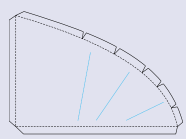
EXPERIMENT MANUAL

THAMES & KOSMOS

PHYSICS workshop

Franckh-Kosmos Verlags-GmbH & Co. KG, Pfizerstr. 5-7, 70184 Stuttgart, Germany | +49 (0) 711 2191-0 | www.kosmos.de
Thames & Kosmos, 301 Friendship St., Providence, RI, 02903, USA | 1-800-587-2872 | www.thamesandkosmos.com
Thames & Kosmos UK Ltd, Goudhurst, Kent, TN17 2QZ, United Kingdom | 01580 212000 | www.thamesandkosmos.co.uk

››› TABLE OF CONTENTS



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

››› KIT CONTENTS

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 anchor pins.

1. Motor Box (x1)
This contains an electric motor, a slot for one C battery (1.5-volt), a switch for forward, reverse, and off, a connecting wire, and a small worm gear to reduce the motor's rotation speed. The engine box is your drive unit. If you add a tiny drop of machine oil (or three-in-one oil) where the little axle protrudes from the housing, it will help the motor run more smoothly. The battery slot has a sliding cover that you can remove when you want to change the battery. A rechargeable C battery (1.2-volt) will also work. If the motor axle appears stuck upon first use, give it a gentle twist with your fingers to release it.

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

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

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

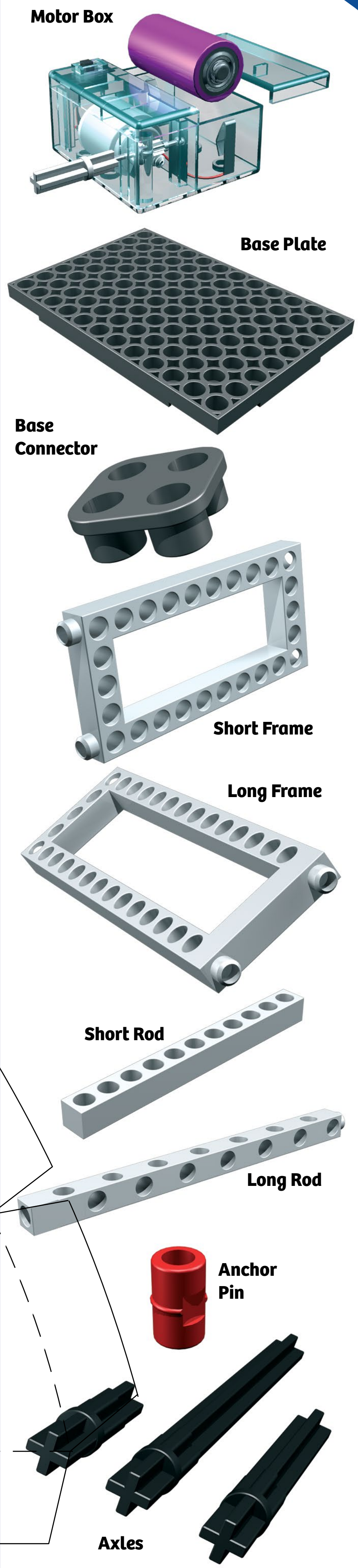
5. Long Frame (14 holes by 5 holes) (x2)
The long frames form the foundations of most of the structures and machines in the experiments.

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

7. Long 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.

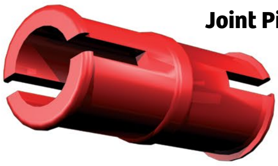
8. Anchor Pin (x20)
This is used for attaching rods and frameworks to one another. Two of its sides are flattened, so you can use the pin remover tool to extract it from a hole during disassembly.

9. Axles: Small (x4), Medium (x4), Large (x4)
The black axles come in short, medium, and long sizes. They have X-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.



