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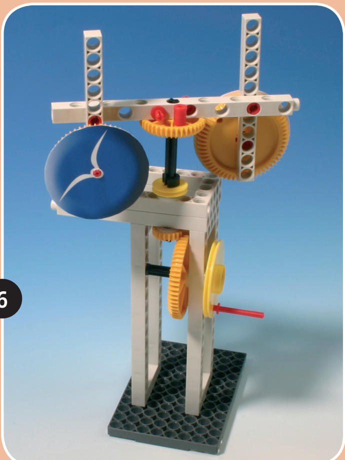
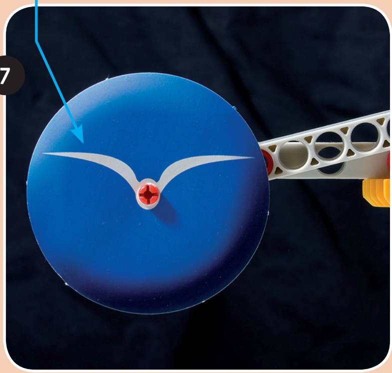


HERE'S HOW IT CONTINUES

7. Set the centrifugal force movie theater against a dark background.

   Adjust the image disks so that the wings are horizontal when extended.

7


Quickly turn the crank and, observing from the front, watch how the pivoting arms fly outward. But keep your eyes at the level of the spinning image disks.

→ WHAT'S HAPPENING?

The two images blend together to create a film of a bird flying, with the wings flapping at varying speeds.

TRANSMISSION OF FORCE

A force can be transferred between different components inside a machine. Mechanical parts such as pulleys and wheels are used for that.

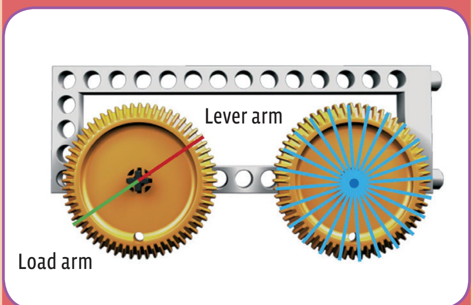
The transfer of forces and movements during rotation is called “transmission,” and it involves one drive wheel that is larger than the one being driven, or powered. That is the way it works in a bicycle: a large gear drives the smaller one at the rear wheel when you push on the pedal.

In this case, the route through which the force is transmitted is a circle, and the outer edges of the interconnected gears cover the same amount of distance. To cover that distance, the smaller one has to complete more rotations than the larger one.

Transmissions and gears

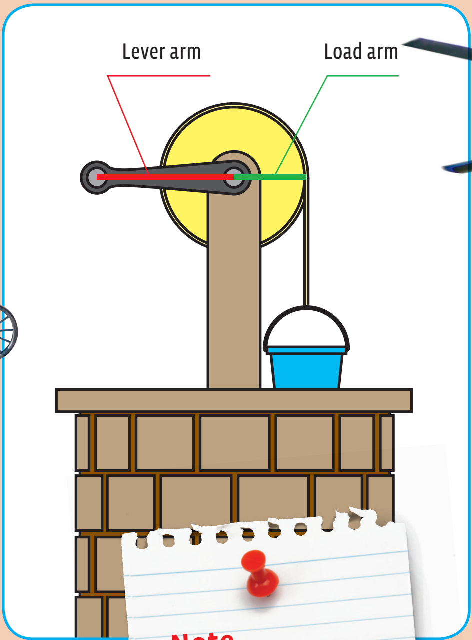
The wheel has been in existence for about 6,000 years. Its discovery was a technological breakthrough, and even today it can be found in half of all modern machines. Of course, a mere wheel disk is no machine by itself. It only becomes one when there is an axle to serve as a point of rotation in its center, such as in the wheel of a cart.

A wheel consists of an infinite number of single-armed levers “taking turns” one after another as the wheel rotates.



A wheel is just a lot of levers that are all turning around the same axis.

CHECK IT OUT



Note

The greater the length of the lever arm relative to the load arm, the easier it is to lift the load.

LOAD ARM & LEVER ARM ...

