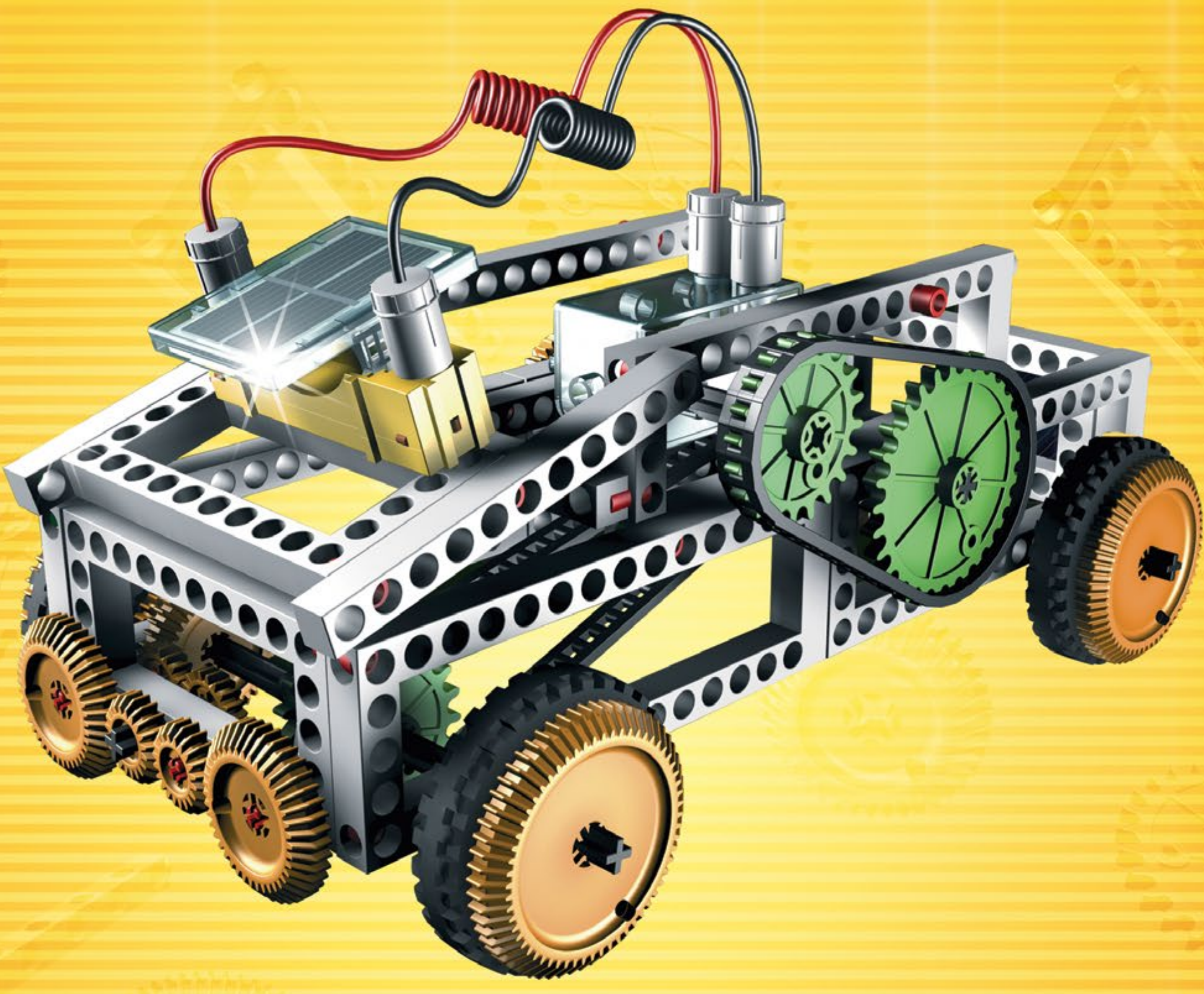
EXPERIMENT MANUAL



PHYSICS
solar workshop

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.

Safety Information

Dear Parents,

This experiment kit will introduce your child to the exciting world of solar technology. Equipped with this manual and the material in this kit, your child could well be on his or her way to becoming a future engineer designing high-tech energy systems.

But first, it is natural to have concerns about safety. The experiment set in front of you conforms to U.S. and European safety standards. These standards include requirements for manufacturers, but they also require that parents stand by their children's side with help and advice. Please tell your child to read all directions and safety instructions and to keep them close at hand for easy reference. Emphasize to your child that he or she should always follow all the instructions and rules of the experiments.

For performing experiments without solar energy, a 1.5-volt AA battery is required, which could not be included in this kit due to its limited shelf life. Please be sure to remove any dead battery from the kit and dispose of it appropriately.

We wish you and your young solar hobbyist a lot of fun and success with these experiments.

Safety Warning for Parents:

- **Warning:** Intended exclusively for children at least 8 years of age!

Safety Warnings for Children:

- Do not insert the cables into an electrical outlet.
- Do not connect the motor box to other power sources.
- The experiment kit should not be connected to other energy sources.
- Do not charge non-rechargeable batteries.
- Different battery types or new and used batteries are not to be used together.
- Use only the recommended battery types.
- Always insert batteries with positive and negative ends in the proper direction!
- Dispose of dead batteries properly and without delay.
- Do not attach the connection clamps to each other.
- Safety equipment, such as components for restricting current, should not be tampered with.

First Edition. Franckh-Kosmos Verlags-GmbH & Co. KG, Stuttgart/2004

Text: Tobias and Reinhold Pehle
Project Manager: Gerhard Gasser
Photos: Medien Kommunikation, Unna, up to p. 6, p. 7 top: Kopf AG, Umwelt- und Energietechnik, Sulz-Bergfelden, p. 11 bottom: HONDA, Deutschland; Inside back cover: public domain image courtesy of NREL.
Original Layout and editing: FROMM MediaDesign GmbH, Selters im Taunus

Second Edition, Thames & Kosmos LLC, Providence, RI, U.S.A.

Translation: David Gamon
Editorial and Production: Ted McGuire
Copy Editing: Jed Wilcox, Christa Raimondo, Stephanie McQuillan

Printed in Taiwan/Imprimé en Taiwan

PRINTED ON RECYCLED PAPER

Experiment Manual

PHYSICS solar workshop

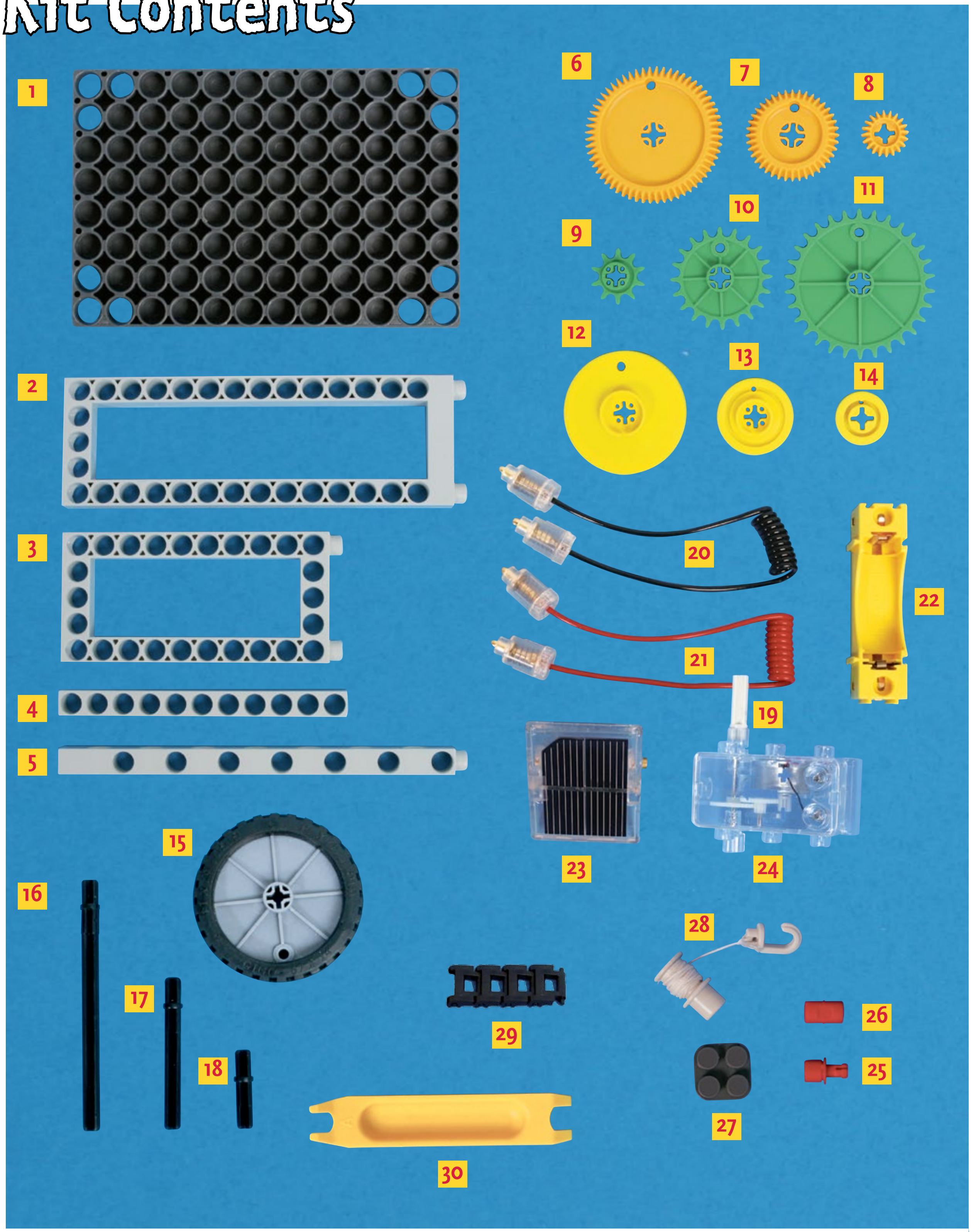
Tobias and Reihold Pehle

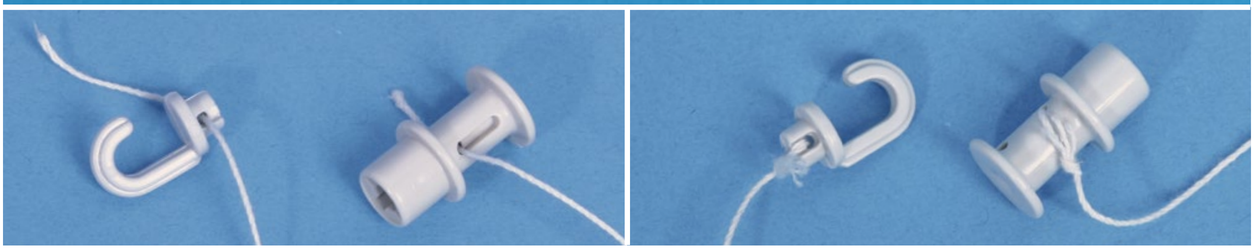
and David Gamon

Franckh-Kosmos Verlags-GmbH & Co., Stuttgart, Germany

Thames & Kosmos LLC, Portsmouth, RI, USA

Kit Contents





The crane hook and the cord holder (28) have to be fastened to the cord.

Contents List

No.	Quantity and Description	Part No.
1	2 x base plate	702 495
2	6 x long frame	702 498
3	6 x short frame	702 497
4	8 x short rod	702 500
5	6 x long rod	702 499
6	4 x large gear wheel	702 506
7	4 x medium gear wheel	702 505
8	10 x small gear wheel	702 504
9	4 x small sprocket wheel	702 507
10	4 x medium sprocket wheel	702 508
11	4 x large sprocket wheel	702 509
12	1 x large pulley wheel	702 516
13	1 x medium pulley wheel	702 518
14	1 x small pulley wheel	702 519
15	4 x tire wheels	702 591
16	5 x long axle shaft	702 501
17	2 x medium axle shaft	702 502
18	5 x short axle shaft	702 503
19	1 x engine shaft	702 801
20	1 x black cable	702 593
21	1 x red cable	702 592
22	1 x battery holder	702 531
23	1 x solar panel	702 530
24	1 x solar engine	702 800
25	5 x shaft plug	702 525
26	28 x anchor pin	702 527
27	2 x attachment plates	702 496
28	1 x crane hook	702 512
	with spool	702 513
	and cord	702 595
29	200 x chain link	702 510
30	1 x anchor pin lever	702 590

For some of the experiments, you will also need:

- 1.5-V AA battery
- various lamps in the house, especially a desk lamp with at least 75 Watts of illumination
- 1 sheet of tracing paper or transparent wax paper
- even surface (e.g. tabletop or pavement)
- uneven surface (e.g. gravel path or lawn surface)
- large, smooth, solid piece of cardboard (e.g. back of a pad of 8 1/2 x 11-inch drawing or writing paper)
- chunks of brick or rocks for a payload
- kitchen or postal scale
- small piece of cardboard (approx. 8 x 11 cm)

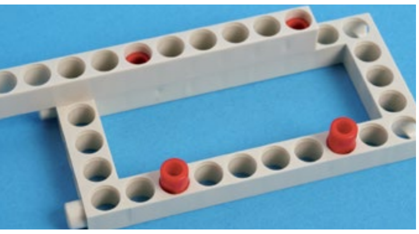
Table of Contents

Tips and Tricks for Model Building and Experiments

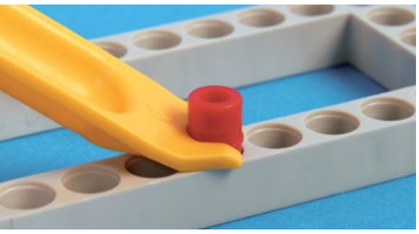
Follow the Instructions Closely

With this experiment kit, you will assemble a variety of solar models and conduct a lot of experiments. It is best to assemble the models in order. Then, it will be easier for you to construct the complicated models at the end. For all the models, it is important that all the individual components are put together properly. Only then will everything work right. To help you with this, there is a picture corresponding to every step in the assembly process. The instructions that go with the picture tell you exactly which pieces to use. Following each piece mentioned in the instructions, there is a number in parentheses. This is the number that you will find in the overview of the kit contents on pages 2-3. So if you aren't quite sure which piece you are supposed to be using, you can check on pages 2-3 to verify exactly which piece it is.

About Connecting Frames and Rods



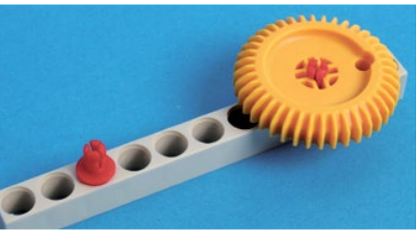
Frames (2, 3) and rods (4, 5) are connected to each other with the help of the anchor pins (26).



You can use the narrow side of the anchor pin lever (30) to pull the anchor pin (26) out again.

The basic construction of all of the models consists of frames and rods, which are connected to each other with the help of anchor pins. Some anchor pins are already permanently mounted to all of the frames and rods. But for most of the connections, you will need the red anchor pins (26). They are simply inserted into the holes of the frames and rods and serve to ensure a secure assembly.

To make it easier to remove the anchor pins from the holes, your kit comes with a small tool, the anchor pin lever (30). It has two different sides, marked "A" and "B." The narrow side with the "A" serves to lever out the anchor pins. The other side, marked with the "B," is wider. You can use it to remove shaft plugs (25) from the frames or rods.



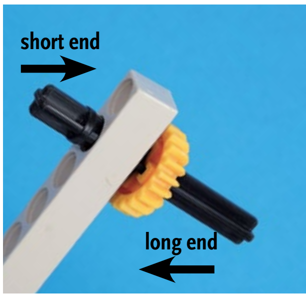
With the help of the shaft plugs (25), you can mount individual gear wheels or sprocket wheels to frames or rods.

The shaft plugs can be levered out with the broad side of the anchor pin lever.

About Wheels and Pulleys

In this box of solar experiments, you will find four types of wheels: gear wheels (6, 7, 8), sprocket wheels (9, 10, 11), pulley wheels (12, 13, 14), and tire wheels (15). They all perform different functions.

Gear and sprocket wheels are used in all of the models. They have two functions: first, they serve to transfer the rotary motion of the solar engine to other components. Second, they are used to secure axles (16, 17, 18, 19) so that they don't slip. The tire wheels are used to transfer the power of a vehicle's engine to the ground surface. The pulley wheels serve to guide the cord. In most cases, wheels and pulleys are secured with the help of the axle shafts (16, 17, 18). You can also attach wheels and pulleys to the engine shaft (19) or secure them individually with the small red shaft plugs (25).



The short end of the axle shaft (16, 17, 18) is built so that the shaft can't slip through a hole.

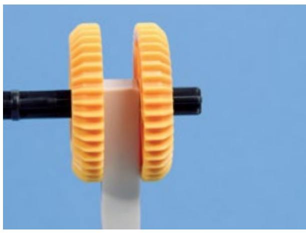
About Mounting Wheels

The axle shafts (16, 17, 18) and the engine shaft (19) each have two different ends: one short and one long. On the short end, wheels and pulleys can only be pushed on a little way. But if you push them onto the long end, you can position wheels and pulleys wherever you want on the shaft.

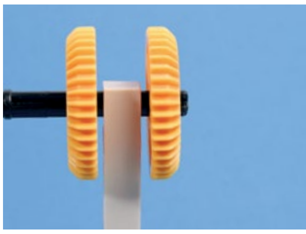
The short end is constructed in such a way that the axle shaft can't slip through a hole. To secure an axle shaft to a rod or frame, it will suffice to push a wheel, sprocket, or gear onto the long end to serve as a bracket. When building a model, you have to pay close attention to which direction an axle shaft is inserted.

With all of the models, wheels and pulleys have to be able to rotate freely. Otherwise, the solar engine won't be able to turn them. For that reason, it is very important that wheels and pulleys have enough "play" — as the professionals call it — and not be mounted too close to other components. So always leave a little room between a wheel or pulley and other components. Then, everything will go smoothly.

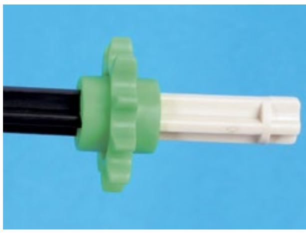
Sometimes, it may be difficult to remove a wheel from its axle. If that happens, use another axle shaft as a tool; hold the wheel tight and push with the other axle shaft against the axle that the wheel is mounted on (see picture at right).



If wheels or pulleys are mounted too close to other components, it is hard to turn them.



If wheels have enough "play," they turn easily.



If a wheel is mounted too tightly on an axle shaft, you can push out the axle shaft with another.

Understanding the Sun and Solar Power

The Sun's Energy

Have you ever really thought about what the Sun means to us, and what it does for us? Let's start right at the beginning, or more precisely, let's start early...

What happens when the Sun rises?

It gets light out. The Sun produces light — just like a lamp, except much, much brighter. As you know, you need electricity to turn on a lamp. Electricity is a form of energy. We can use this electricity in many different ways, just one of which is illuminating a filament in a light bulb. The Sun, on the other hand, needs no electricity to create brightness. Actually, it is just the opposite. The Sun is itself an energy source that provides us with our daylight. Its power is so great that not even all the lamps in the world could produce as much light as the Sun.

The energy from the Sun is called radiant energy. About 600 million tons of hydrogen are fused into helium in the Sun's interior every second, producing a radiant energy of 63,000 kilowatt-hours per square meter (kWh/m^2). At a distance of 150 million kilometers, where the Earth orbits the Sun, the power of this radiation still amounts to 1,400 kWh/m^2 (or Joules). Only about half of that energy is absorbed by the Earth, while the other half is reflected back into space.

The Sun's radiation is highly variable in different regions of the world. That has to do with cloud cover and the tilt of the Earth. In Pennsylvania, about 1,000 kWh/m^2 of solar energy are available per year, while the figure is about 1,700 in Los Angeles, 2,000 kWh/m^2 in the Caribbean, and 2,200 kWh/m^2 in the Sahara desert. Compare these numbers to the fact that the average American uses only about 13,500 kWh in a whole year.

We can do some calculations to find that the Earth gets about 5.45×10^{24} Joules of energy from the Sun every year. That's 545 with 22 zeros after it! To put this in perspective, the amount of energy produced and consumed in one year by everyone on Earth is only about 4.26×10^{20} Joules. Thus, the Sun gives us about 13,000 times more energy than we consume in a year! This means that in less than an hour, the Sun delivers as much free energy as all of the Earth's inhabitants combined use in an entire year. So scientists have naturally asked themselves the following question:

How can we capture the Sun's energy and use it for other purposes?