Shaft Plug

Joint Pin



Shaft Pin

Large Gear Wheel

Medium Gear Wheel

Small Gear Wheel

Large Sprocket Wheel

Medium Sprocket Wheel

Small Sprocket Wheel

Chain Link

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

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

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

13. Large Gear Wheel (x2)
The kit's gear wheels are orange. The large wheel has 60 teeth around its periphery. Like all the gear wheels, this one has slanted teeth on one side, and on the other side it is flat. The hole in the middle lets you mount it on an axle or a shaft plug. The small hole near the edge of the wheel (or crank-hole) holds the shaft pin so you can crank it. A gear wheel lets you transfer force and motion onto another wheel (or another gear shaft). In that process, you can increase the force while decreasing the rotations, or increase the rotations while decreasing the force.

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

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

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

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

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

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

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

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

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

23. Rubber Bands (x4)
There are three different sizes of rubber bands: short, medium, and long. They do the work of drive belts, springs, and energy stores.

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

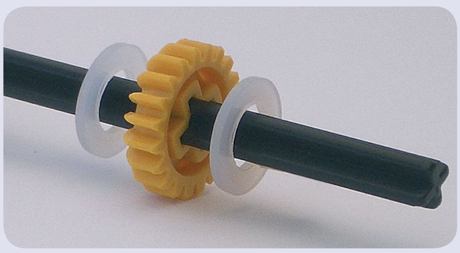
25. Crankshaft (x2)
This serves admirably as a crank handle.

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

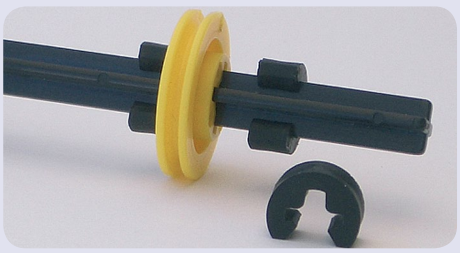
27. Anchor Pin Lever (Part Separator Tool) (x1)
This is a handy tool for extracting anchor pins and shaft plugs from holes. The thicker end lifts out the anchor pin, the thinner end the shaft plug. You can use the long axle to push out anchor pins, shaft plugs, shaft pins, and base connectors.

28. 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.

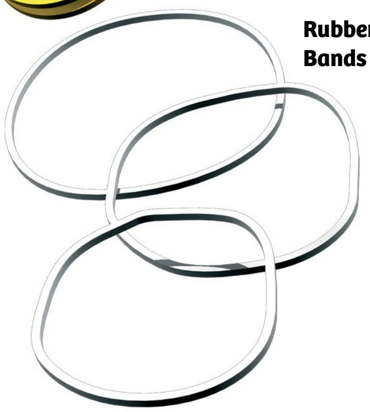
29. Axle Lock (x10)
These are designed to prevent a wheel from wandering along the axle, or slipping. They are easy to install without having to remove the wheel or the axle.

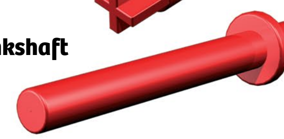


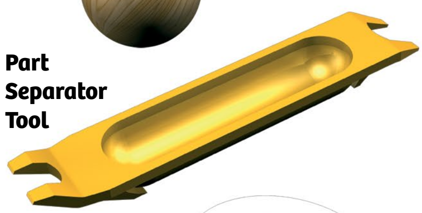
Plastic washers can be used to separate gears.



Axles locks will keep wheels and axles from slipping.