... are the same length in a wheel. So no force is saved there. Why, then, is a wheel considered a simple machine that makes work easier? Well, if you were to drag the load across the ground without wheels, it would require more force, since you'd have to overcome the resistance of friction.

↑ Helicopter

A helicopter has the ability to take off and land straight up and down. To do that, it makes use of one or more motor-driven rotors for its lift and forward propulsion.

Its rotor blades are mounted at a slant. They create lift by acting as rotating inclined planes, and the lift is further amplified by the profile of the blade. So helicopters are considered rotary-wing aircraft.

As far back as the end of the 15th century, Leonardo da Vinci created sketches of this kind of aircraft, although it took until the 20th century to be translated into reality. The first helicopter is thought to have been built by the Bréguet brothers in August 1907. Their craft, which they called a “gyroplane,” lifted just a few centimeters off the ground.

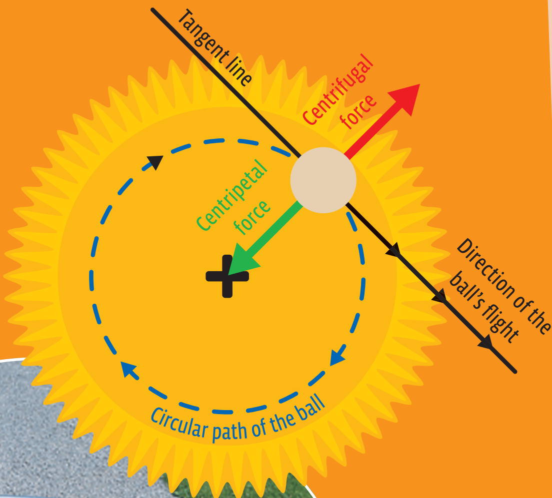
CHECK IT OUT

FEELING MASSES

Mass makes an object inert. It wants to stay in place when it rests. And when it does move, it wants to continue whatever movement it happens to be making at that moment. Only external forces can shift it away from that path. An object moving in a circular path wants to break away from the path and keep moving in a straight line.

So, for example, the ball in Experiment 14 that was flung away from the top flew off at a tangent — a straight line touching the circular path. Up to that point, centripetal force had held it to the circular path.

This force is directed at the center point of the circle. The ball "fights" against it with an equally strong opposing force known as centrifugal force (literally, a force "fleeing from the center"). You could see this in the centrifugal force movie theater in Experiment 15 as well.



Note
The centrifugal force (drawn in red) acting on a body is exactly as great as the opposing centripetal force (in green).

Kinetic Energy

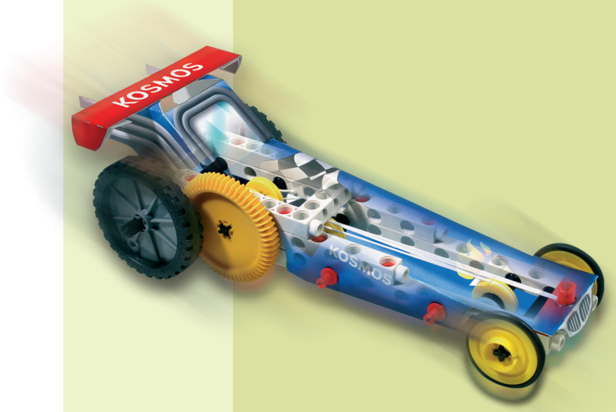
Who hasn't dreamed of driving a turbocharged dragster or maybe speeding across the sand in a sail wagon?

You'll be able to try both those things with the models in this section — two models that will let you take advantage of stored energy or wind power to fulfill your big dreams on a miniature scale.