This is where the **solar cell** comes in. A solar cell is a device that converts sunlight into electrical current. The word "solar" comes from the Latin language, in which "sol" means Sun. There are many ways that solar cells can be used. In this experiment kit, we will be using the Sun's energy to power a small motor used in various models. Solar cell technology is also called **photovoltaic** technology.

Solar cells make it possible to convert the Sun's energy into electricity. The Sun can deliver 13,000 times more electricity than the entire world uses in one year.

The Solar Engine

You are probably already familiar with many kinds of engines, such as the gasoline-powered engines in cars. Those only run as long as there is fuel in the tank. And you know about toy cars that run on batteries, which will run only until their batteries are used up. Both of these kinds of engines have major disadvantages. First of all, fuel and batteries are expensive. On top of that, they pollute the environment. Cars emit toxic and environmentally harmful gases. Used batteries get thrown into the trash. Since they contain environmentally harmful materials, they have to be disposed of in time-consuming and labor-intensive ways. In addition, they add useless mass to our landfills.

Your solar engine, on the other hand, needs neither gas nor batteries. After it is made, it produces its own electricity for free, for a long time. It creates no toxic gas emissions, nor does it add to the landfill. So a solar engine is environmentally friendly as well as inexpensive.

There is one small disadvantage to a solar engine. In order to run, it needs light — ideally, bright sunlight.

Since sunlight doesn't reach us at night, a solar cell can only produce electricity from the Sun's energy during the day. However, the electricity produced by a solar cell from sunlight can also be stored. To do that, you need special rechargeable batteries and extra equipment. In order to produce and store as much electricity as possible in a photovoltaic installation, at the level that a family might need, you need a lot of solar cells. These are housed in large, flat panels or modules, which you can already see on some buildings.

Where Does Our Energy Come From?

Most of the energy we use comes from the Sun, in one way or another. This table provides a lot of information about our eight most popular energy sources, how they work, where they come from, and whether or not they are **sustainable**. Sustainable means that they can continue indefinitely without running out or causing other problems over time.

Name	Examples	Definition	Energy Origin	Percentage of world's power coming from this source	Is it renewable, relative to human life?
Fossil Fuels	Gasoline in a car, oil in a furnace, natural gas stove, coal in a power plant	Fossil Fuels are organic materials that release a lot of heat when they are burned. The heat can be used to heat water to turn turbines to generate electricity. They also produce a lot of pollution when burned.	The remains of prehistoric plants and animals, which grew and stored energy from the Sun	Petroleum: 38% Coal: 24% Natural Gas: 24%	No, only over millions of years
Hydro	Waterwheel used to grind meal, hydro-electric dam used to generate electricity	Hydro power is simply power from falling water. Today, it is mainly used in the form of dams that trap water and funnel it through turbines to produce electricity.	The Sun evaporates water from the oceans, the evaporated water rains out of the sky to help form rivers which run back to the ocean.	7%	Yes
Nuclear	Big reactors in power plants and submarines	A complex system sets off a chain reaction of fission, or splitting, of uranium atoms. This produces lots of heat, which is used to spin turbines which in turn produce electricity.	The energy stored in the bonds inside uranium atoms	6%	No, Earth has a limited amount of uranium in it
Geothermal	Geothermal power plants	Geothermal power is generated using heat from deep inside the Earth to create steam which is used to drive turbines to produce electricity.	The temperature at Earth's core is estimated to be 5,000 to 6,000° C. This heat was originally generated when Earth formed, and additional heat is formed as radioactive elements decay inside the planet.	<1%	Yes
Solar	Photovoltaics (solar cells) produce electricity, solar water heaters heat water, solar towers collect heat to turn turbines to produce electricity	Solar power is energy from the Sun. It can be captured and converted into useful energy in a variety of ways. Without the Sun, there would be no life as we know it on Earth. All living things need energy from the Sun, either directly or indirectly, to survive.	Nuclear fusion reactions in the Sun fuse hydrogen atoms together into helium atoms, yielding huge amounts of energy.	<1%	Yes
Wind	Windmills, wind power generators	Naturally occurring wind (moving air) is used to turn turbines to generate electricity. In the past, windmills turned wind power into mechanical energy used to grind corn.	Winds occur on Earth for two reasons. First, the Sun heats the Earth in different places at different times, causing certain areas to have warmer air than others. This causes pressure differences, and air will flow from areas of high pressure to areas of low pressure. This, combined with the fact that Earth rotates, causes the winds to blow as they do.	<1%	Yes
Biomass/ Wood	Sugar cane converted into a combustible fuel, animal waste converted into methanol fuel	Biomass is an umbrella term used to describe any organic, non-fossil material that can be used as fuel. It is often plant and animal "waste" products that are not useful for another purpose. Biomass commonly used for fuels includes corn stalks, sugar cane, wood by-products, animal manure and even household waste.	Biomass grows because of energy from the Sun, either directly as in the case with plants, or indirectly, as in the case with animals that eat plants to grow.	<1%	Yes, theoretically biomass can be grown at the rate it is consumed for fuel
Tidal	Turbines in tidal areas	Tidal power is power from the movement of the tides in the ocean. It can be harnessed by placing turbines in parts of the ocean with strong tidal currents. The currents turn the turbines that produce electricity.	The tides are caused by the gravitational pull of the Sun and the Moon on the water in the oceans.	<1%	Yes

Did you know . . .

. . . that the temperature on the surface of the Sun is over 6,000° C (about 10,800° F)?

In the center of the Sun, the temperature is 15-20 million ° C (~27-36 million ° F). The diameter of the Sun, at 1,390,600 km, is over 100 times that of the Earth. Its surface is 12,000 times as great as that of our planet. The Earth itself would fit into the Sun 1,300,000 times. If you picture the Sun as a ball 20 m across, the Earth would be about the size of a soccer ball 2 km away. The actual distance of the Sun from the Earth is about 149,500,000 km.

. . . and that the Sun is only middle-aged?

Even though the Sun is estimated to be about 4.6 billion years old, scientists calculate that it will continue to shine at its current energy level for another 5 billion years. So the Sun's energy will be available for human usage for a long time to come.

History of the Solar Cell

In 1839, the French physicist Alexandre-Edmond Becquerel discovered that light can influence electrical processes. He determined that metal electrodes immersed in acid produce more electricity when they are placed in the sunlight. Later, scientists named this the **photoelectric effect**, or **photovoltaic effect**. This was a very important discovery because it clearly showed that under certain circumstances, light can be converted into electrical energy.

In 1883, an American inventor named Charles Fritts built the first solar cell, but it was very inefficient. A lot of time passed and a lot of research was done before the first modern solar cell was patented by another American named Russell Ohl. In 1958, the U.S. sent the first solar-powered satellite into space, showing how much photovoltaic technology had progressed in just over 100 years.

How Does a Solar Cell Work?

A solar cell is a flat device that uses an electronic component called a **semiconductor** to convert **photons**, or the massless particles of light energy, into electrical energy. The semiconductor creates a **voltage**, or difference in electrical potential energy, between two surfaces when it is exposed to light. You can think of it like a battery, which also has a voltage between to points. This is just a brief explanation of how a solar cell works. To explain it more thoroughly, we must first discuss electricity.

The phenomenon of electricity is nothing more than the movement of negatively charged particles, called **electrons**, through a material, called a **conductor**. Electricity flows easily through some materials, like metal, and poorly or not at all through other materials, like plastic. We have discovered materials, like silicon, which are naturally poor conductors in pure form, but can be treated to become better conductors under special conditions. These are **semiconductors**.

In a solar cell, electrons are excited into motion by exposure to energy from light. The solar cell is designed to make the electrons flow in a specific direction, creating a negative pole on the side where there are more electrons and a positive pole on the side where there are fewer electrons, or more "empty holes" for electrons. To achieve this electron flow, pure silicon must be treated to become a better conductor. This is done by adding impurities, or other elements, to the silicon, in a process called **doping**.

There are two layers of treated silicon in the solar cell. Phosphorus is added to the first layer, resulting in an abundance of free electrons. Because electrons have a negative charge, this layer has a negative charge, and is thus called **n-type** doped silicon. The other layer is doped with Boron, resulting in an absence of electrons, or more holes for electrons. This gives the layer an overall positive charge, and is thus called **p-type** doped silicon (Figure 1).

The n-type silicon layer is positioned right next to the p-type layer (Figure 2). All of the free extra electrons in the n-type layer flow to fill up the holes in the p-type layer, creating an electric field. Right along the line where the two layers meet, something interesting happens: electrons are able to move from the n-type layer into the p-type layer, but not from the p-type layer into the n-type layer. This area where

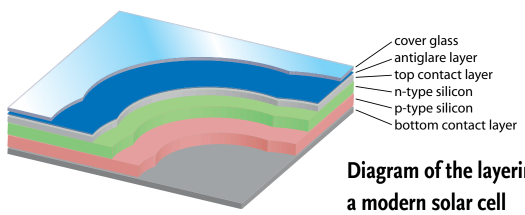
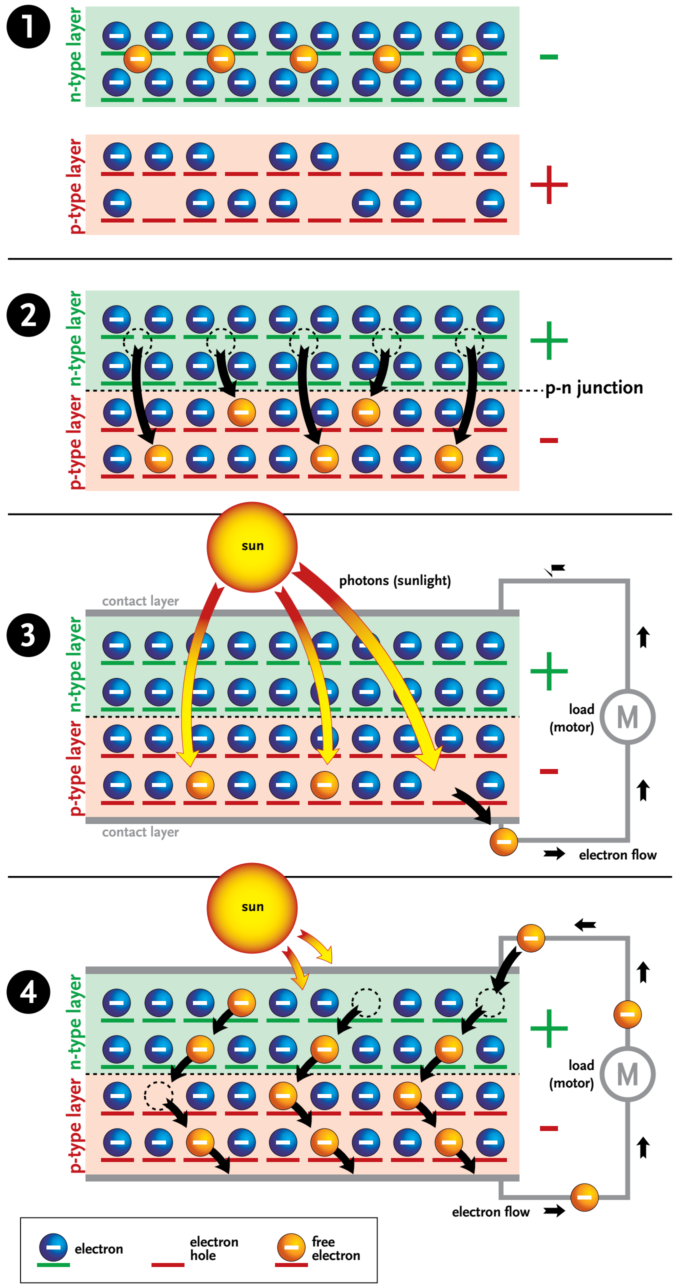


Diagram of the layering in a modern solar cell



the two layers meet is called the **p-n junction**. You can think of it like a hill, where electrons can easily roll down the hill (to the p-type layer) but it is very hard for them to go back up the hill (to the n-type layer).

When the cell is exposed to light, the energy from the light excites the electrons in the p-type layer, and they break free from their holes (Figure 3). With contacts and wires attached to conduct electrons out of the p-type layer, through a **load** (such as a light bulb or motor), and back to the n-type layer, we now have a complete solar cell circuit. When an electron moves, the hole it was previously sitting in becomes empty, and another electron can easily move into its position (Figure 4). And because electrons can only travel in one direction through the p-n junction, they must pass through the wire and load to get back to the n-type layer. This creates the **electric current**.

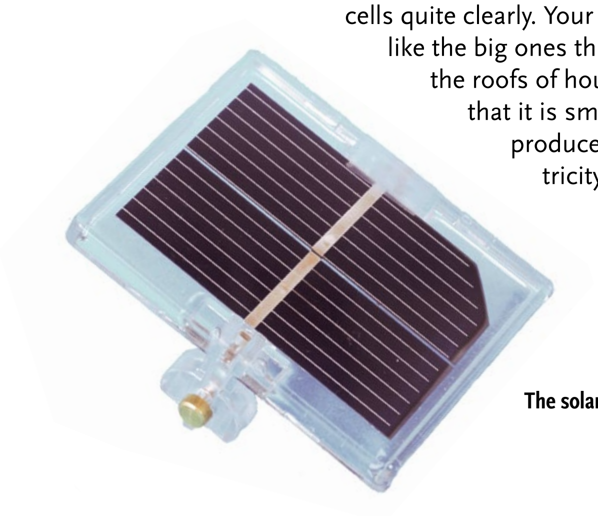
This basic solar cell with one p-type layer, one n-type layer, and one p-n junction is called a first generation photovoltaic. A second generation photovoltaic has many layers and multiple p-n junctions, to absorb more light. There is also a third generation photovoltaic, which does not use the traditional p-n junction at all.

This is a simplified description and we encourage you to find out more about how solar cells work from books, the internet, and your science teacher.

Powering an Engine with the Energy of the Sun

The Solar Module

If you are going to be a solar engineer and make use of the Sun's energy, you first need a solar cell to convert light into electricity. In your experiment kit, you will find a small solar module (23) with several solar cells. They are integrated into the black strips located under the protective layer of plexiglass. If you turn the module over, you can see the individual cells quite clearly. Your module is just like the big ones that you see on the roofs of houses, except that it is smaller and can't produce as much electricity.



The solar module (23)

In order to pass on the power of the Sun, each of your module's two brackets has a round metal conductor. It is through these two terminals that the positive and negative current produced by the solar cells becomes usable.

Your experiment kit includes a battery holder (22) onto which the solar module is mounted. In the battery holder, the electrical current is passed on to the two sockets located on top of it on the left and right. The electrical cables (20/21) are inserted into these sockets. One cable is red, and the other is black. So the battery holder has two functions: it serves as something to attach the solar module to, as well as something that connects the electrical cables to the module. You can connect all kinds of electrical equipment (the technical term is "electrical load") — most importantly, the motor — to these cables.

Your New Solar Engine

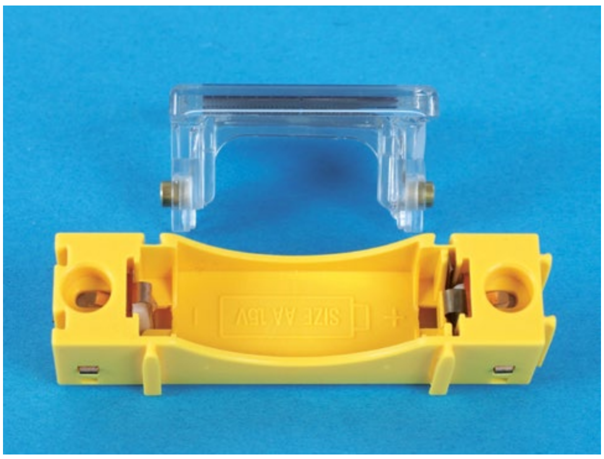
In our first experiment, we will use the Sun's energy to drive your kit's engine and turn a small sprocket wheel.

Experiment 1

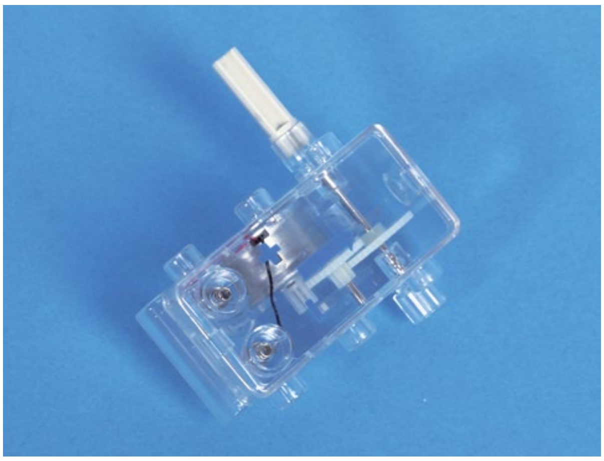
› **You will need:** parts from the parts list (next page, upper right)

Instructions

Insert the small gray engine shaft (19) with a small sprocket wheel (9) mounted on it into the engine (24). Secure the engine and the solar module (23) with the battery holder (22) to the base plate (1), as shown in the photo at the top of the next page. Then connect the engine and battery holder with the electrical cables (20/21). The red cable is the positive



The battery holder (22) isn't just for mounting the module (23). The cables that will supply the engine with electricity are also attached to it.



In most of the models, the small engine shaft (19) is inserted into the solar engine (24) in order to transfer the engine's power to the model.

Parts List

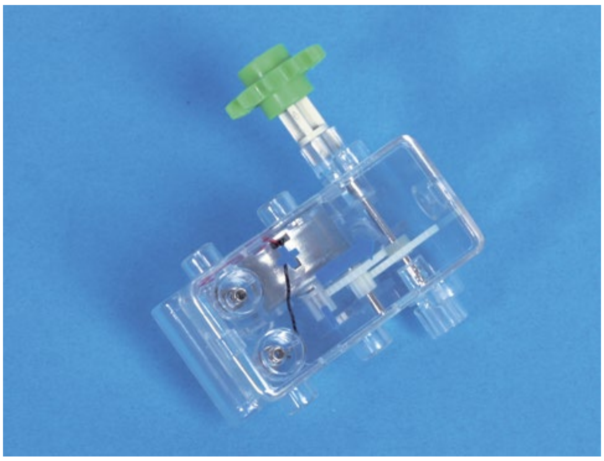
1 x base plate **1**	1 x small sprocket wheel **9**
1 x engine shaft **19**	1 x black cable **20**
1 x red cable **21**	1 x battery holder **22**
1 x solar module **23**	1 x solar engine **24**

line and the black one is the negative line. Be sure to pay attention to the plus and minus symbols on the battery holder and the engine when you attach the cables. Then take your model into bright sunlight and orient the module toward the Sun. What happens?

Results

As soon as enough light falls on the solar module, the engine will start to turn. Direct sunlight is bright enough to get your engine going. In shade, it isn't bright enough — the engine won't move. Light and shadow are like the on-off switch for the solar engine. The solar cell has the ability to convert light into electrical current, and it is this electrical current that drives the engine. The engine stops when not enough light falls on the solar module. In your house — often, even right next to the window — the light isn't intense enough. The bigger a solar cell is, the more current it can produce. It also makes a difference how the solar cell is constructed. On your module, there are just a few small solar cells that are only capable of producing a little current. That is why your engine needs a lot of light in order to turn.

IMPORTANT NOTE ABOUT LIGHT SOURCES!
Not all light sources produce enough light for the solar cell to power the motor. We recommend at least a 75 Watt incandescent bulb in a suitable desk lamp fixture. Fluorescent lights, flashlights, and low-voltage halogen lights will not work well. Of course, the Sun is much more powerful than household lamps and should be used if possible.



In our first experiment, a small sprocket wheel (9) mounted on the engine shaft is turned. Mount it so that it sits flush at the front.

Your first solar model turns the small sprocket wheel inserted onto the engine shaft.

Little Shadows

It would be interesting to know just how much light your solar module needs in order to run the engine.