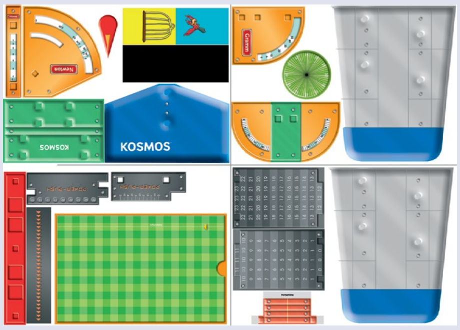




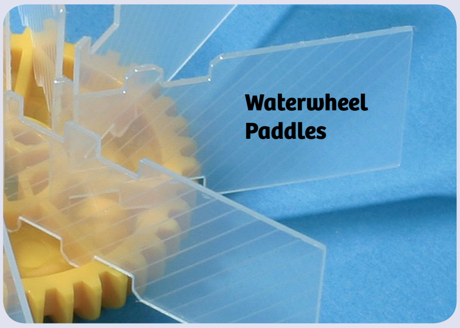


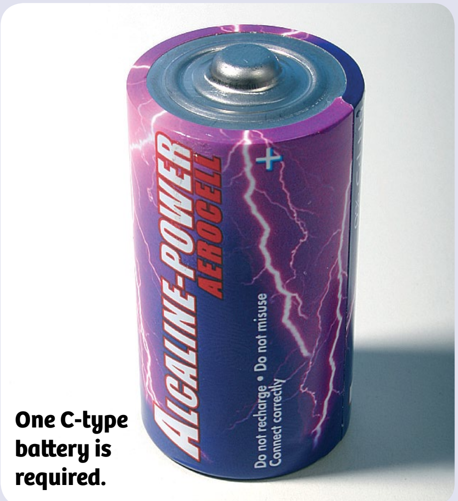
30. Die-Cut Paper Sheets (x1)
Remove each individual piece as you need it for its experiment. If any bits of paper remain attached to one of the pieces, just remove them carefully with a pair of scissors.

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



The Die-Cut Paper Sheets


Waterwheel Paddles



One C-type battery is required.


This diagram shows how you lengthen an axle.

Before You Begin Your Experiments

You will need one C battery (1.5-volt), or one C rechargeable battery, which is 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, tea light candles in aluminum containers, paper napkins, transparent adhesive tape, permanent marking pen, quart-sized plastic drinking bottle, freezer bag or plastic shopping bag, etc.).

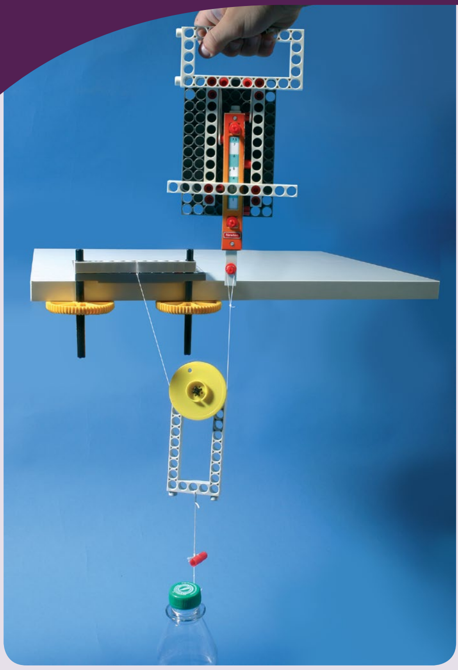
Beneath the text of pages 2-3, you will see a pattern for the **sail** of the sail car (see the Workshop on page 12). Trace the lines with a permanent marking pen onto a freezer bag or a sheet of plastic from a good-quality plastic shopping bag, and cut the sail out with scissors.

The rotor blades for the **wind-power generator** (page 47) will be assembled from pieces from the die-cut sheets. If you want to leave the wind power generator outside for a long time, you will need to cut the blades and tailpiece out of plastic. Just get a couple of thick flexible plastic presentation folders from a stationery store — they come in a variety of colors and thicknesses. If you have plastic folders that are too thin, you can make the blades and tailpiece out of two layers held together with tape. To get the size and shape of the plastic pieces right, trace around the die-cut paper pieces with a waterproof marker.