Turbo-Dragster

YOU WILL NEED

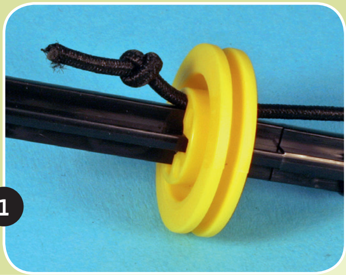
→ 1 small frame (8)
→ 4 long rods (9)
→ 2 long axles (11)
→ 3 medium axles (12)
→ 3 axle locks (5)
→ 1 large gear (17)
→ 1 small gear (19)
→ 1 medium pulley (15)
→ 3 small pulleys (16)
→ 2 wheels with tires (28)
→ 8 anchor pins (1)
→ 1 joint pin (2)
→ 1 connection bridge (22)
→ 6 washers (6)
→ 2 medium tires (29)
→ 2 "dragster" die-cut sheet parts (32)
→ 7 shaft plugs (3)
→ 50 cm of elastic band (27)
→ *measuring tape, glue*



HERE'S HOW

1. First, pull the elastic band through the "cross" in the center of one of the small pulley wheels and knot the end. Slide the pulley onto one of the medium axles — this will serve as the rear axle of your dragster.

2.–3. Now assemble the chassis. To ensure that the small pulley in the center will be able to sit as far to the right of the axle as possible, the short end of the axle should be inserted into the frame on the left. As you assemble the parts, pay attention to the placement of the rest of the elastic band.

1


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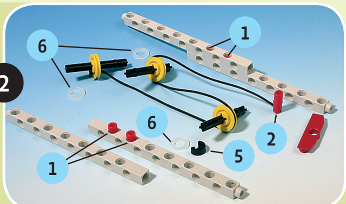

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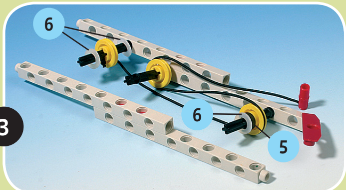


EXPERIMENT 16

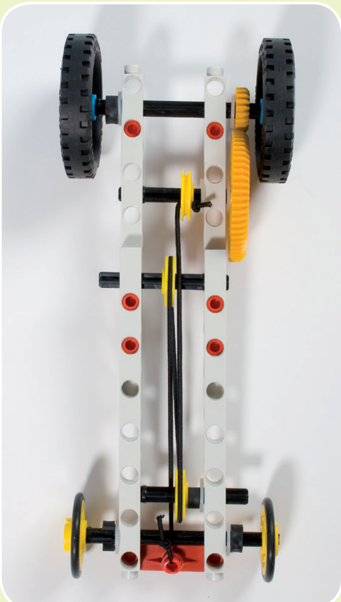
Turbo-Dragster

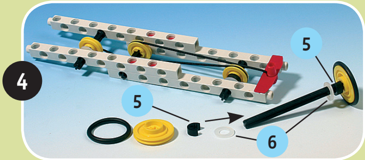
NEED HELP?
For larger images, go to www.thamesandkosmos.com/support/pd

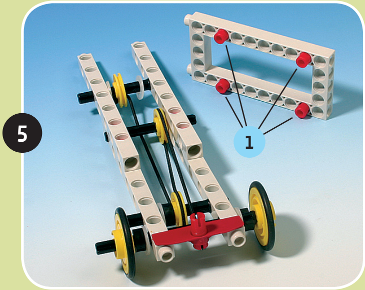
HERE'S HOW IT CONTINUES

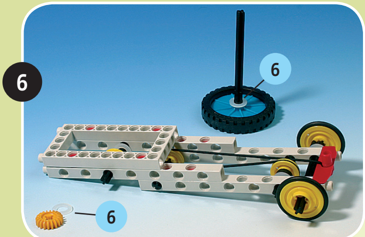
4.–6. With the help of the joint pin, secure the elastic band in the hole of the connection bridge from the top. The band should be slightly stretched. Add the front wheels and mount the small frame to the rear.

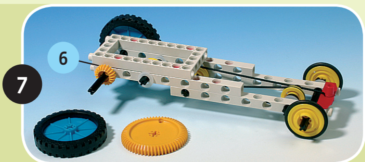
7.–8. Add the rear wheels and the large gear.