Experiment 2

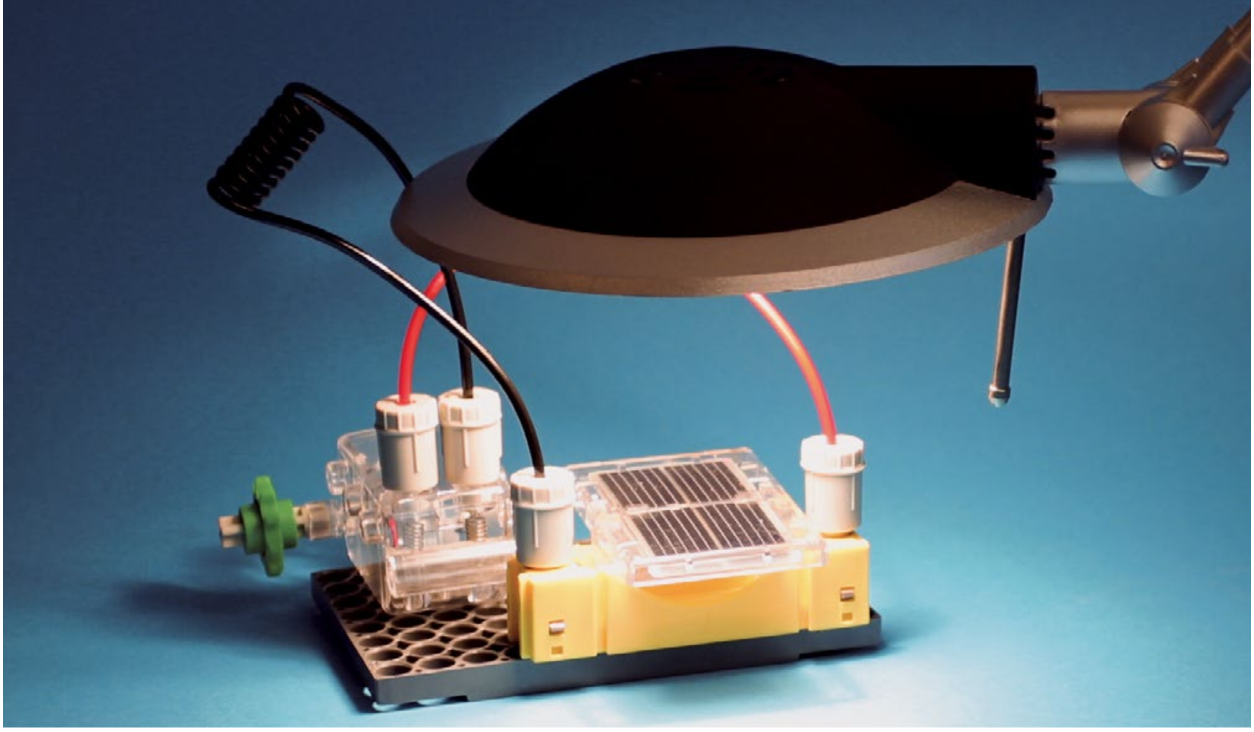
› **You will need**: your solar model from the previous experiment

Instructions

Set your solar model in bright sunlight so that the engine turns. Next, hold your finger over the solar cell. Does the sprocket wheel still turn? What happens when you hold two or more fingers over the solar module? Try adjusting the distance between your fingers and the solar module.

Results

When you hold your finger over the solar module, it creates a small shadow. The shadow in turn darkens a small part of the surface of the panel in which the solar cells are located. The rest of the panel still gets enough light to run the engine. The more of the panel that you cover in shadow with your fingers or hand, the less light the solar cells get. When there isn't enough light, the engine won't move.



Your solar engine doesn't only run in bright sunlight. It will also run on bright light from a lamp. Use a 75 Watt incandescent bulb in a desk lamp.

Artificial Clouds

You know the story: it's a bright sunny day, then it gets cloudy and the nice weather is over. You have to go inside if the sky darkens with heavy black thunder-clouds. And worst of all: your solar engine won't work. But why is it that the sunlight on an overcast day isn't enough to power the engine?

Experiment 3

› **You will need**: bright sunlight, your solar model, a sheet of 8 1/2 x 11-inch transparent paper (white tracing or wax paper)

Instructions

Hold the transparent paper over your solar module while the engine is turning. Then fold the paper down the middle and hold this smaller surface over the solar cells. Fold the paper again and again, observing what happens each time you hold it over the solar module.

Results

When you hold the unfolded thin, transparent sheet over the solar cell, enough light still gets through and the engine still turns. When you fold it, the sunlight has to get through another layer in order to reach the solar cell. The more you fold the sheet, the more layers you create. Each layer absorbs some of the light. When there are too many layers, there isn't enough light getting through to the cell and the engine stops. When the sky gets overcast, the same thing happens. Layers of clouds come between the Sun and the Earth. Enough light can still get through a thin layer of cirrus clouds to power the solar model. But not enough of the Sun's rays can get to your model through thicker layers of cloud cover.

Artificial Sun

As you know, light isn't only produced by the Sun. A lamp with an incandescent or halogen bulb can also provide light. Will this kind of light also run your motor?

Experiment 4

› **You will need**: daylight, your solar model, an assortment of lamps in your house

Instructions

On a bright sunny day, turn on several lamps in your home, such as floor lamps, overhead lights, and desk lamps. Hold your solar module directly under the lamps. What happens?

Results

Your solar cells don't just convert sunlight into electrical current. If a lamp produces enough light, it can also run the solar engine. In that sense, lamps work just like an artificial Sun.

Not all of the lamps in your house will provide enough light. The incandescent bulbs in electric lights have different levels of strength. The strength of these kinds of lights are indicated in watts (W). A bulb with 60 watts creates much brighter light than one with 15 watts. Also, some lights use a reflector to focus their light, creating greater brightness at a specific point. Reflectors are usually silver-colored.

There are some kinds of lighting that have built-in reflectors as well as ones that concentrate light. Because there are so many different kinds of lamps and lighting, one might be bright enough to run the engine while another might not.

The Artificial Sun's Power

Why doesn't the solar engine run in every part of your home — even in a particularly bright room? The next experiment should shed some light on this.

Experiment 5

› **You will need**: solar model and a light in your house that is strong enough to move the solar engine when you hold the engine directly beneath it

Instructions

Hold your solar model directly under the light that is strong enough to run the engine. Then gradually increase the distance between the lamp and solar module. What happens?

Results

The farther away you get from the lamp, the less light is emitted from it. You can see that particularly clearly on a street at night, when a car drives toward you with its headlights on. When the car is still far away, all you see is two small points of light. But when it drives by you, the light of the car is much, much brighter. Because the brightness of a light source drops with distance, the solar cell won't get enough light to run the motor when it is too far away.

Ambient Light

During the day, daylight enters your home. A term for this kind of light is ambient light (literally meaning "surrounding light"). In the next experiment, we will see if ambient light has any effect on the solar cell.

Experiment 6

› **You will need**: solar model, a long ruler, a light in your house that is strong enough to run the solar engine when you hold the module directly beneath it. A desk lamp works the best.

Instructions

In the middle of a sunny day, hold your model under a light that is strong enough to run the engine. Increase the distance until the engine stops. There has to be a lot of sunlight entering the room. Measure the distance between the lamp and the model. Write down the measurement. Repeat the experiment after sundown and compare the distances measured. If you don't want to wait until evening, you can just shut the blinds.

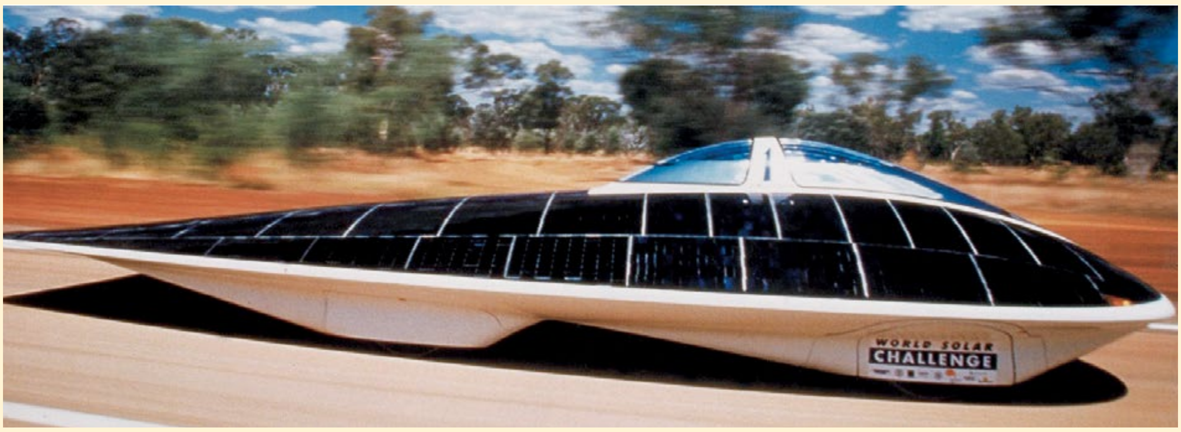
Results

During the day — even when the sky is overcast — sunlight enters your house. The solar cell can make

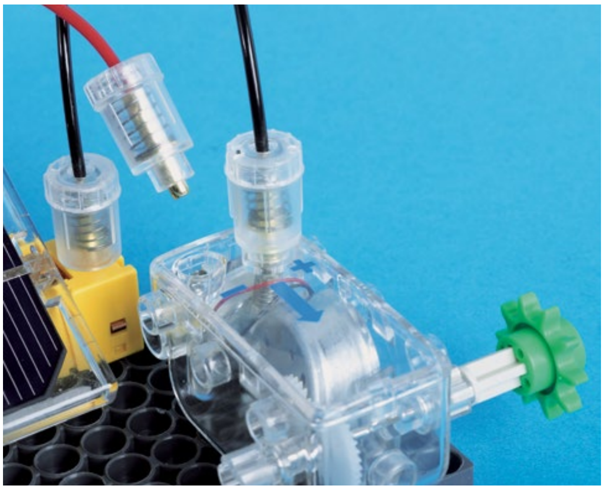
Did you know . . .

. . . that there is a world championship for solar cars?

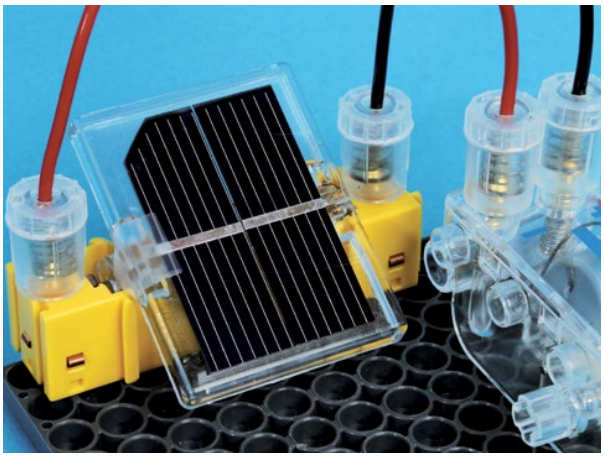
Every year, a solar car world championship is held in Australia. In the contest, the cars have to drive about 3,000 km across the entire continent. The one that finishes first is the world champion. The fastest solar cars reach speeds of over 100 km/h, driving on normal roads. During the race, the solar cars are accompanied by separate cars driven by their team members. Most of the teams in the contest come from universities. Many of the electricians and mechanics are students who take part in the race for fun. All the race cars are unique models, each one different from the next. That means they are also very expensive. These solar race cars typically cost more than $300,000 to build.



The Honda Dream, a spectacular solar race car.



You can change the rotation direction of the engine by reversing the connections of the cables to either the engine or the battery holder.



The rotation direction of the engine follows the direction of the flow of current. The solar module producing the current determines its direction of flow (see the text on p. 13).

If the solar module is turned around, the current flows in the opposite direction. That makes the rotation direction of the engine change, too (see the text on p. 13).

use of this light. Even when just a little enters in, it can be used to produce electricity. But most of the time, it will be too weak to start the engine. The more light that reaches the solar cell, the more electricity it produces. Starting at a certain level of brightness, the cell will produce enough electricity to run the engine. During the day, sunlight combines with the light from the lamp. That is why the engine runs at a greater distance from the lamp than in the evening. After the Sun sets, there is no more daylight and the light from the lamp has to run the solar engine by itself.

Reverse Movement

Up to now, your solar engine has only run in one direction. Now we'll find out how to make it run in reverse.

Experiment 7

› **You will need**: your solar model

Instructions

Run your model in bright sunlight. Watch the direction that the small sprocket wheel turns. Then remove both electric cables from either the engine or the battery holder and plug them back in, but this time in the opposite sides. Hold your model in bright light again. What happens?

Results

After you reverse the cables, the wheel turns in the opposite direction. That is because electrical current always flows in just one direction. The engine rotates in the same direction that the current flows. The direction of flow can be changed by reversing the current supply — which is exactly what you do when you switch the cables. It makes no difference whether you switch them at the battery holder or the engine. The direction of current flow is determined by the solar cell. Remember what you read on page 7 about how solar cells work?

Switching the Solar Module

If it is the solar module that determines the direction of the flow of current, it should be possible to change the rotation direction of the engine by mounting the module the other way around.

Experiment 8

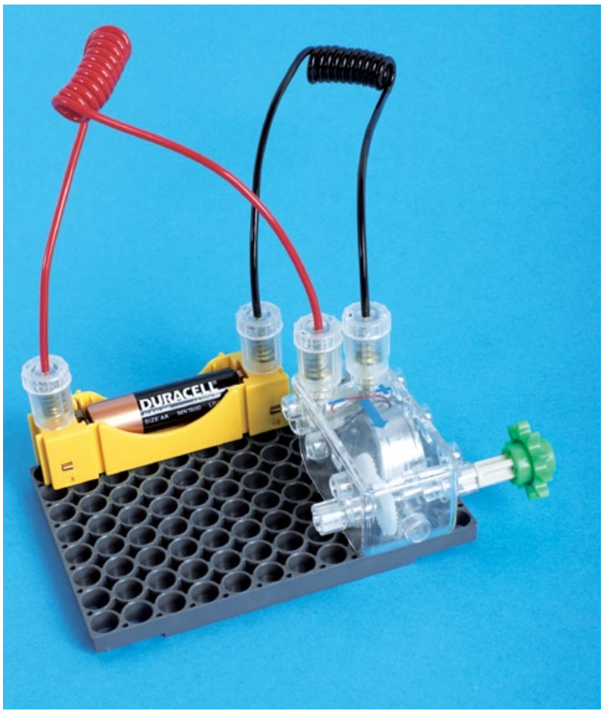
› **You will need**: your solar model

Instructions

Run your model in bright sunlight. Note the direction of rotation of the sprocket wheel. Mount the solar module the other way around on the battery holder. What happens?

Results

When the module is turned around, the electricity flows in the other direction, which makes the engine run in the opposite direction as well. If you want to reverse the direction of movement of a model — whether to make a vehicle go forwards and backwards or to wind a cord up or down — it is easiest just to mount the module the other way around.



If the Sun isn't shining, you can also run your engine with a battery. This should only be done when absolutely necessary, though, and not as a rule.

Battery Power

The Sun only shines in the day — so it can't run your engine at night. That is why the engine also runs on a battery, so you can still perform your experiments.

Experiment 9

› **You will need**: your solar model, a 1.5-V AA battery

Instructions

Switch out your solar module for a 1.5-V AA battery. When you insert it, pay attention to the plus and minus signs. Watch what happens.

Results

The battery turns the motor and the wheel just as well as the solar module. Of course, the engine doesn't stop when you change the lighting, as it does with the solar module. If you want to shut off the engine, you have two options: either remove the battery from the holder or pull out one of the cables. It makes no difference whether you remove the cable from the engine or the battery holder.

You can also change the rotation direction of the engine in exactly the same manner as when it is running by solar power — the engine runs in the opposite direction when you reverse the orientation of the battery. Or, of course, you can still switch the cables at the battery holder or the engine.

Batteries cost money, get used up quickly and pollute the environment. The Sun's light, on the other hand, is available in large quantities for free, and it doesn't pollute the environment. Therefore, whenever light conditions permit, you should avoid using battery power. It is only a solution of last resort. If you do use batteries, it is best to use rechargeable ones, since they are more environmentally friendly. Large solar facilities, in fact, charge rechargeable batteries during the day so that electricity is also available at night.

The battery holder with battery

Your First Solar Vehicle

Parts List	
4 x long frames **2**	1 x short frame **3**
1 x short rod **4**	2 x medium gear wheels **7**
3 x small gear wheels **8**	1 x small sprocket wheel **9**
1 x medium sprocket **10**	2 x long axle shafts **16**
4 x tire wheels **15**	1 x black cable **20**
1 x engine shaft **19**	1 x battery holder **22**
1 x red cable **21**	1 x solar engine **24**
1 x solar module **23**	8 x anchor pins **26**
2 x shaft plugs **25**	

The solar tractor works with a gear drive. The small gear wheel on the engine turns the rear axle.

Solar Tractor

Your new solar engine works particularly well for powering vehicles. The first one we will build is a tractor.

Experiment 10

› **You will need**: the parts from the parts list, artificial Sun

Instructions

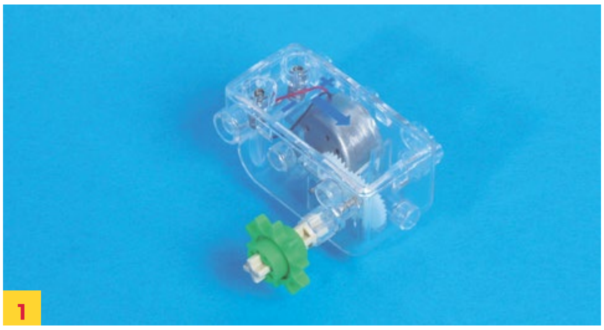
Carefully study the tractor assembly instructions on the following pages and follow them to assemble your model. You will need all the parts in the list on the left.

Be careful to connect the parts exactly as shown in the pictures. It is particularly important to count the holes in the rods and frames so you insert the anchor pins in exactly the right ones. For the tractor to run well, all the wheels have to be able to turn easily. After assembling the axles and wheels, make sure that everything has enough play (see page 5).

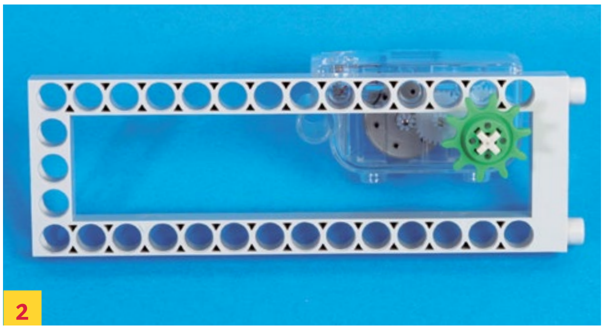
When you have finished assembling the tractor, hold it under an artificial Sun, e.g. a desk lamp. Carefully observe how the power of the engine is transmitted to the other parts of your model.

Results

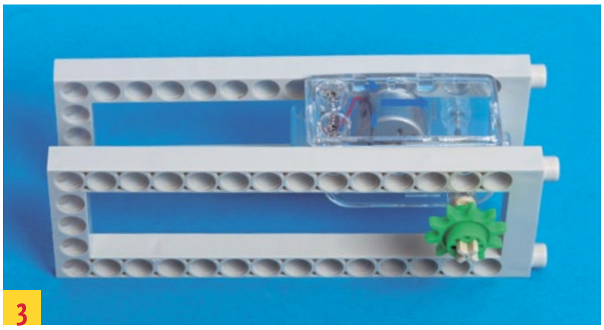
The small sprocket wheel mounted on the small engine shaft drives the medium sprocket wheel on the rear axle of the tractor. That turns the rear axle and the large wheels attached to it. So the power of the engine is transmitted through two sprocket wheels. The teeth of both wheels are constructed so that they mesh with each other precisely.



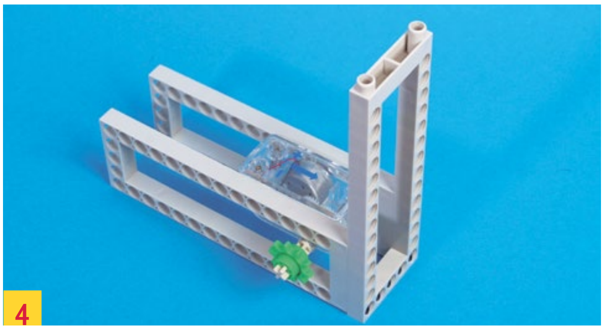
1. Insert the engine shaft (19) into the solar engine (24). The short end of the shaft goes in the engine block. Then mount a small sprocket wheel (9) on the shaft.



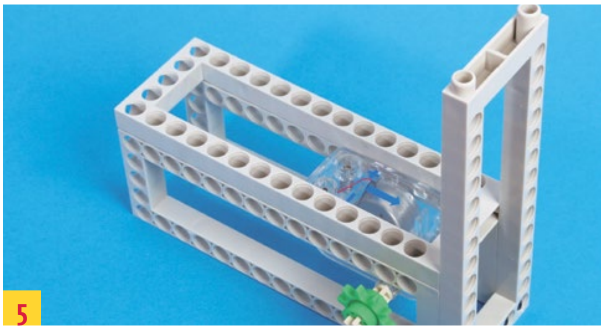
2. The solar engine is mounted on a long frame (2). The engine's anchor pins go in the second, fourth, and sixth holes from the right.