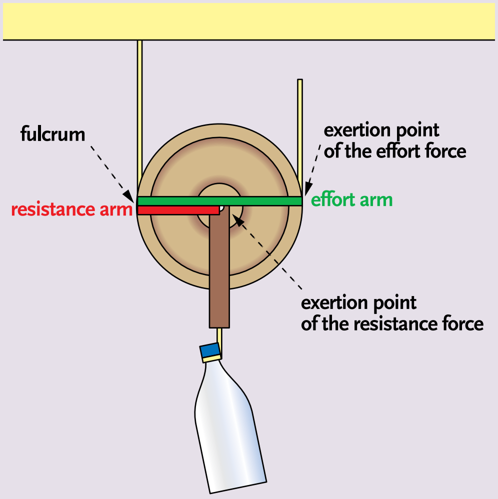
In a few of the models, the axles will also have to be **lengthened**. The best way to do that is to connect two axle shafts with a small gear wheel. Just insert one end of each axle into the gear wheel from each side. To make it super-secure, you can strengthen the clamp by inserting a bit of tissue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

cm vs. in

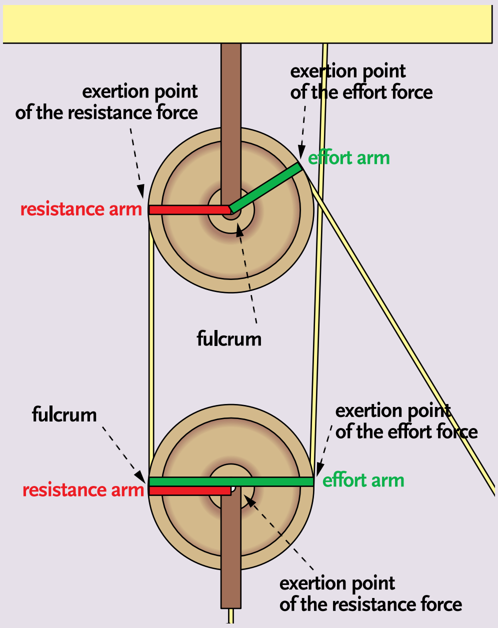
Throughout this kit, the Metric System of units is used instead of the Imperial System of units. Although you may be more comfortable with units from the Imperial System such as inches and feet, scientists around the world use the Metric System in order to be able to clearly communicate with each other 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.



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

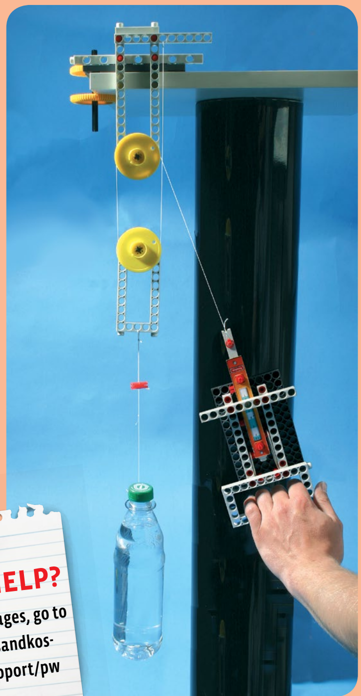
Hook the end of the string over the force scale as shown below, suspend the pulley with the bottle from the string, and read how much force you saved.

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

You will need the fixed pulley again (see page 25 for assembly), as well as the 0 to 7.5-N force scale (right), and a second **pulley** with an attachment for the load. Take note of the way you should thread the **string** through the components (see diagram, lower left).



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

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.

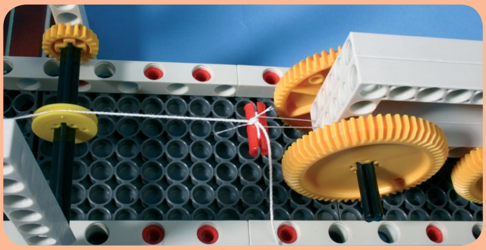
Forces on a Sloping Path — the Inclined Plane