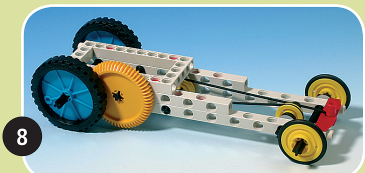




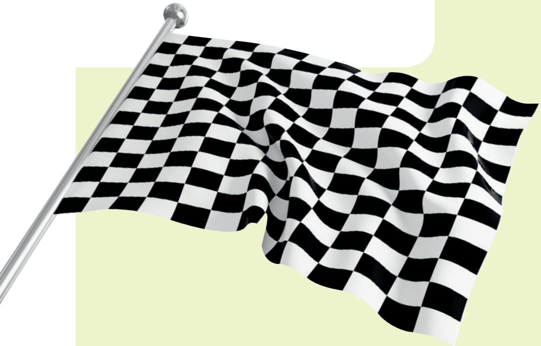








Turbo-Dragster



HERE'S HOW IT CONTINUES

9.–10. Attach the outer body with the help of the shaft plug, and glue on the red spoiler. Be careful not to let the rear wheels or the large gear wheel rub against the paper!

Wind up the rubber band motor with three turns of the large gear, and place the dragster on a smooth surface. Now you can fully wind up the rubber band motor.

How far does your dragster go?

→ WHAT'S HAPPENING?

The tighter the elastic band is wound, the more potential energy it contains. More work is generated and your dragster can start more quickly and drive farther.

EXPERIMENT 17

Speedy sail car

YOU WILL NEED

→ 4 long rods (9)
→ 2 short rods (10)
→ 1 long axle (11)
→ 1 medium axle (12)
→ 3 short axles (13)
→ 4 axle locks (5)
→ 1 small gear (19)
→ 2 medium pulleys (15)
→ 2 small pulleys (16)
→ 2 medium tires (29)
→ 2 small tires (30)
→ 7 anchor pins (1)
→ 2 shaft plugs (3)
→ 2 connection bridges (22)
→ 1 rubber band (24)
→ 6 washers (6)
→ "sail" cutout sheet (33)
→ 55 cm of string (26)
→ 2 x 12 cm of cord (26)
→ *glue, scissors*
→ *hole punch, pen*
→ *hair dryer*

You will find the sail on the cutout sheet →

1

2

3

HERE'S HOW

1. Use the scissors to cut the sail along the marked cutting outlines. Glue the gray surfaces together.

2. Bend back the narrow strip along the dotted line, and glue it in place.

3. Use the hole punch to make one hole at the top and one in the middle, so you can tie the sail to the mast.

EXPERIMENT 17

Speedy sail car

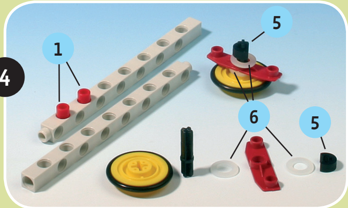
HERE'S HOW IT CONTINUES

4.–6. Now you can start to assemble the skeleton of your sail car.

7. Wrap the rubber band three times around the bottom of the mast. Pull the long cord through the two long rods as shown in the illustration, and tie them tightly to the washer.

8. Push the long axle halfway into the pocket of the sail. Use the rubber band to fasten the medium axle to the mast along with the gear.

4



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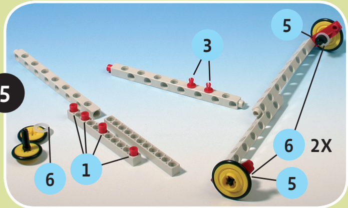

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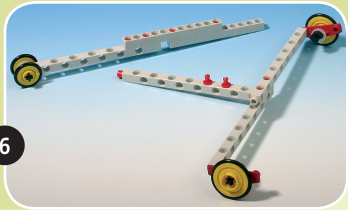


7

8

EXPERIMENT 17

Speedy sail car

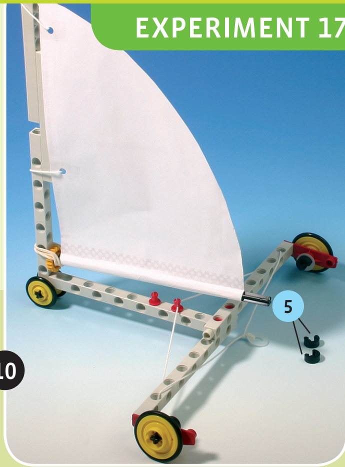
HERE'S HOW IT CONTINUES

10.–11. Push the sail over the medium axle and tie it tightly to the mast with the two short pieces of cord. Attach the washer to the cord with the help of the two axle locks.