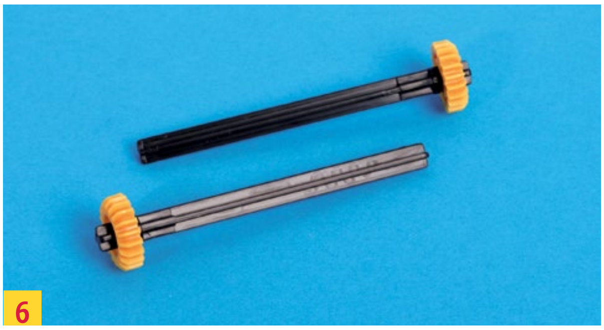
3. From the other side, attach a second long frame (2) to the engine. Press both frames together firmly, so the assembly is stable.



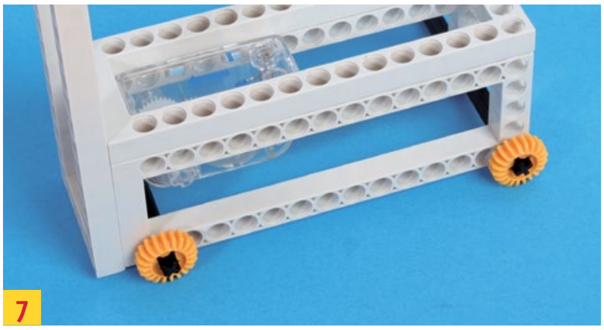
4. The anchor pins on the long frames serve to attach another long frame (2), which you mount vertically.



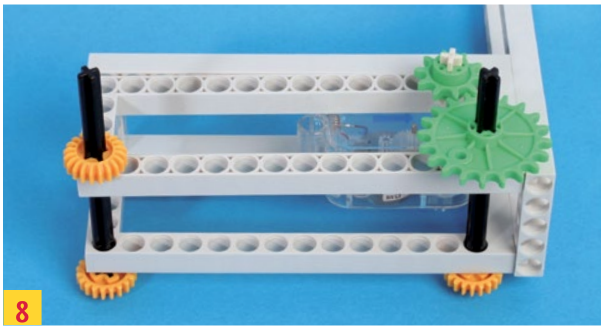
5. Another long frame serves to provide additional strength. This one is set right on top of the two long frames with the engine.



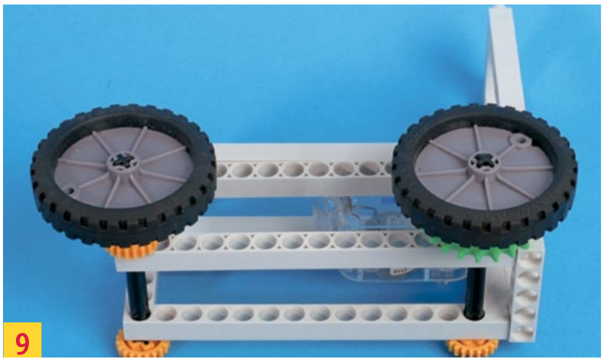
6. Now we'll prepare the axles. Take two long axle shafts (16) and insert a small gear wheel (8) over the short end of each one.



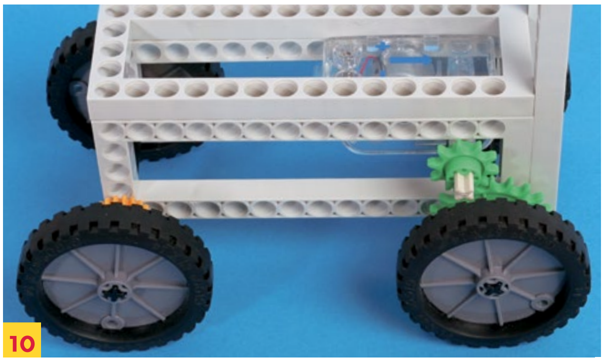
7. Push the two axle shafts through the outer holes of the frames at the bottom. The gear wheels should be on the side away from the engine shaft.



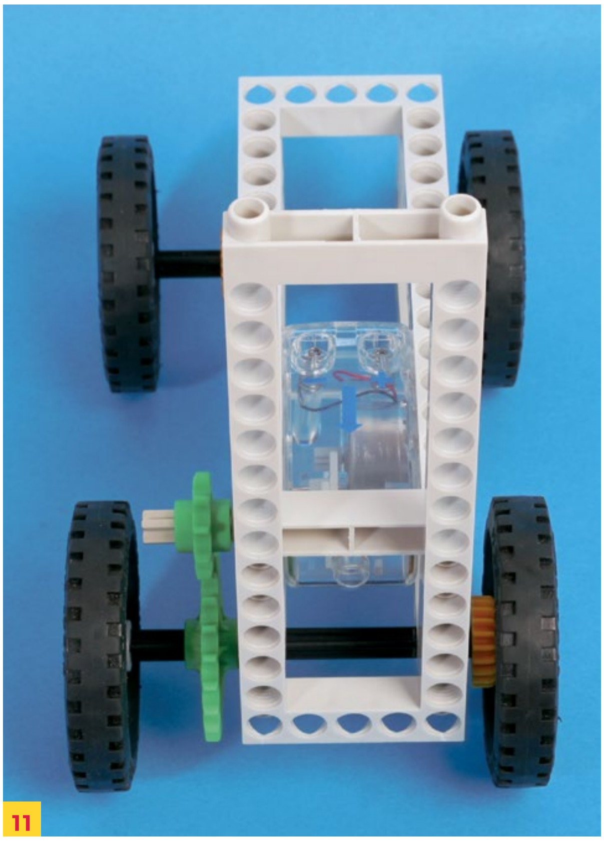
8. Insert a small gear wheel (8) and a medium sprocket wheel (10) on the other side. The teeth of the sprocket wheel should mesh with those of the wheel on the engine.



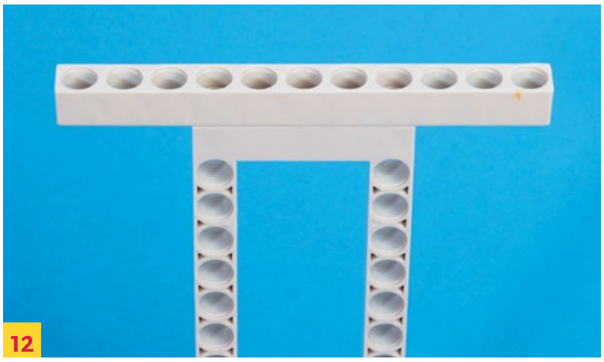
9. Now mount the first two tire wheels (15) on the axle shafts. The wheels should sit flush with the end of the axle.



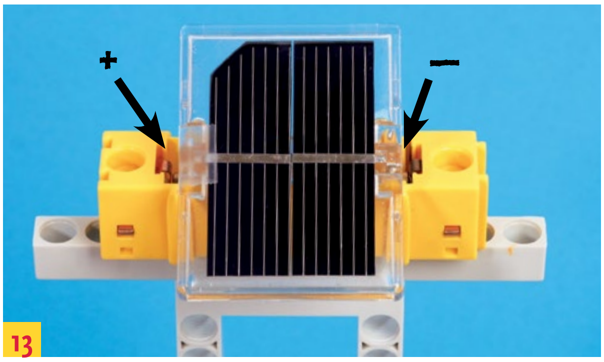
10. Now mount one tire wheel (15) on each of the axle shafts on the other side of the model.



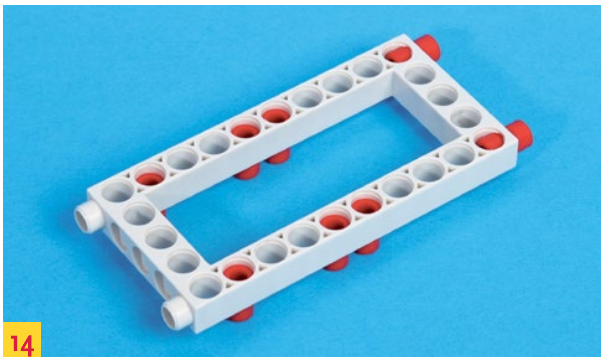
11. Align the wheels and axles as shown in the picture, and be sure that the axles turn easily.



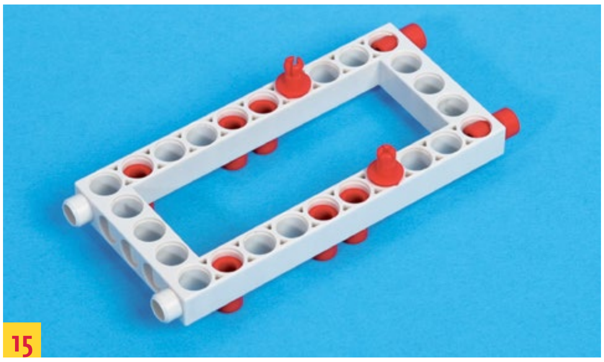
12. Mount a short rod (4) on the top of the long frame sticking up straight in the rear.



13. The battery holder (22) with the solar module (23) goes on this short rod. Pay attention to the "+/-" signs.



14. Take a short frame (3) and insert 8 anchor pins (26) into it as shown in the picture.



15. At the front, your model will get two ornamental "headlights." Start by inserting two shaft plugs (25) into the frame.

Under the Artificial Sun

In the next experiments, we will find out how strong your engine is, and what kind of performance your solar module can deliver.

Experiment 11

› **You will need**: your model, artificial Sun, smooth, flat surface such as a table top

Instructions
Now place your tractor on a smooth, flat surface, such as the top of a desk. Hold an artificial Sun — e.g., a desk lamp — directly over the solar module. Watch what the vehicle does.

Results
As soon as enough light strikes the solar module, your tractor starts moving. When the tractor moves beyond the cone of light, it stops: The solar module isn't getting enough light anymore.

Driving in Reverse

If you attached the cables correctly, your vehicle moved forward. Now we'll make it go backward.

Experiment 12

› **You will need**: your model, artificial Sun, smooth, flat surface

Instructions
Remove the solar module from the battery holder and mount it the other way around, as shown in the pictures on the left half of page 12. Place the vehicle under the artificial Sun and let it move.

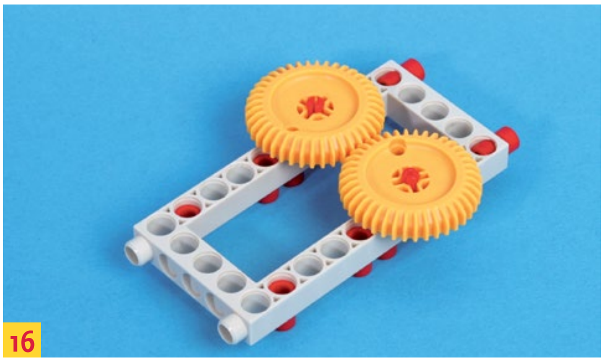
Results
When you turn the solar module, the direction of the flow of current is reversed as well. So now the tractor drives backward.

Experiment 13

› **You will need**: your model, artificial Sun, smooth, flat surface

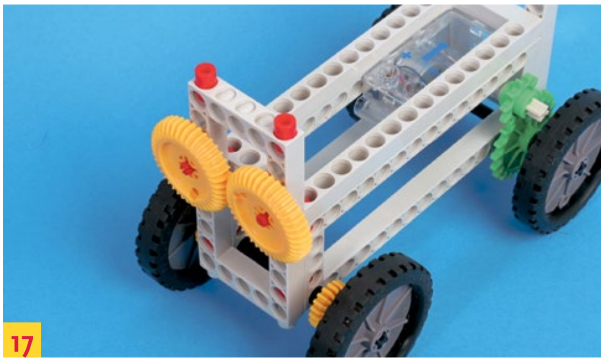
Instructions
Now switch the cables at the battery holder or the engine. What happens?

Results
Your tractor drives forward again. When the cables were switched, the direction of current flow was reversed yet again.



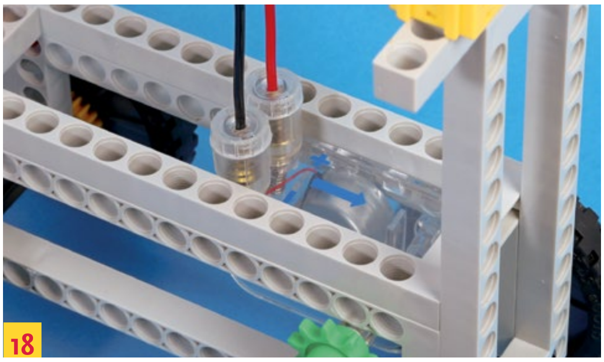
16

16. Next, attach the "headlights": Mount two medium gear wheels (7) on the shaft plugs.



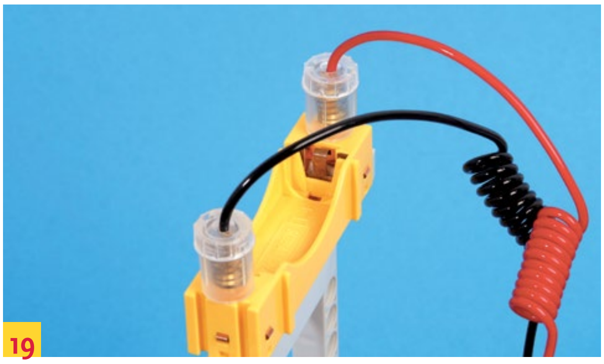
17

17. Now mount this small frame at the front of the model. The end with the red anchor pins goes on top.



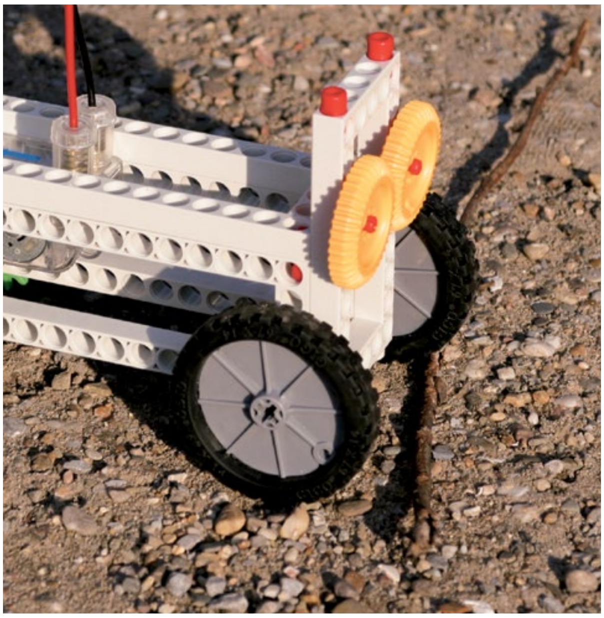
18

18. Now attach the cables to the engine. The red cable (21) attaches to the positive pole, the black one (20) to the negative pole.

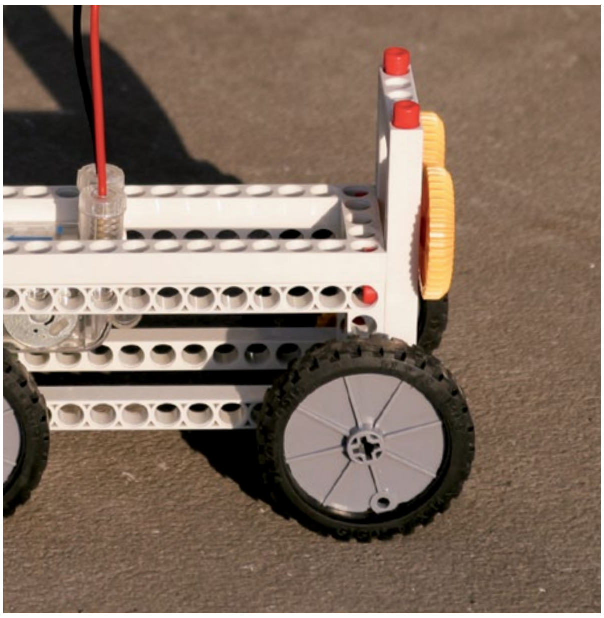


19

19. When you attach them to the battery holder, make sure that the red one goes to the positive side and the black one goes to the negative side.



On a bumpy surface, little rocks or twigs can create obstacles for your model. Unfortunately, its engine isn't powerful enough to overcome them.



On a smooth surface, your solar vehicle runs flawlessly. Of course, the Sun has to be shining brightly enough.

A Drive in the Sunshine

In the next experiments, we will see how your tractor drives in the sunlight.

Experiment 14

› **You will need**: your model, bright sunlight, the back side of a large 11 x 17-inch pad of drawing paper or other large, solid, smooth piece of cardboard

Instructions
Lay a pad of drawing paper with its back side up, or some other smooth, strong cardboard, in bright sunlight. Orient the module toward the Sun. Be sure that the cardboard is lying flat. Then let your solar tractor drive on it.

Results
As soon as enough sunlight hits the solar module, the engine starts to run, which turns the axles and the wheels. The power of the sunlight is enough to run your tractor on a smooth, even surface — your tractor is running on solar power.

A Drive on Bumpy Ground

Up to now, you have only run your vehicle on a smooth surface — the back side of the drawing pad. Now we'll see how it does on a bumpy surface.

Experiment 15

› **You will need**: bright sunlight, solar model, level but bumpy ground (e.g. a level gravel path or a lawn that isn't too steep)

Instructions
Let your solar tractor run in bright sunlight on a bumpy surface. Make sure that it isn't going uphill or downhill. How does it perform now?

Results
Your tractor either won't start correctly or won't move at all. As soon as the tires hit any little obstacle, you have to give the model a push to get it moving again. The engine isn't powerful enough to overcome these little obstacles. The solar cells simply produce too little electricity to drive the tractor over level but bumpy ground. The same goes for all of the model vehicles in this experiment kit. In order to get the models to run well on bumpy ground, you would need much larger and more powerful solar cells. But they would be very costly.

A Downhill Drive

You know from riding a bicycle that you have to use much less energy to go downhill. Does the same apply to your solar vehicle? You will find out in an experiment on an "inclined plane." An inclined plane is a firm, flat surface that can be used to make a downhill slope.

Experiment 16

› **You will need**: light, solar model, large drawing pad or other strong cardboard

Instructions
Let your solar tractor drive down the inclined plane. Use the back side of a drawing pad, lifting the end of

the drawing pad just a little. What happens when the tractor goes downhill?

Results
Your tractor runs easily downhill. If you watch carefully, you will see that it even goes a little faster than when you hold the cardboard level. On a downhill drive, the engine has to expend less energy. Can you use this effect to get your tractor to drive on a bumpy surface?

Experiment 17

› **You will need**: bright sunlight, solar model, bumpy ground that drops away (e.g. gravel path, paving stone with rough surface, or lawn)

Instructions
Run your solar model in bright sunlight down a slightly sloping, bumpy surface. How does its performance change?

Results
When it's going downhill, your solar vehicle moves along quite easily. The bumps in the ground no longer present any serious obstacles. The engine power is the same as when it drives over flat, bumpy terrain, but with the downward slope the engine doesn't have to expend as much energy to drive the tractor. Instead, it can use its power to move the tires over little obstacles.

An Uphill Drive

From riding a bicycle, you not only know that it's a lot easier to go downhill, but also that you need a lot more energy to go uphill. If it's too steep, you even have to get off and walk. The strength of your body is no longer enough to conquer the incline. Is it like that with your solar model too? We'll use the inclined plane to investigate that, too.

Experiment 18

› **You will need**: light, solar model, large drawing pad or other strong cardboard

Instructions
Have your tractor drive up an inclined plane. Use the back side of a drawing pad. During the drive, slowly lift the front end of the drawing pad. What happens when the solar tractor drives uphill?

Results
When your tractor drives uphill, it goes slower. And when the slope is too great, it won't move. The power of the engine is not enough to turn the wheels.

So the speed depends on the slope. Or, put differently: with a slope, the engine's force has to be applied not only to moving the tractor forward, but to moving it upward as well.

Driving with the Battery

So far, we have been running the tractor on solar energy. Now let's see whether its driving performance changes when we use the battery instead of the solar module.

Experiment 19

› **You will need**: solar model, battery, large drawing pad or other strong cardboard, flat and slightly sloping bumpy ground

Instructions
In your model, switch out the solar module for the battery. Make sure that the battery is fully charged. Carry out experiments 14 through 18 one more time and observe how the vehicle performs.

Results
The driving performance of your model hardly changes. The engine runs just as well with the energy of the solar module as it does with the energy of a 1.5-volt battery.

Your Engine's Performance

The engine and solar module in this experiment kit are not strong enough to make fast, powerful vehicles — like those remote-controlled cars that run on big rechargeable batteries. For that, you would need much larger and more expensive solar modules. But the photo cells are good enough to power a vehicle in bright sunshine on flat, even ground or down a bumpy slope.

Your engine is not without power, though. In the next experiments, we will find out what it is capable of.