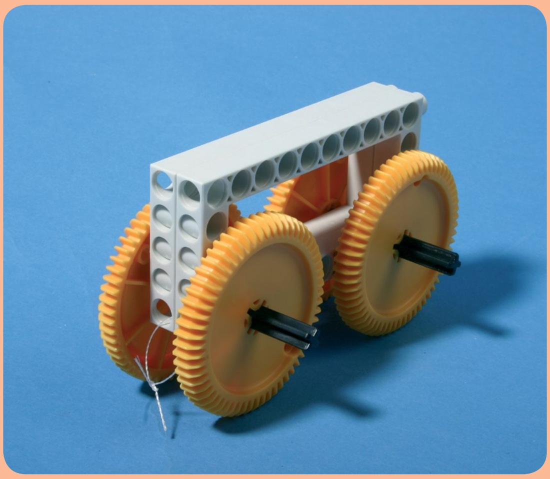
A wheelchair cannot climb stairs. That is why there is often an extra path designed for wheel chair users, alongside the section with stairs used by other pedestrians. If you were pushing your heavily-loaded bicycle along, would you prefer to push it up the wheelchair ramp or carry it up the steps? Without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

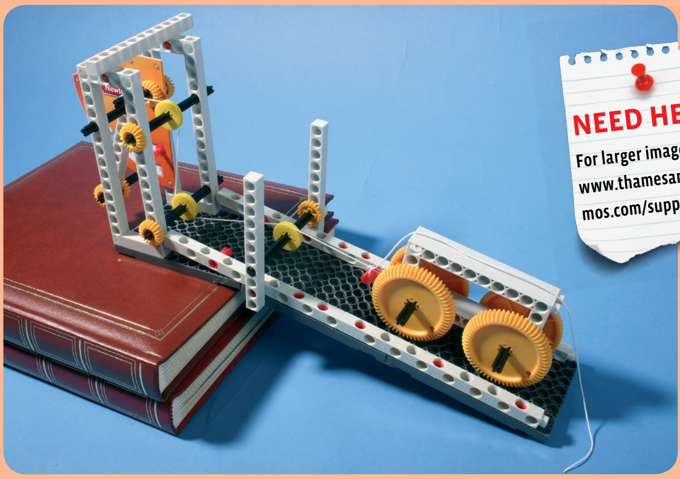
The ramp is an **inclined plane**, a surface that lies at a slant relative to horizontal. In order to observe experimentally how forces are distributed on it, we will first assemble a force scale for 0 to 2 N. In addition, we will build a test vehicle and an inclined plane, which we will attach to the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

WORKSHOP 15: TEST VEHICLE ON AN INCLINED PLANE

Assemble your test vehicle as shown in the illustration. Tie a short pull-cord loop to the **frame** before mounting the front **wheels** (left). Then slip the loop over the **joint pin** tied to the end of the **string** (top right). That is how the vehicle is connected to the force scale (0 to 2 N) (see page 23 for assembly) over the **pulley wheels**, shown in the picture on the bottom right.







NEED HELP?

For larger images, go to www.thamesandkosmos.com/support/pw

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 pulley wheels. 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 joint pins. 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.

DID YOU KNOW?

Why is it called a pulley?

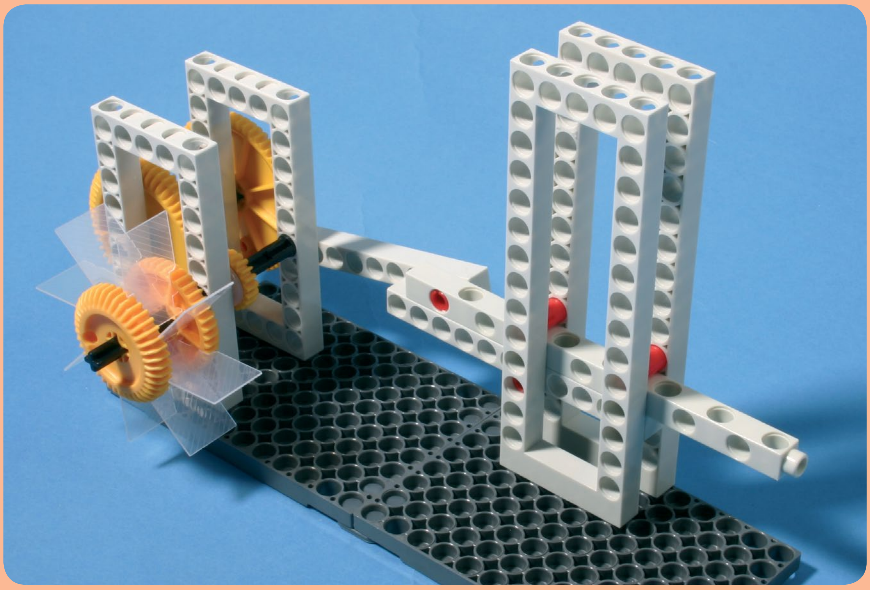
You might think a pulley gets its name from the fact that you can use it to pull things up. In fact, the name comes from polos, Greek for “hinge.”