12. Now you're ready to test the hair dryer (set to cold) on various sail positions. Find the right position for the sail car to reach the greatest speed.

Also try testing your sail car in a quiet paved area when the wind is blowing. You will be surprised how fast it can go. Be sure that all the wheels are turning easily and that the car doesn't tip over with a strong wind.

10



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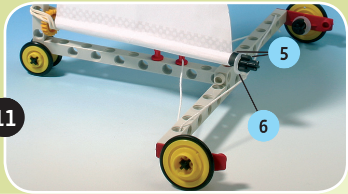

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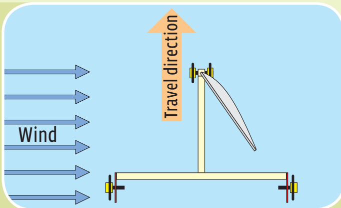
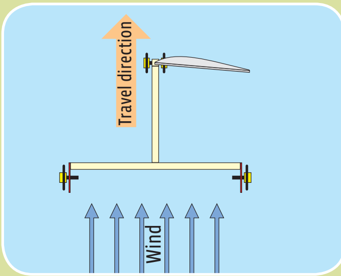
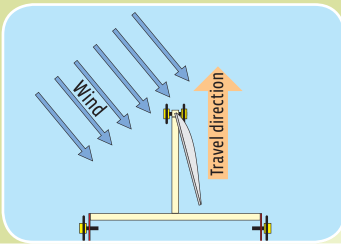


"beam reach"



"running"



"close hauled"

→ WHAT'S HAPPENING?

The sail car shows you clearly how you can use the power of the wind for locomotion.

CHECK IT OUT

Note

Energy is the ability of a body to perform work.

Keyword: Energy ↓

If water, for example, is resting in a dammed lake, one speaks of **potential energy**. Potential energy is converted into **kinetic energy** (literally, “movement energy”) when the water flows down pipes to a power plant, where turbines convert the kinetic energy into electrical energy.

Energy, in other words, comes in various forms: The water, or the wound-up rubber band in your model car, provides mechanical energy. A generator provides electrical energy, while gasoline and heating oil provide chemical energy.

↑ SAND YACHT

These days, sail wagons are built for pleasure or sport. Most modern sand yachts look something like a kayak with three wheels and a sail. Simpler models consist of nothing but an uncovered tubular frame.

A driver steers the sand yacht by manipulating its movable front wheel. With a good wind, the faster ones can attain speeds of over 150 km/h. Some models will let you replace the wheels with runners in winter. Then you can even sail over ice-covered lakes.

A dragster making a spectacular start.

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The most important units of measure in physical science:

The unit of length is the meter (1 m).
→ 1 m = 100 centimeters (cm) = 1,000 millimeters (mm)
→ 1,000 m = 1 kilometer (km)

The unit of volume is the cubic meter (1 m^3).
→ 1 m^3 corresponds to a cube with sides 1 m in length.
→ 1 m^3 = 1,000 liters (L)
→ 1 L = 1 cubic decimeter (dm^3) = 1,000 cubic centimeters (cm^3) = 1,000 milliliters (ml)

The unit of angle is the degree (°).
→ A complete circle is divided into 360°;
→ A right angle has 90°, a semicircle has 180°.

The unit of time is the second (s).
→ 3,600 s = 60 minutes (min) = 1 hour (h)

The unit of mass is the kilogram (kg).
→ 1 kg = 1,000 grams (g) = 1,000,000 milligrams (mg)

The unit of speed is meters per second (m/s).
→ This unit indicates the distance covered in a certain amount of time, which is also measured in kilometers per hour (km/h).
→ 1 m/s = 3.6 km/h

The unit of force is the newton (N).
→ 1 N is the force needed to accelerate (to make go faster) a mass of 1 kg by 1 m/s in 1 second. The unit of weight (force of gravity) is likewise the newton (N).
→ In everyday life we normally use mass, indicated in kilograms (kg). The force of gravity acting on the mass of 1 kg at Earth's surface equals 9.81 N.

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