Load and Speed

Conversion to a Transport Vehicle

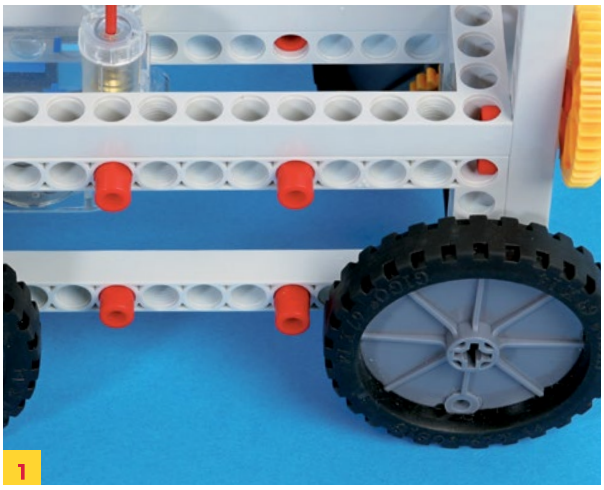
As you know from sports, force can be applied in many different ways — to lift weights, for example, or to run fast. It's the same with your solar engine. The two most important jobs that a vehicle engine does are to transport objects and to create speed.
In order to transport objects, your solar vehicle needs a cargo bed. For that, we will first have to rebuild your tractor a little.

Experiment 20

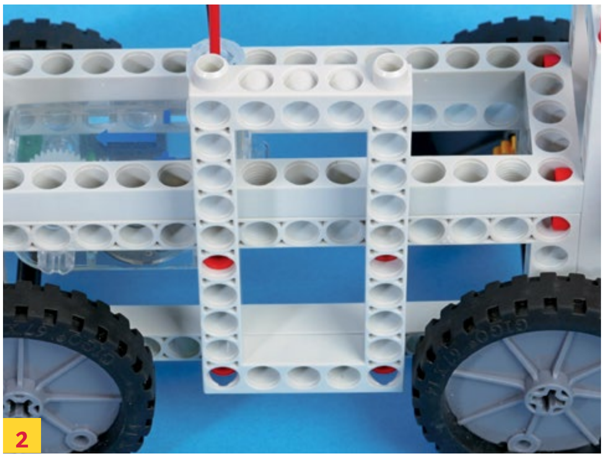
› **You will need**: solar tractor, 1 x base plate (1), 2 x short frame (3), 8 x anchor pins (26), bright sunlight, smooth and even surface

Instructions
Rebuild your tractor into a transport vehicle by adding on a large cargo bed as shown in the pictures on these two pages. Run your transport vehicle in bright sunshine on a smooth, even surface — for example, the back side of a large pad of drawing paper. What happens?

With just a few parts, you can convert your tractor into a transport vehicle. A base plate serves as the large cargo bed.



1. Insert four anchor pins (26) into each of the long side frames on both sides of the vehicle. Attach the pins to the upper and lower portions of the frames as shown in the picture.



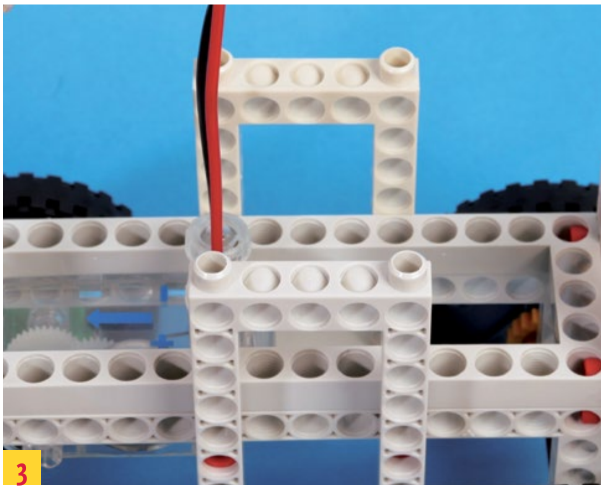
2. Now hang a short frame (3) on the four anchor pins on one side of the vehicle. The lower end of the short frame should align flush with the lower section of the long frame.

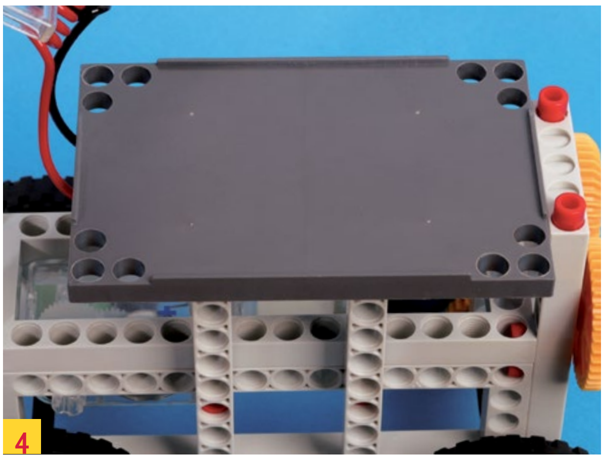
Results
The parts that you have assembled have only a modest weight to them. Simply converting the tractor to a transport vehicle should not have changed its driving performance yet.

Adding a Load

Now let's find out how much weight your first solar vehicle can handle. We can only determine how strong your solar transporter is by loading weights onto its cargo bed. The technical term is "payload."

Experiment 21
› **You will need**: light, solar transporter, level ground, blocks or small stones as payload


3. Hang a short frame (3) on the four anchor pins on the other side as well. The two short frames should be positioned exactly across from each other at the same height.


4. Now attach a base plate (1) to the top. It should extend right up to the short vertical frame at the front. On each side, the base plate should be positioned over a row of holes.

Instructions
Collect a variety of things that you can use to load your vehicle, such as wooden blocks or small rocks. Start with light objects. Check to see if your solar transporter can carry the load. Keep increasing the weight. What happens?

Results
Your solar transporter can easily carry light objects. The more weight you add to the platform, the harder it is for the vehicle. When you load on too much weight, the engine can't carry the payload — your vehicle stays put.

Maximum Payload

Of course, it would be interesting to know exactly what the maximum payload is for your transport vehicle. To determine that, you will need a kitchen scale.

Experiment 22
› **You will need**: light, solar transporter, level ground, blocks or small stones as payload, kitchen scale

Instructions
Find out what the maximum weight is that your solar car can carry and how much weight will overburden it. To do that, weigh the payload with your kitchen scale before loading it onto the cargo bed. Keep increasing the weight of the load until the engine isn't strong enough to move the vehicle. Write down your findings.

Results
Your model is pretty strong. In bright sunlight and on an even surface, it can pull up to 500 grams (about 1 lb.) of weight.

Transporting a Load Uphill

When you were investigating the driving performance of your tractor, you learned about the considerable influence that inclines and declines can have. In the next experiments, we will determine whether slopes can also have an influence on payload.

Experiment 23
› **You will need**: light, solar transporter, large drawing pad, blocks or small rocks as payload

Instructions
Have your model drive up a slightly inclined plane. Vary the payload and observe what happens.

Results

Your solar transporter can't carry as big a payload uphill as it can on level ground. Since it is going uphill, it not only has to move the weight in the driving direction, but also upward. So the slope has a considerable influence on its maximum payload.

Experiment 24

› **You will need**: light, solar transporter, large drawing pad, blocks or small rocks as payload

Instructions

Now have your model drive down a slightly downhill slope. Try changing the payload and see what happens.

Results

Going downhill, your solar transporter can carry an even heavier payload than when it drives on level ground.

Weight and Speed

In the next experiment, we will investigate the effect that weight has on the vehicle's speed. Speed is an indication of how much time an object — a car, person, or even a rolling ball — takes to cover a certain distance. If you want to determine speed, you therefore have to know the precise values of two things: the distance covered and the time. If, for example, a car drives 50 kilometers per hour (km/h), that means it drives a distance of 50 km in exactly one hour. If we want to determine the precise speed of your solar car, we will need a watch to measure time and a measuring tape to measure distance.

Your solar transporter can't drive as quickly with a heavy payload as without one. The engine has to expend its force carrying the load.

Experiment 25

› **You will need**: light, solar vehicle, a long measuring tape, a stopwatch (you can also use a regular watch if it has a second hand), paper and pen, a firm, flat surface (for example, an asphalt sidewalk), bright sunlight

Instructions

Mark off a distance of 1 m on the ground. Be sure that the ground is flat and that your car won't be driving uphill or downhill. With a stopwatch, measure the amount of time that your model takes to cover the distance of 1 m when it isn't carrying a payload. Note down the number. Repeat the experiment with various amounts of payload and compare the time values.

Results

The more payload you add to the cargo bed, the slower your vehicle becomes. So there is a direct relationship between weight and speed. You know this relationship from your everyday life: You can walk a lot faster when you aren't carrying anything. The more weight you carry, the less power is available to produce speed. It's exactly the same with engines: their power can either be applied to transporting a payload or to driving fast.

The power of a vehicle's engine is indicated in kilowatts (kw). Truck engines often produce as many kw as the engine of a Formula One race car. Of course, they are built quite differently. With trucks, the power of the engine is used to transport as large a payload as possible. With race cars, on the other hand, the most important thing is to drive as fast as possible. As a result, they can only carry a small payload.

With most of the cars you see on the street, the power of the engine is geared in a variable way. This allows them to carry a relatively large payload or climb a steep hill in one gear, and drive very fast in another gear.

The Purpose of Chains

Drive Chains

Your solar transporter is moved by a gear drive. In the next experiment, we will take a look at another kind of technology used for transferring the force of the engine, namely a chain drive.

Experiment 26

› **You will need**: solar transporter, 53 chain links (29), medium-sized sprocket wheel (10)

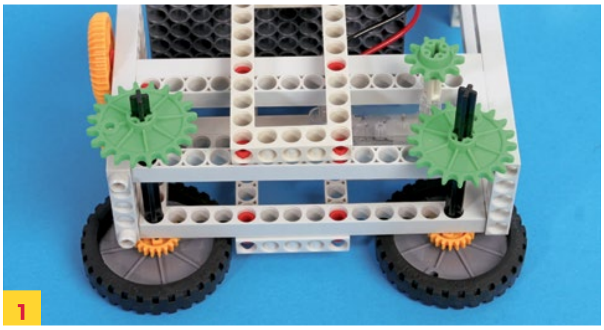
Instructions

Rebuild the solar transporter exactly as shown in the pictures on this page. When you connect the chain links, listen for two clicks as each link is attached to the next one. The links have two different sides: one is smooth, the other a little uneven. Connect the links so that the smooth side is on the outside. Before closing the chain, wrap it around the sprocket wheels. Joining the links can be difficult, and will require a little patience. All of your chain links are black. In the illustrations, some of the links are colored so that you can easily tell them apart from the other things in the photos.

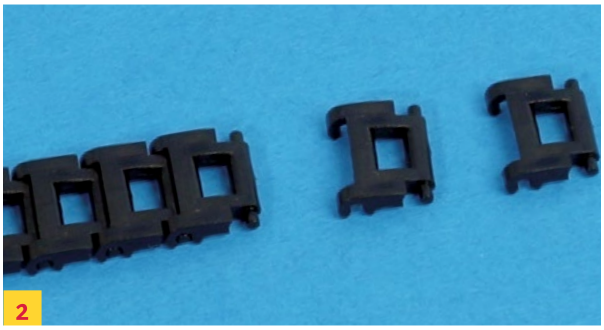
After assembly, take your model for a drive in bright sunshine. Pay attention to the way the engine's force is transferred through the chain.

Results

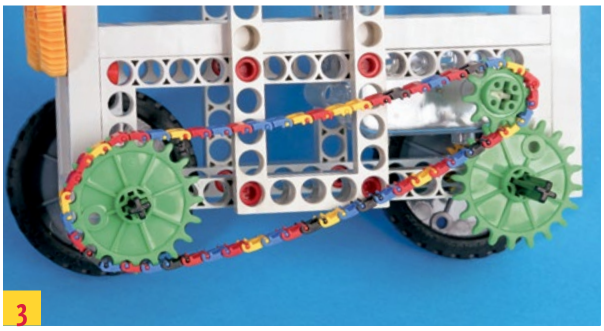
You are already familiar with the principle of the chain drive from your bicycle, which also transfers force from your pedals to the rear wheel by way of a chain. A chain drive is more complex than a gear drive — you need more parts and the mounting process is a little more difficult. So what is the advantage of the chain drive? The answer is simple: with a chain, the force can be transferred over a greater distance. With a gear drive, both gear wheels have to be placed right next to each other, whereas with a chain drive they can be mounted far apart.



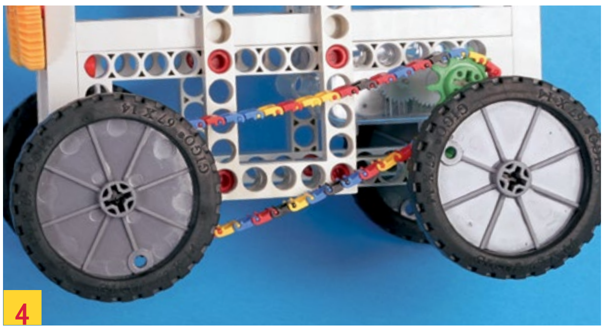
1. Remove the wheels from the side with the engine. Then push the small sprocket wheel as far as possible toward the end of the engine shaft. Place a medium-sized sprocket wheel (10) on the front axle.



2. Assemble a chain from 53 chain links (29). Spread it out with the smooth side up. Each chain link has to snap into place twice when you connect it to the next one.



3. Wrap the chain around the small sprocket wheel on the engine shaft and the medium sprocket wheel on the front axle. The chain should not be too tight or too loose.



4. Now mount the two wheels again. Check that the chain drive moves easily and the vehicle runs smoothly.

Too Tight or Too Loose

The chain drive works well because the chain is just the right length. But what happens when the chain is too tight?

Experiment 27

› **You will need**: solar transporter

Instructions
Remove one chain link. What happens?

Results
The chain pulls with difficulty, and even bends the axles a little. When that happens, the axles lose their play and can't turn easily. The engine's power is no longer enough to move the vehicle.
And what about the opposite? What effect does a chain have if it's too long?

Experiment 28

› **You will need**: solar transporter, at least five extra chain links (29)

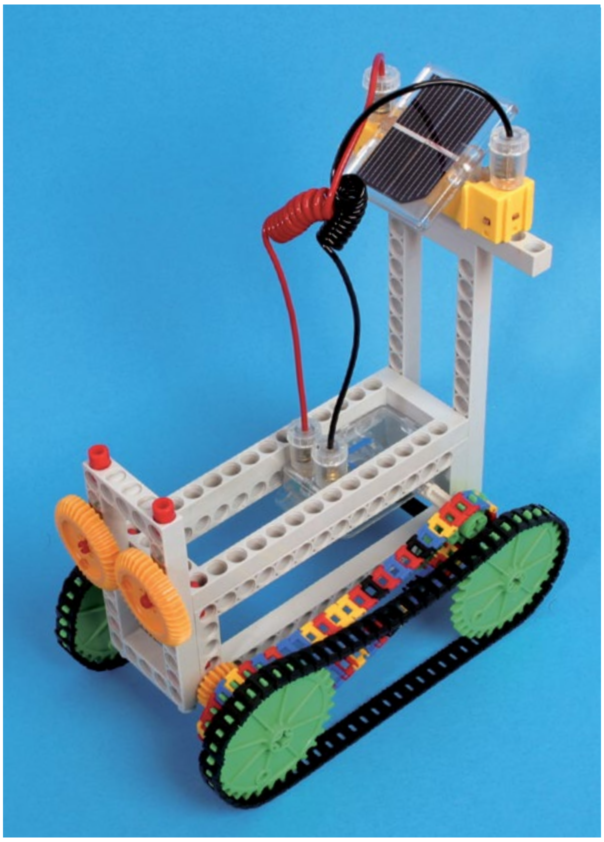
Instructions
Lengthen the chain by five links to 58. What happens now?

Results
The engine does run, and the chain drive works, but the chain flops around. There is a risk that it might get tangled up and twisted, and jump off the sprocket wheels. Then, your model would certainly not work well any longer.
So when you assemble your models, be sure that the chain is neither too tight nor too loose. That will ensure that they will run well.

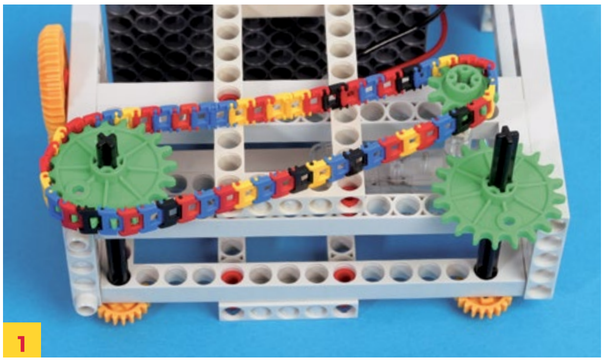
Caterpillar Tracks

Chains can be used for other things besides drive chains. With many kinds of vehicles, they take the place of regular wheels. Examples of this are caterpillar tractors, dredgers, or some military vehicles.

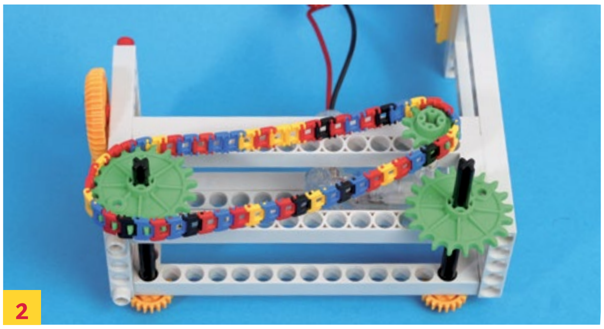
Chains that are used instead of wheels to move a vehicle across the ground are sometimes called caterpillar tracks. We will try switching out the wheels for caterpillar tracks and then compare the performance of the tracks with that of the wheels.



To equip your vehicle with caterpillar tracks, remove the cargo bed and switch out the tires for large sprocket wheels.



1. First, remove the four wheels. The tires will be replaced by sprocket wheels and caterpillar tracks.



2. Then dismantle the cargo bed, removing the base plate and the two short frames supporting it. Also pull out the eight anchor pins from the large frames.

Experiment 29

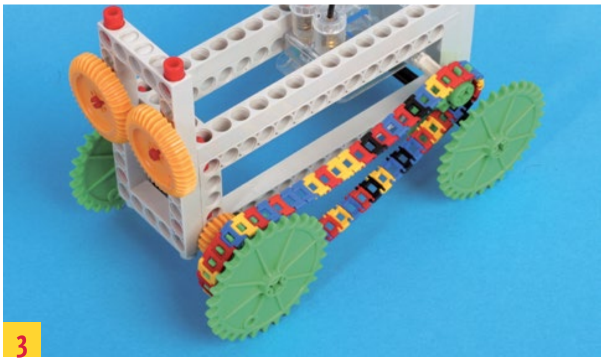
› **You will need**: solar transporter, 140 more chain links (29), four large sprocket wheels (11)

Instructions

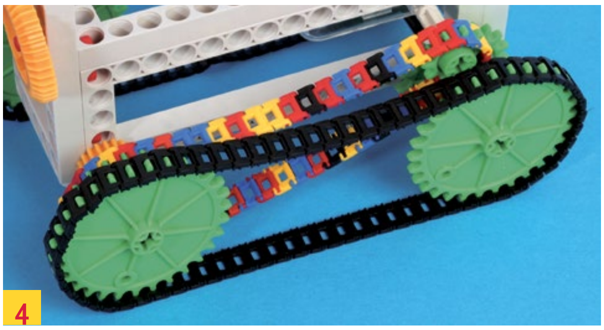
Convert your solar transporter into a caterpillar track vehicle, as shown in the pictures on these two pages. You will just need chain links (29) and the large sprocket wheels (11). You will have to remove the cargo bed, because otherwise one side of its support framework would interfere with the mounting of the caterpillar track. Then take your model for a drive in bright sunlight. What do you observe?

Results

At first glance, your caterpillar track vehicle drives just like a vehicle with wheels. Under normal driving conditions, there do not seem to be any significant differences between vehicles with caterpillar tracks and ones with wheels.



3. Now mount the four large sprocket wheels (11) on the ends of the axles. Be sure that both sprocket wheels are positioned exactly opposite each other, forming a straight line, on both sides of the vehicle.



4. Make two chains of 70 chain links (29) each. Wrap the chains around the large sprocket wheels. Check that everything moves smoothly and easily.

Driving Over an Obstacle

Caterpillar track vehicles show their strengths most clearly when driving over uneven terrain. We will see that in the next experiment.