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%).

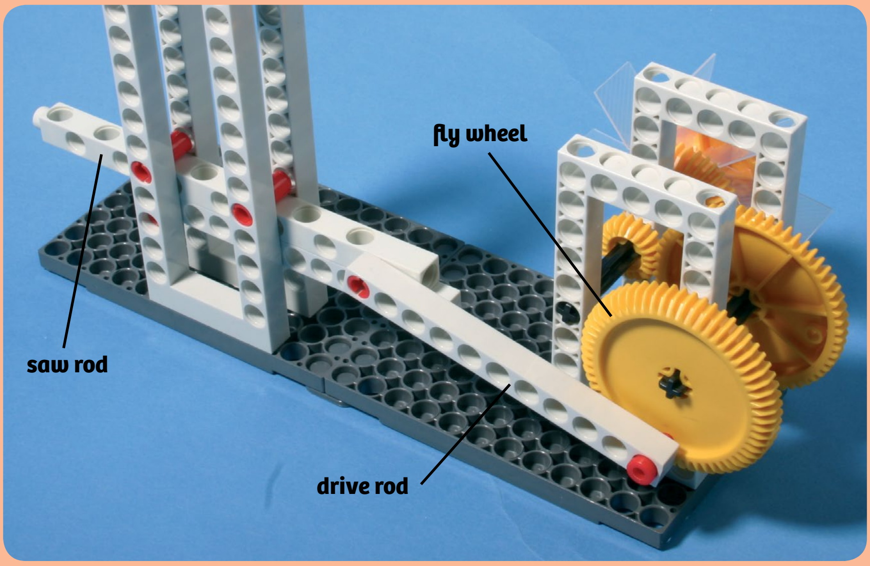
The driver has to take a longer stretch of road into account in order to get his car over the mountain. If the side of the mountain is too steep for a car to be able to drive up it on a straight road, then switchbacks have to be built — that is, the road has to wind back and forth.

WORKSHOP 24: WATER-POWERED SAWMILL

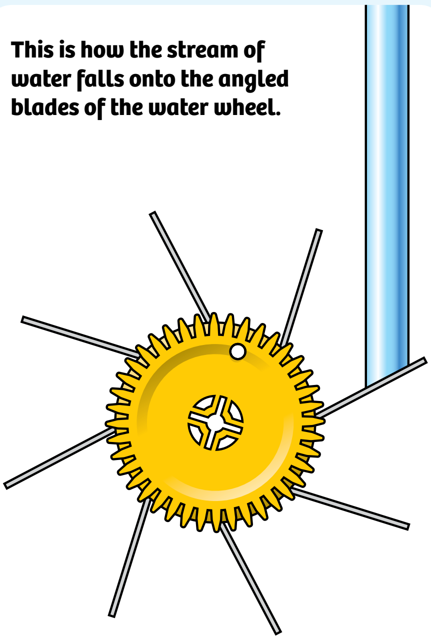
Insert the waterwheel blades into the interior compartments of one of the **gear wheels** and hold them in place with the other **gear wheel**. The saw **rod** glides back and forth on the **short rod** and is guided from the top by two **shaft plugs** or **anchor pins**. The connecting rod (**drive rod**) is attached to the flywheel (**large gear wheel**) with a **shaft pin** and to the saw with a **joint plug**.