Experiment 30

› **You will need**: your solar-powered caterpillar track vehicle, smooth, even, slightly down-sloping surface (for example, a tilted drawing pad), a long crayon or pencil

Instructions

Lay a long pencil or crayon across the path of your caterpillar track vehicle to serve as an obstacle. Let your vehicle get a running start and drive over the obstacle, while you hold the pencil or crayon in place. Pay close attention to what happens with the tracks as they roll over it.

Results

As they roll over the pencil, the links of the chain wrap themselves around the obstacle. So the chain adjusts itself to fit the uneven ground. That improves the traction of the entire vehicle — it doesn't slip the way a car with wheels would do.

Driving Over Uneven Terrain

Now let's see how your caterpillar track vehicle handles when driving over a lot of obstacles, as it would encounter if the terrain were uneven.

Experiment 31

› **You will need**: your solar-powered caterpillar track vehicle, several long crayons or pencils, bumpy, slightly down-sloping ground

Instructions

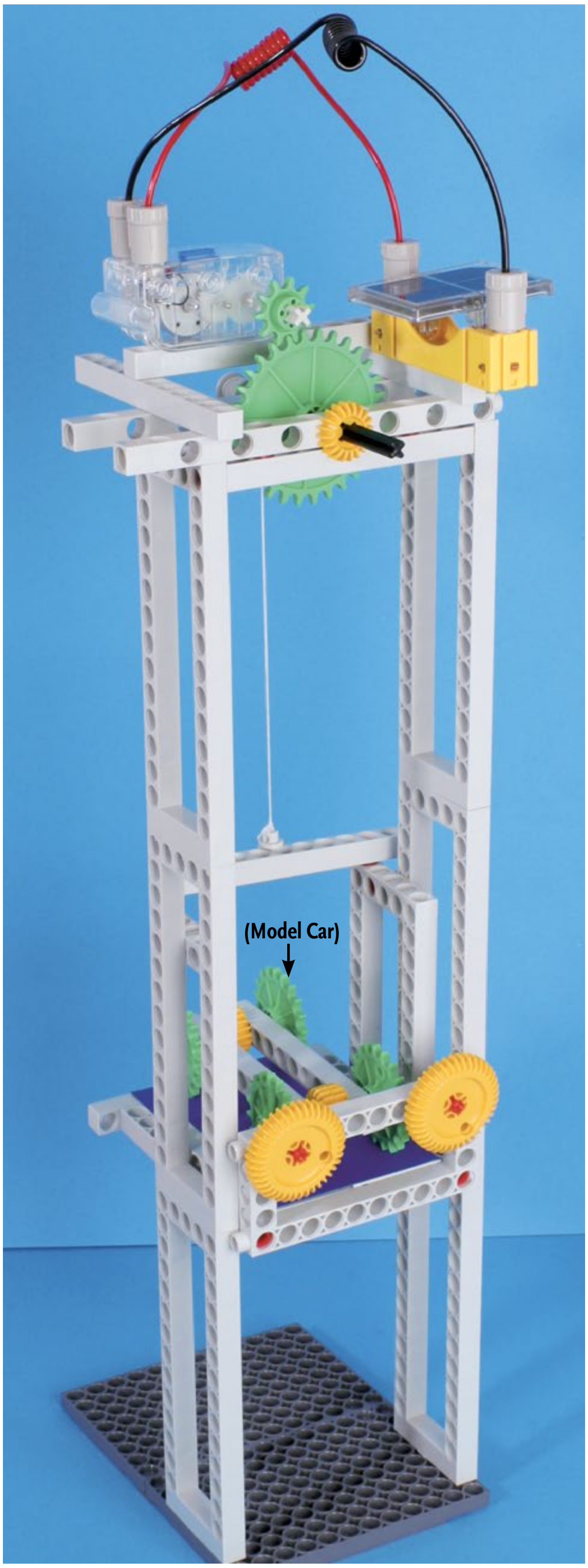
Now lay several pencils on the surface at an angle, so that when one track is on the ground the other will be rolling over a pencil. Hold the pencils in place. Observe how the tracks behave.

Results

The caterpillar tracks accommodate themselves very well to the uneven surface and compensate for bumps. If the obstacle is too large, however, the vehicle gets stuck.

The inventors of the caterpillar track copied this principle from nature: caterpillars also move similarly to these tracks. That is why the treads are called caterpillar tracks, and why the vehicles are known as caterpillar track vehicles.

Large Platform Elevator



The large platform lift consists of a support framework, lift system, and elevator cage.

Raising and Lowering with the Sun

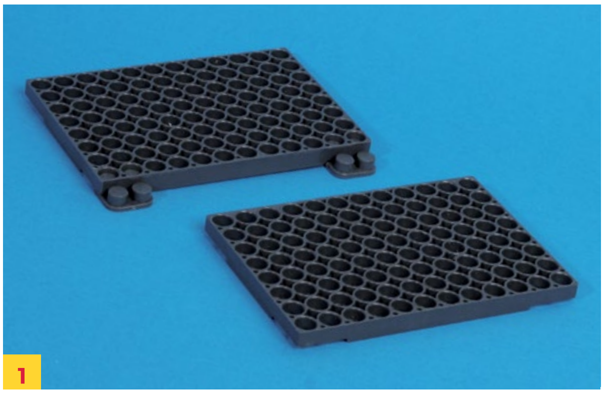
The solar engine can be used for other things besides driving a vehicle forward and backward. With this model, we will be applying solar energy to the raising and lowering of a platform. You will be using the crane hook, cord, and spool (28). You first have to attach the cord to the spool and hook (see the pictures on p. 2). The spool will be mounted directly on the engine shaft. When you are working with the crane hook, cord, and spool, be sure that the cord doesn't get tangled on the axles when it is wound up. Most important of all, be sure to stop the platform at the right time when you are raising or lowering it. The simplest way is to hold your hand over the solar module to prevent the cells from getting enough light.

Components of the Model

This large model, which is quite easy to build, actually consists of three parts. First, there is the tall support structure, assembled out of long and short frames. It is mounted securely on two base plates, which form its foundation. On top of the framework, there is the drive system. In addition to the engine, the solar module is mounted here. You will need a special support frame for both.

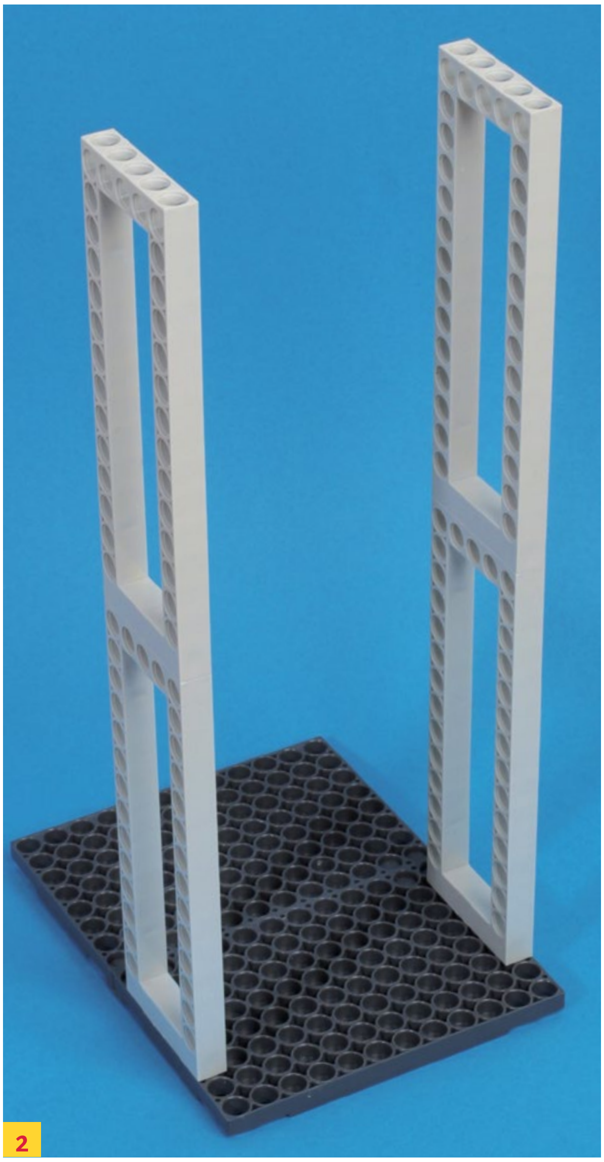
The third element is the elevator cage. This is constructed from frames and rods, with two medium gear wheels inserted into the front for decoration. The cage is suspended directly from the crane hook. In order for the load to sit securely in the cage, it is recommended that you cut out a piece of cardboard to fit on the bottom of the cage. Any sturdy cardboard will do, but colored cardboard looks particularly nice. If you like, you can also build a small car that you can move up and down with the model. Of course, you can also raise and lower other objects — e.g., toy cars, toy figures, or building blocks. Try to figure out how much weight your platform lift can handle.

Parts List	
2 x base plates **1**	6 x long frames **2**
6 x short frames **3**	5 x short rods **4**
2 x long rods **5**	2 x medium gear wheels **7**
1 x small gear wheel **8**	1 x small sprocket wheel **9**
1 x large sprocket wheel **11**	1 x long axle shaft **16**
1 x engine shaft **19**	1 x black cable **20**
1 x red cable **21**	1 x battery holder **22**
1 x solar module **23**	1 x solar engine **24**
2 x shaft plugs **25**	21 x anchor pins **26**
2 x attachment plates **27**	
1 x crane hook with spool and cord **28**	
1 piece of sturdy cardboard (8 x 11 cm)	



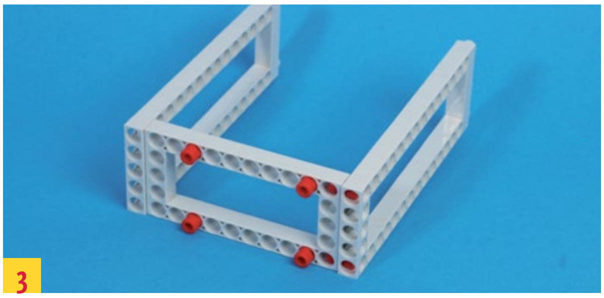
1

1. The foundation consists of two base plates (1). Combine these into a single surface with the attachment plates (27).



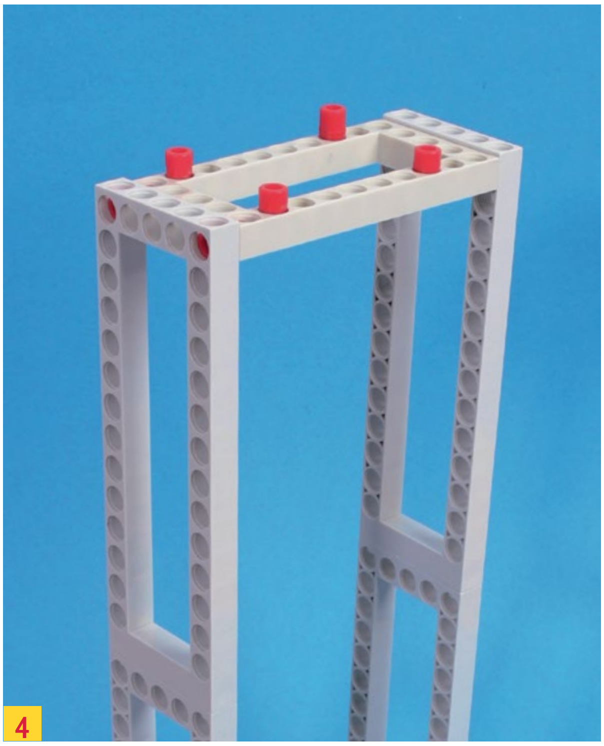
2

2. Next, connect two long frames (2) to make each of the two tall framework sections and mount these on the foundation. Pay attention to the holes the frames are mounted in.



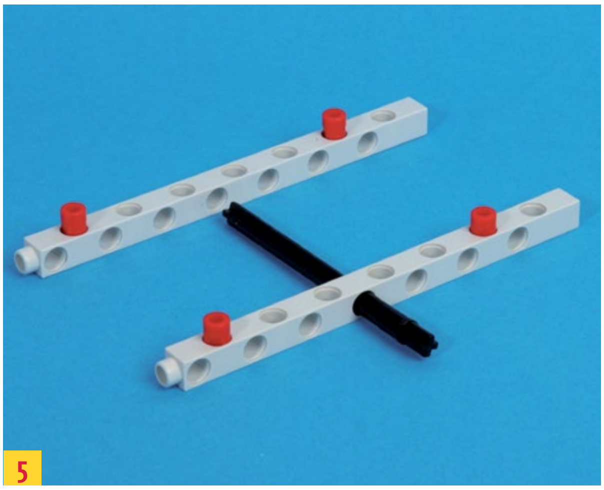
3

3. Attach two long frames (2) to one short frame (3) with two anchor pins (26). Insert four more anchor pins (26) into the short frame.

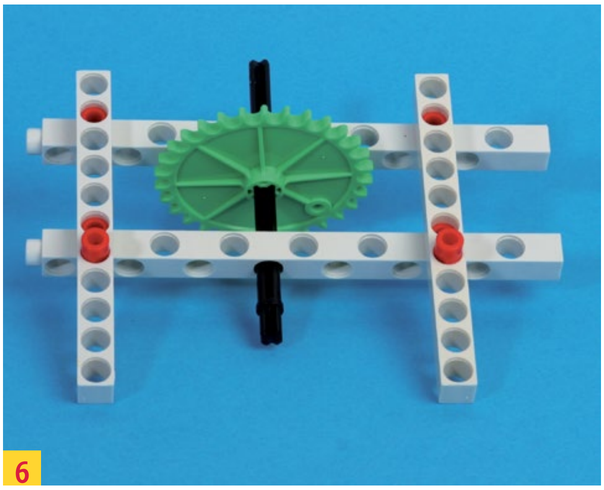


4

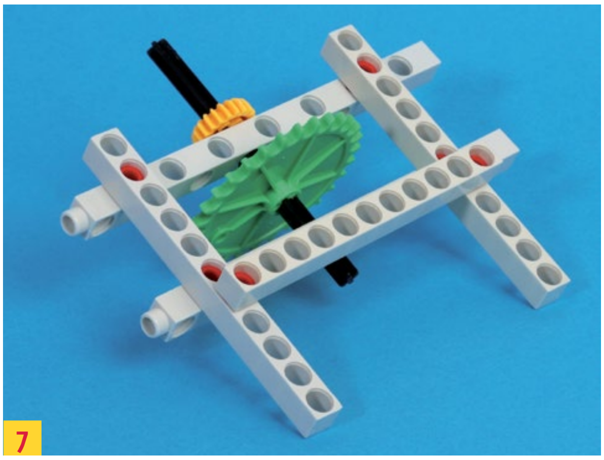
4. Now mount the "U," which you just constructed out of the two long frames and the short one, onto the two tall framework sections.



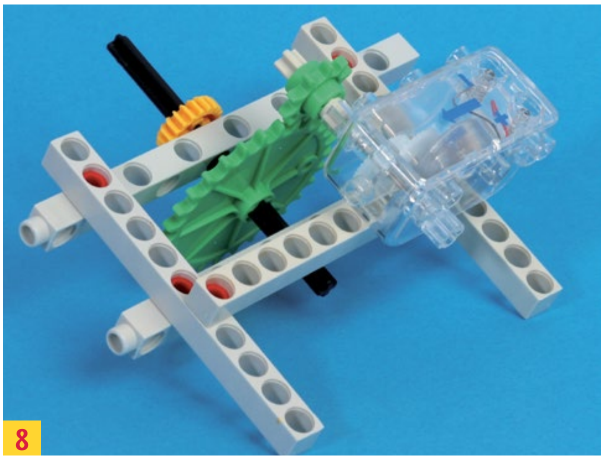
5. Now you will construct the lift system. Insert four anchor pins into two long rods (5) and insert a long axle shaft (16) through the center of one rod.



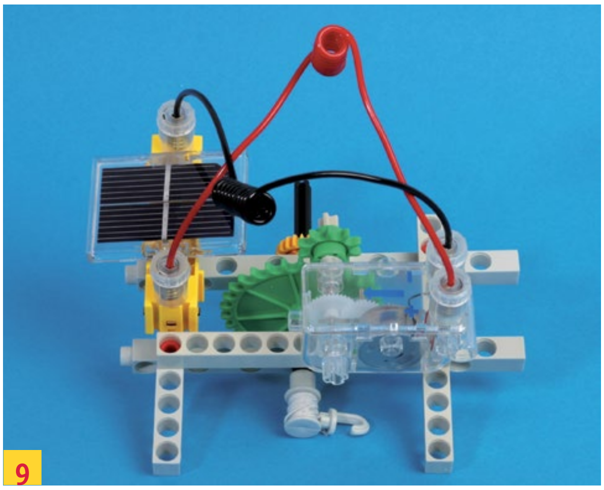
6. Push a sprocket wheel (11) onto the axle shaft and guide the shaft through the second long rod. Now attach two short rods (4) with two more anchor pins (26).



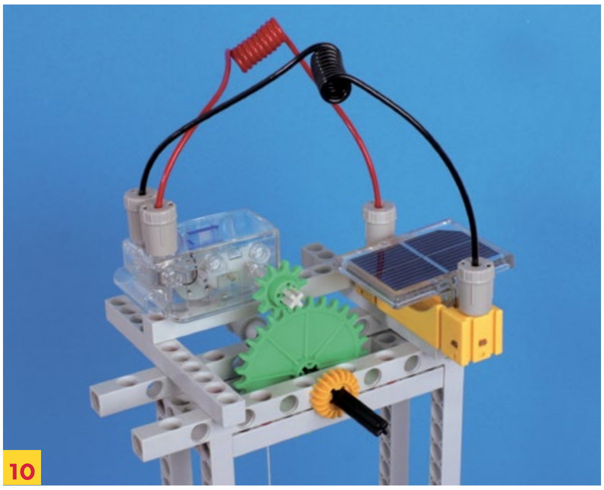
7. Next, attach another short rod (4) to the anchor pins on the short rods you just mounted. Also, push a small gear wheel (8) onto the shaft.



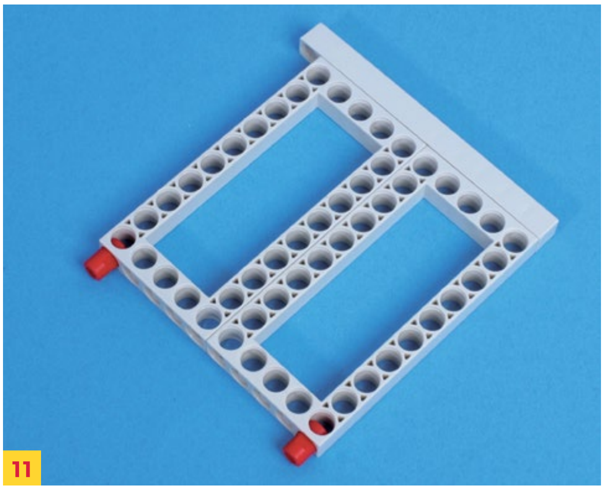
8. Insert the engine shaft (19) into the solar engine (24). Mount a small sprocket wheel (9) onto the shaft. Mount the engine so that the small sprocket wheel moves the large sprocket wheel.



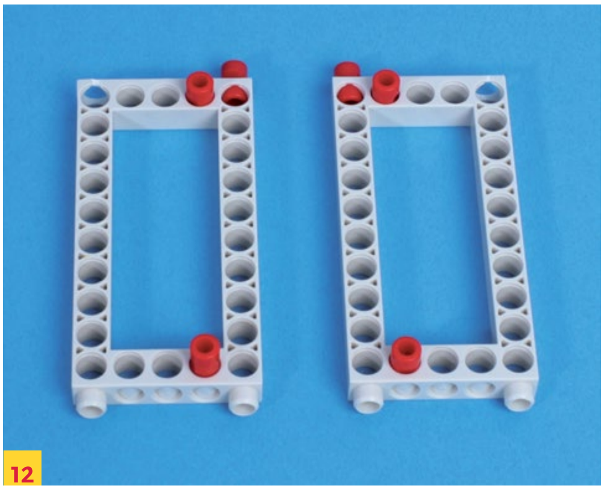
9. Now attach the battery holder (22) to the short rod on the left, mount the solar module (23), and attach both electricity cables (20/21). Then attach the crane spool (28).