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



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



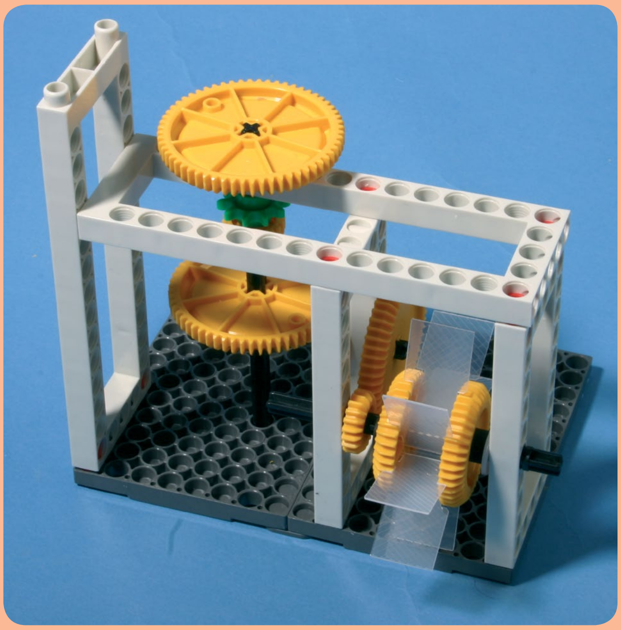
EXPERIMENT 23: ENERGY IN A BOTTLE

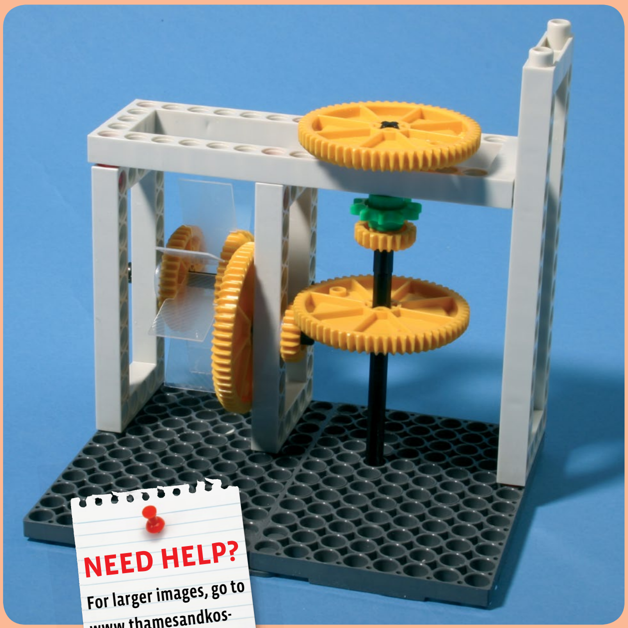
Place your water-powered sawmill in a bowl, in the sink, or in the bathtub and fill a bottle with water. Lift the bottle a little higher than the water wheel and let the water flow out slowly so that the stream hits the center of the blades. Then, gradually raise the bottle higher and higher. Repeat 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

Assemble the Potter's Wheel as shown. The upright axle supporting the two **large gear wheels** and one **small sprocket** is composed of one **long axle** and one **short axle**. The upper most **large gear wheel** uses an extra support disk, as does the **small gear wheel** on the other side of the **short axle** (between water wheel and potter's wheel). 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.



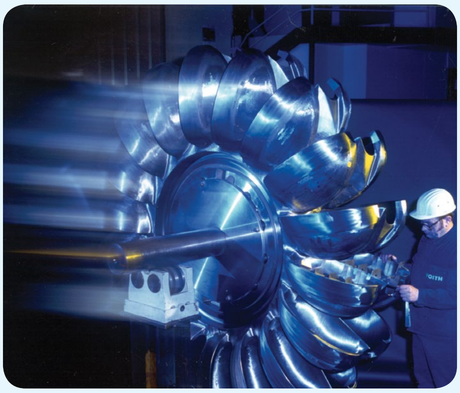


NEED HELP?
For larger images, go to www.thamesandkosmos.com/support/pw

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.