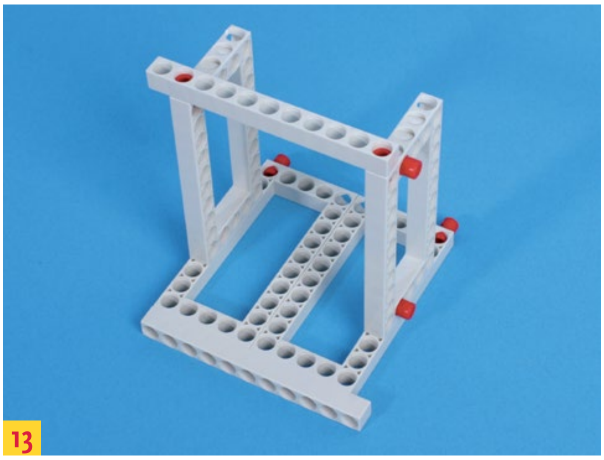
10. Next, mount the lift system onto the top of the support framework. The short rod on which the engine is mounted should sit flush with the front of the framework.



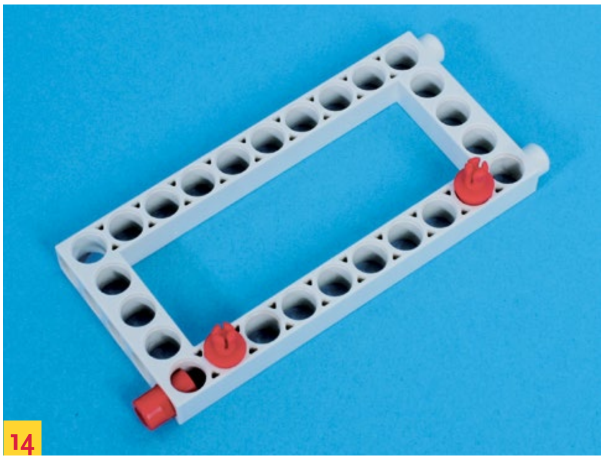
11. The floor of the cage is made of two short frames (3) connected by a short rod (4). You will need to use two anchor pins (26).



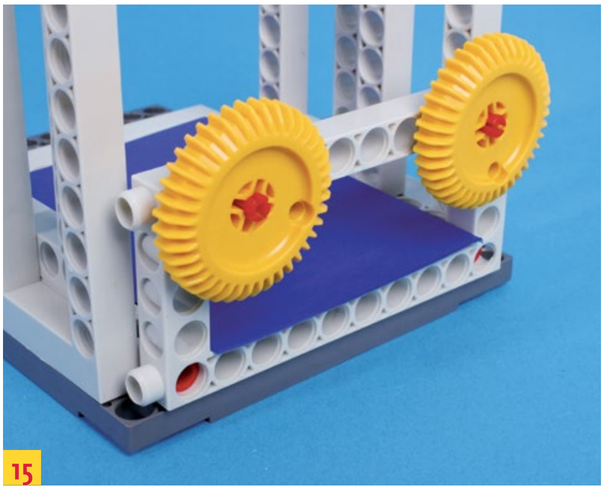
12. Each of the side walls consists of one short frame. Take two short frames (3) and insert six anchor pins (26) as shown in the picture.



13. Now insert the two short frames into the floor. A short rod (4) connects the frames at the top for stability.



14. One more short frame (3) prevents the cargo from falling out of the cage. Insert two shaft plugs (25) and one anchor pin (26) into the frame.



15. Place the cage in the elevator shaft and add the short frame from the last step. Two medium gear wheels (7) go on the shaft plugs. A piece of cardboard (8 x 11 cm) will strengthen the floor.

16. Finally, suspend the cage from the crane hook. The hook itself should hang from the center hole of the small rod lying across the top of the framework.

Your Solar Car

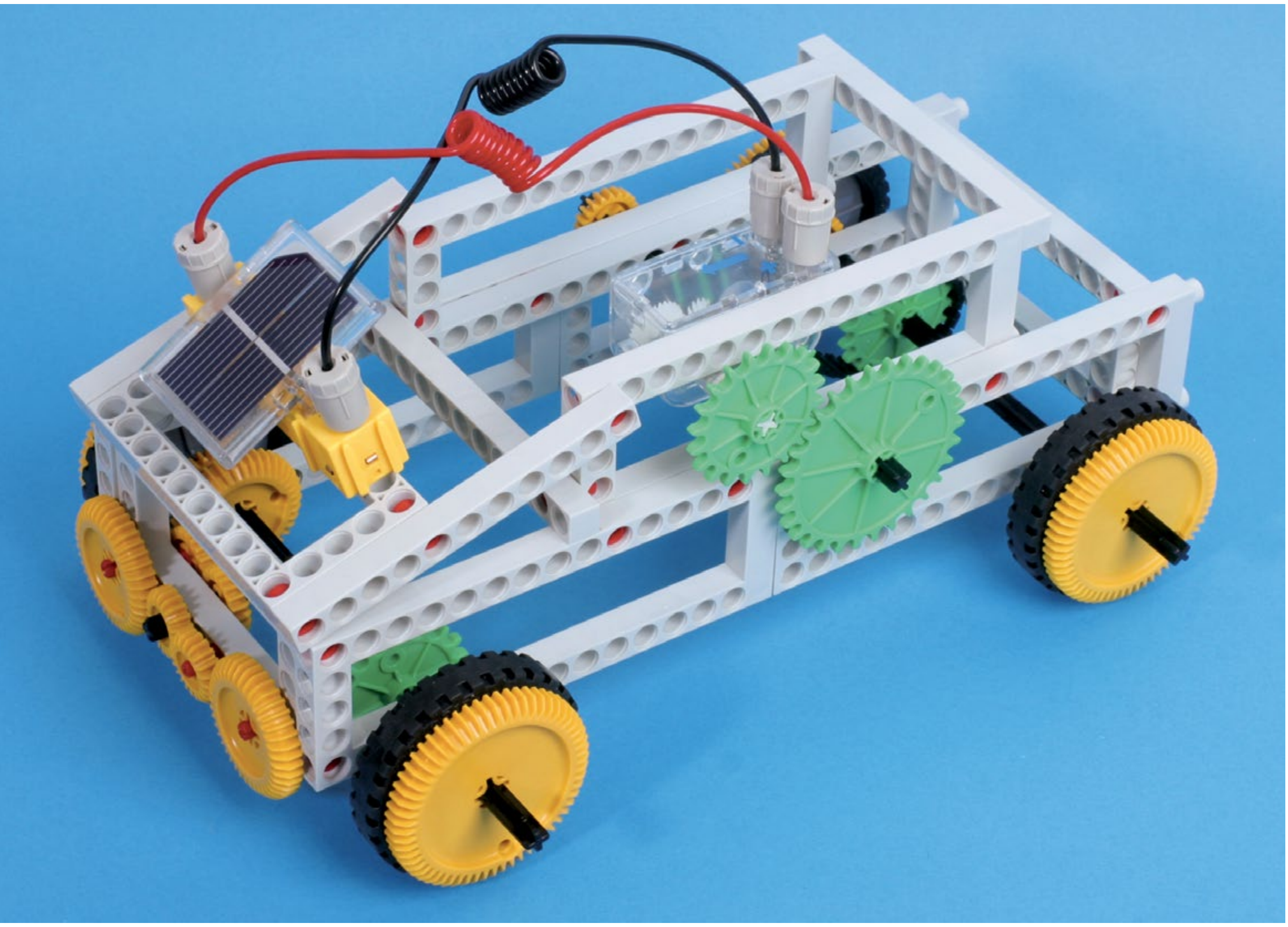
Solar Car Assembly

This solar car is actually pretty complicated to build. It is relatively wide, so the front and rear axles and the drive shaft have to be made out of two axle shafts joined together in order for them to be long enough.

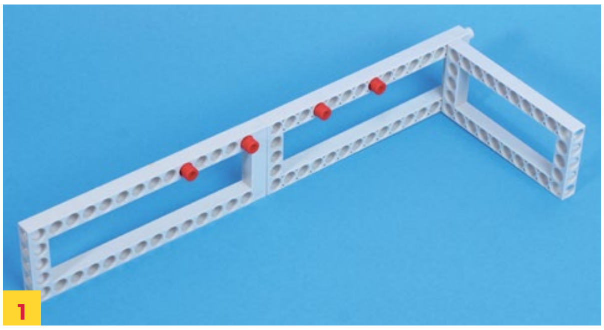
When lengthening the axle shafts, the important thing is to have the short ends of the shafts located on the inside. They are inserted into a small sprocket wheel, which holds them together. Be sure that the ends of both axle shafts are pushed equally far into the sprocket wheel, so the sprocket wheel is positioned exactly between the two shafts. Finally, check to make sure everything holds together solidly.

Parts List

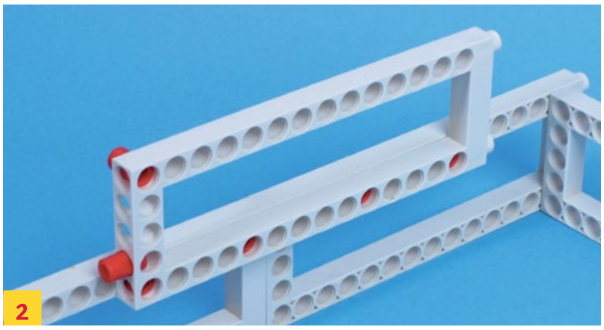
6 x long frames **2**	3 x short frames **3**
4 x short rods **4**	4 x large gear wheels **6**
3 x medium gear wheels **7**	9 x small gear wheels **8**
4 x small sprockets **9**	2 x medium sprockets **10**
1 x large sprocket **11**	4 x tire wheels **15**
5 x long axle shafts **16**	1 x medium axle shaft **17**
1 x short axle shaft **18**	1 x engine shaft **19**
1 x black cable **20**	1 x red cable **21**
1 x battery holder **22**	1 x solar module **23**
1 x solar engine **24**	4 x shaft plugs **25**
18 x anchor pins **26**	43 x chain links **29**



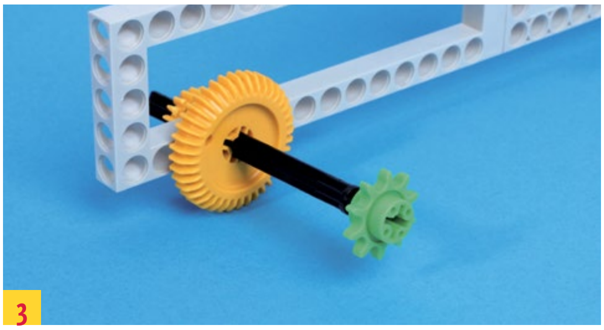
Your solar car operates with a combination gear and chain drive. The engine turns a drive shaft by way of the two outer sprocket wheels, from which the force is transferred to the rear axle by way of a chain.



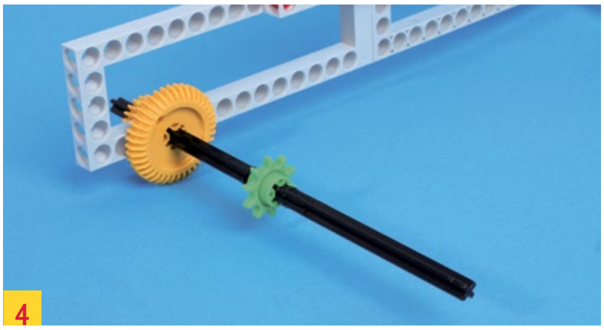
1. Two long frames (2) connected together serve as the side sections. Then insert four anchor pins (26) into the frames and attach a short frame (3).



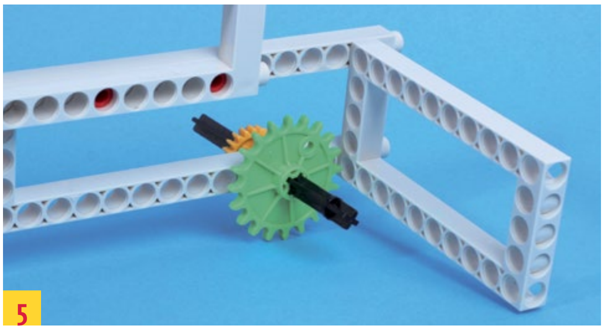
2. Now mount another long frame (2) on the anchor pins in your large side section. Insert two more anchor pins (26) into this frame.



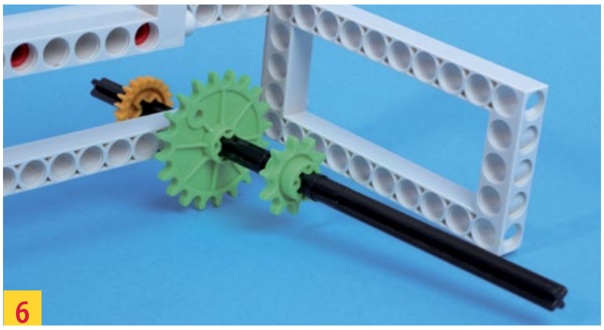
3. A long axle shaft (16) goes into the fourth hole of the frame. Place a small gear wheel (8) onto one side and a medium gear wheel (7) onto the other side. Then, put a small sprocket wheel (9) onto the long end.



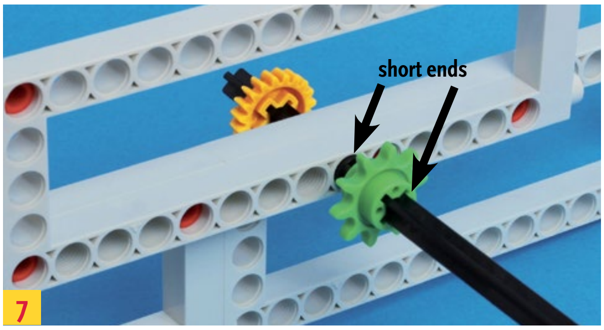
4. The axle is lengthened with another long axle shaft (16). The axle shaft's short end goes into the small sprocket wheel.



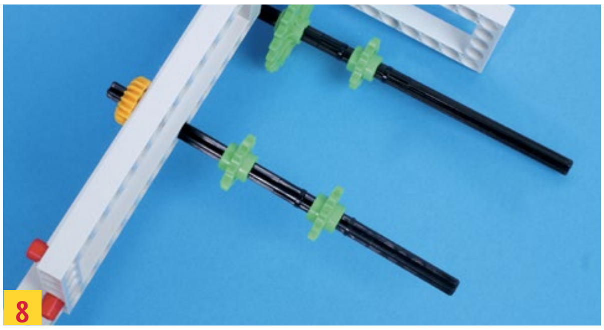
5. For the rear axle, insert a long axle shaft (16) into the fourth hole from the right. It is secured with a small gear (8) and a medium sprocket wheel (10).



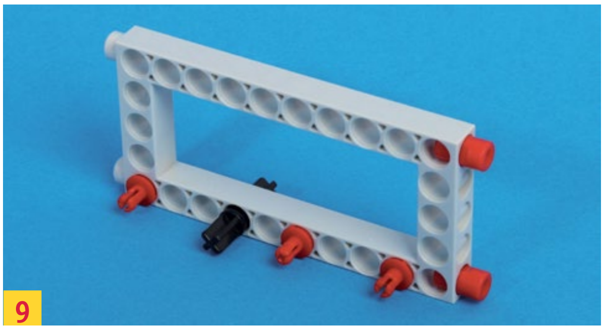
6. You will have to lengthen the rear axle as well. Slide on a small sprocket wheel (9) and then insert a long axle shaft (16).



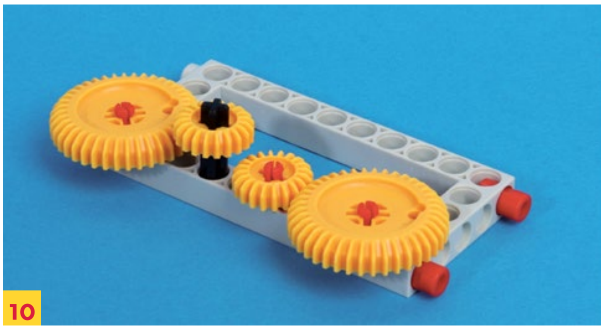
7. Now, mount the drive shaft. It is secured to the frame by a small gear wheel (8) and a small sprocket wheel (9).



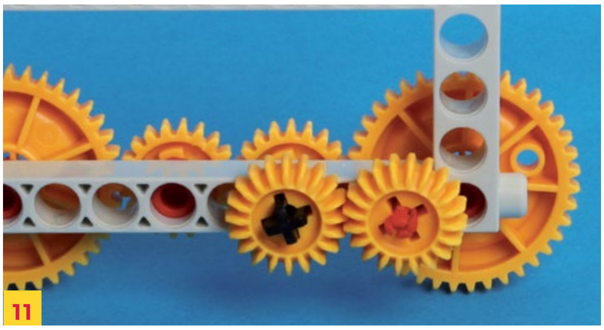
8. The drive shaft has to be lengthened too, although just with a medium axle shaft (17). The two shafts are held together with a small sprocket wheel (9).



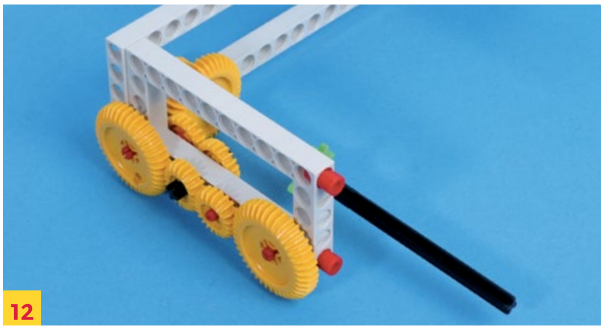
9. The grill is made of a short frame (3) into which you stick two anchor pins (26), one short axle shaft (18), and three shaft plugs (25).



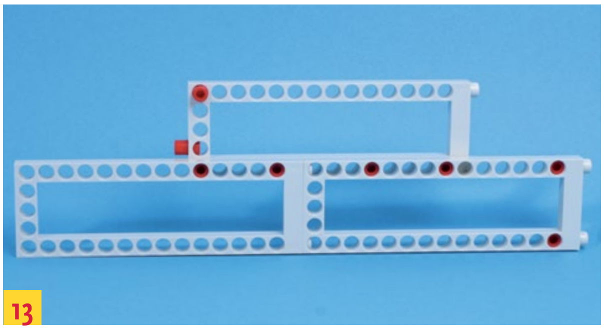
10. Stick two small gear wheels (8) and two medium gear wheels (7) onto the small axle and the three shaft plugs.



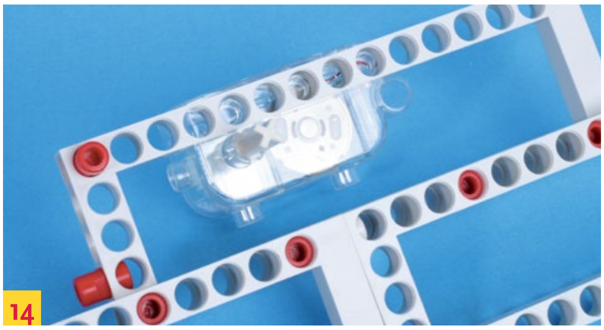
11. Two more small gear wheels (8) go on the rear side. Stick one on the axle, and attach the other to the second hole from the right with another shaft plug (25).



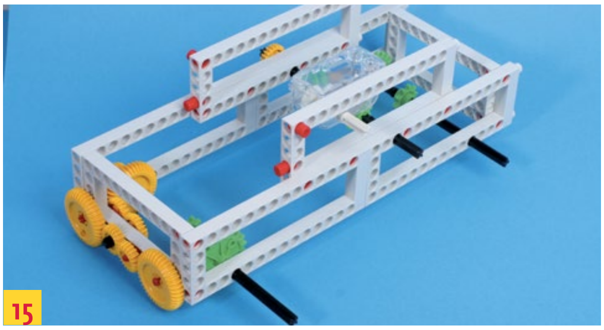
12. Now you will mount the small frame to the front end of the double frame. Rotate the axle and make sure that all of the gears move easily.



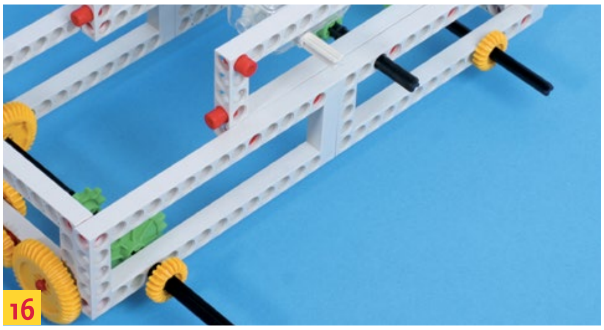
13. Assemble the second side section out of three long frames (2), just like the first one. You will be using eight anchor pins (26) in all.



14. Now attach the solar engine (24) to the upper frame. Make sure that the engine sits in the right holes. Then insert the engine shaft (19).

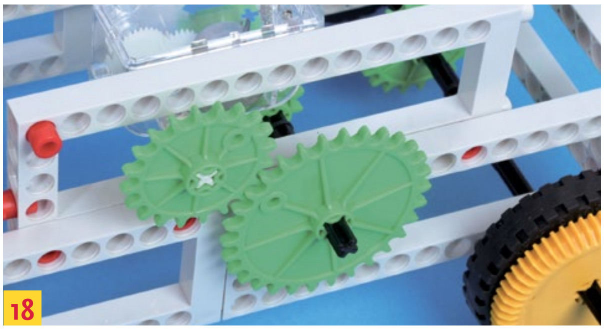


15. Now connect the two side sections. Be sure to insert the axles into the right holes and check that they turn easily.

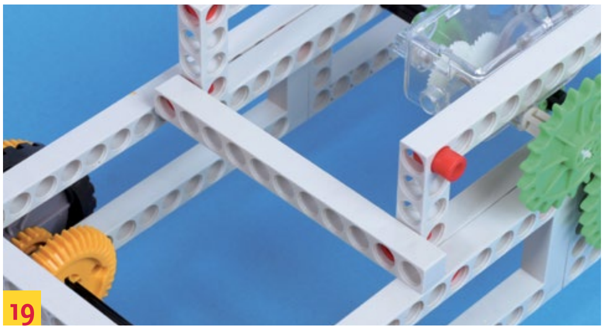


16. Stick one small gear wheel (8) onto the free end of each of the front and rear axles (two gear wheels total).

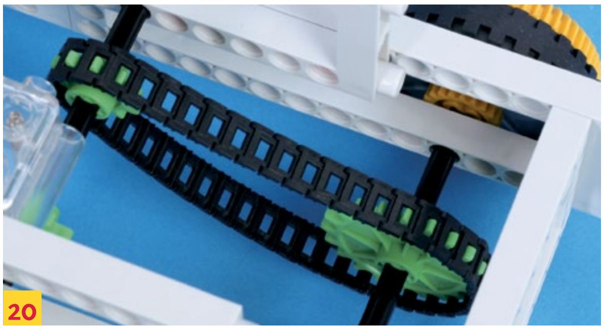
17. Now mount the four tire wheels (15) onto the front and rear axles. For looks, add a large gear wheel (6) to the outside of each one.



18. For the power transmission between engine shaft and drive shaft, mount a medium sprocket wheel (10) on the engine shaft and a large sprocket wheel (11) on the drive shaft.

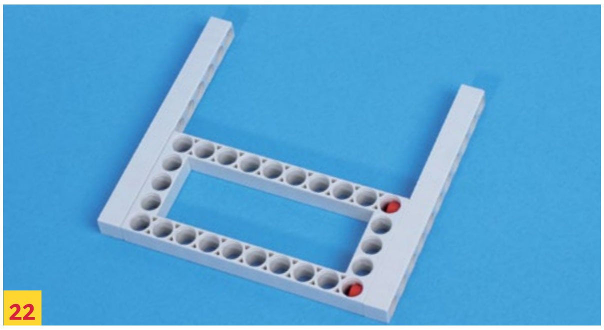


19. At the front, a short rod (4) stabilizes the construction. It attaches to the two upper frames by the two anchor pins (26).



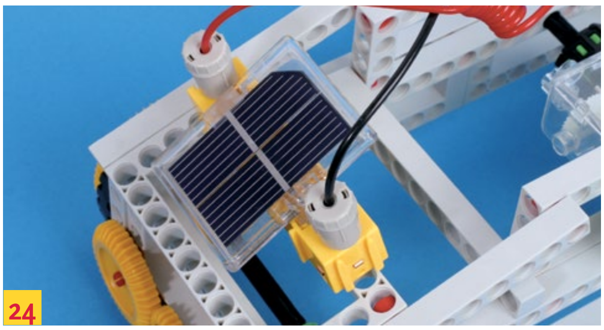
20. The lower chain is made out of 43 chain links (29). Before attaching it, adjust the two sprocket wheels so they form a straight line.

21. At the rear as well, reinforce the construction with a short rod (4) attached to the two long upper frames.



22. For the front section, connect two short rods (4) with one short frame (3). You will need to use two anchor pins.

23. Then attach this structure at the front to the two long upper frames. You will have to push the two rods out a little bit.



24. Finally, mount the battery holder (22) with the solar module (23) to the frames at the front. Then connect the electricity cables (20/21) to the engine.

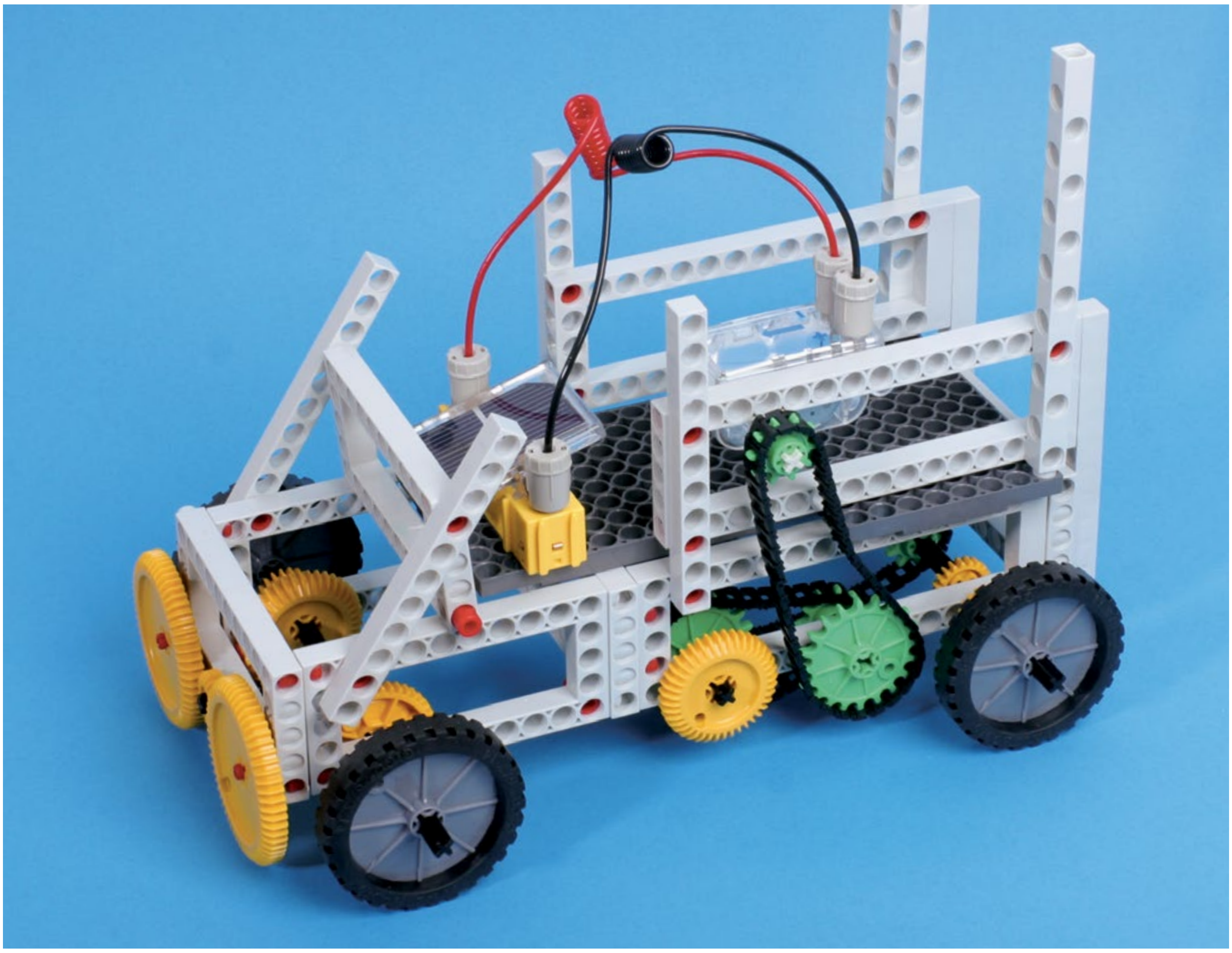
Truck with Large Cargo Bed

Undercover Technology

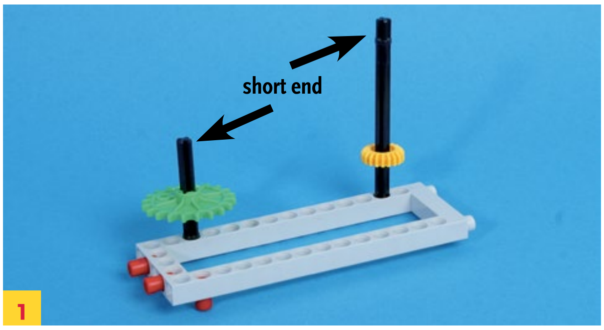
This truck has command of a pure chain drive that turns the wheels on the rear axle. The unusual thing about it is that the transmission to the rear axle is practically invisible. Only the chain from the engine to the drive shaft is visible — the other chains are hidden by the large cargo bed. The big headlights on the front grill turn when the truck is moving. They are set in motion by the front wheels, and have no direct contact with the engine. The yellow gear wheels move in reverse of the vehicle's motion: while the truck is driving forward, they turn in the opposite direction. Another special feature is the vehicle's moveable front end.

Parts List

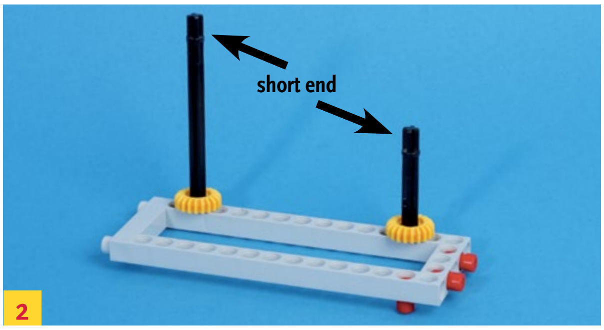
2 x base plates **1**	4 x long frames **2**
6 x short frames **3**	6 x short rods **4**
2 x long rods **5**	2 x large gear wheels **6**
4 x medium gear wheels **7**	10 x small gear wheels **8**
4 x small sprockets **9**	3 x medium sprockets **10**
4 x tire wheels **15**	4 x long axle shafts **16**
2 x medium axle shafts **17**	2 x short axle shafts **18**
1 x engine shaft **19**	1 x black cable **20**
1 x red cable **21**	1 x battery holder **22**
1 x solar module **23**	1 x solar engine **24**
3 x shaft plugs **25**	24 x anchor pins **26**
121 x chain links **29**	
2 x attachment plates **27**	



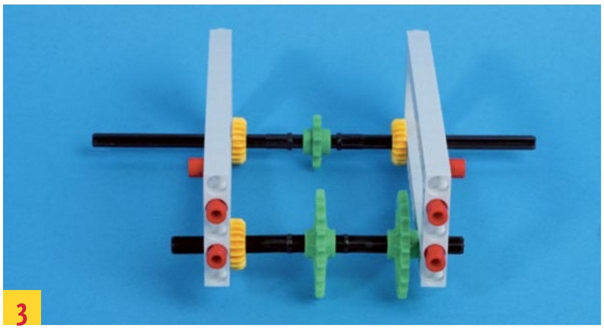
On this truck with a big cargo bed, it isn't just the tires that turn: The gear wheels on the front grill are also rotated by the front axle.



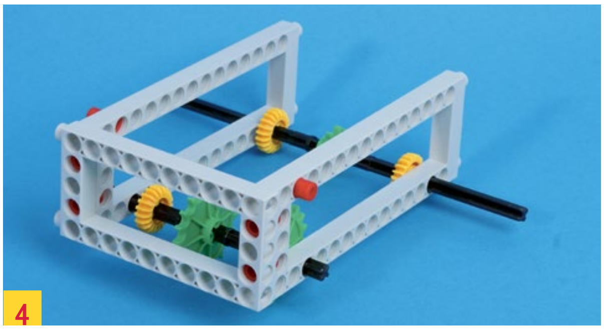
1. Start with a long frame (2), three anchor pins (26), one medium (17) and one long axle shaft (16), one small gear wheel, and one medium sprocket wheel (10).



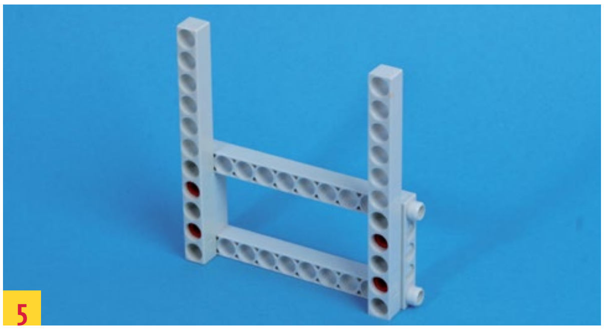
2. Equip a second long frame (2) with the same components, except use a small gear wheel (8) instead of the medium sprocket wheel.



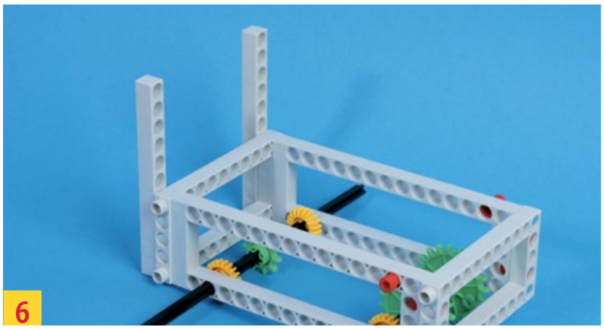
3. Now you will combine the two frames together. Connect the axle shafts with one medium sprocket wheel (10) and one small sprocket wheel (9) to form two long axles.



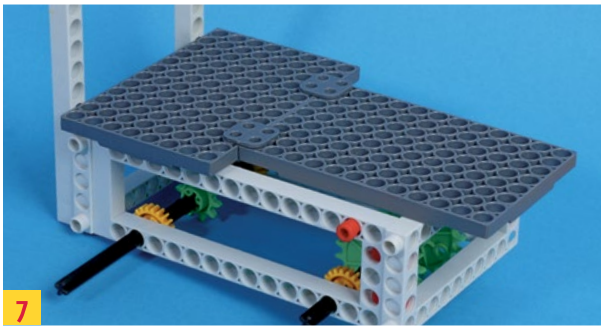
4. Now connect the two side sections with a short frame (3) and align the gear wheels on the axles.



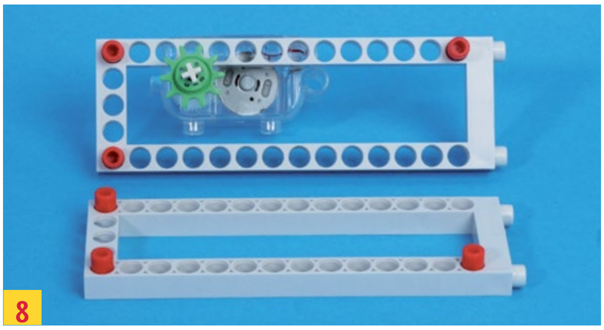
5. For the other end's attachment section, use four anchor pins (26) to mount two short rods (4) to another short frame (3).



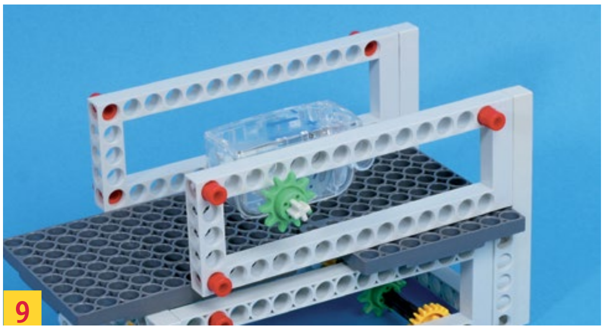
6. Now attach the second frame to the side sections. The two small crossways-mounted frames serve to stabilize the structure.



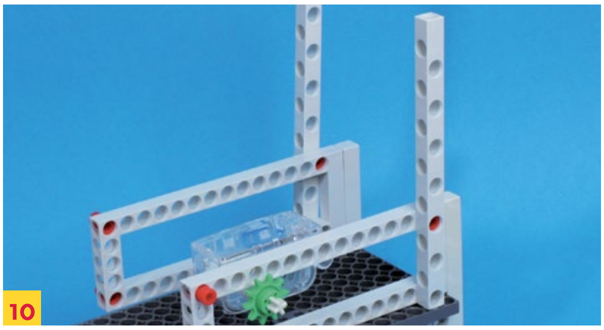
7. The two base plates (1) form the cargo bed. They are connected with the two attachment plates (27) into a single continuous surface and then placed on the framework.



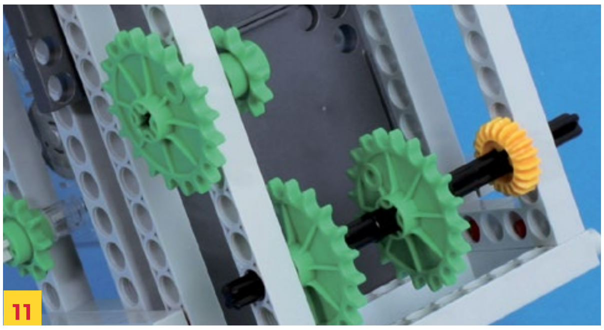
8. Insert three anchor pins (26) into each of two long frames (2). Attach the engine (24) with engine shaft and a small sprocket wheel (9) to the rear frame.



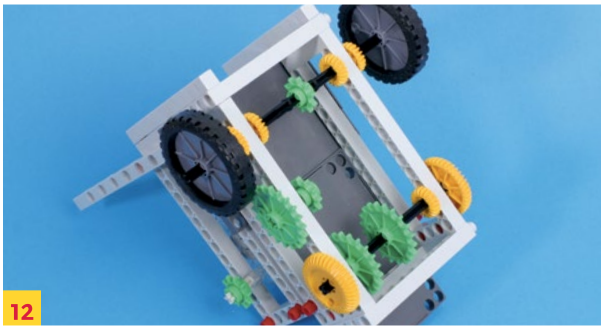
9. Attach the two frames to the short rods. They hold the cargo bed in place, which can now no longer move up or down.



10. Next, place two long rods (5) on the rear of the base plate and push them onto the side anchor pins. Now the cargo bed definitely won't be able to slip.

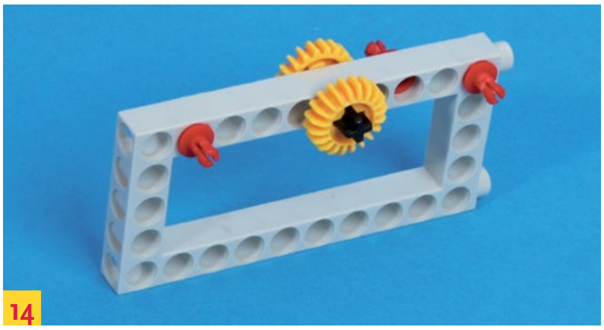


11. A short axle shaft (18) with a medium (10) and a small sprocket wheel (9) forms the drive shaft. Insert the shaft into the frame five holes above the axle shown at the bottom of the picture.

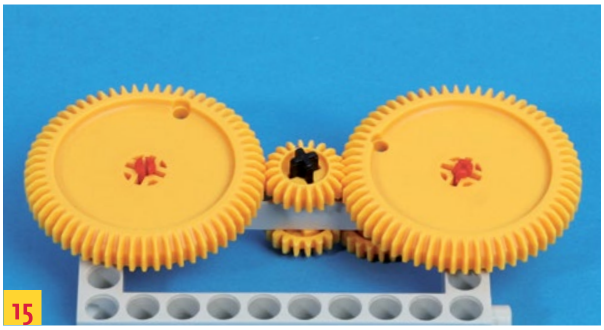


12. Two tire wheels (15), two small gear wheels (8), and two medium gear wheels (7) complete the axle. After assembly, make sure that the axle shafts turn easily.

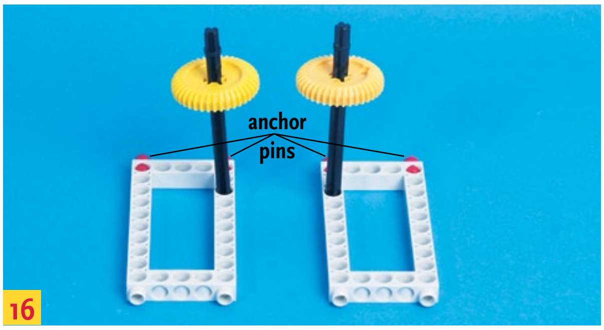
13. Align the sprocket wheels to form a straight line. Then attach the drive chains. They are made of 31, 44, and 46 chain links (29).



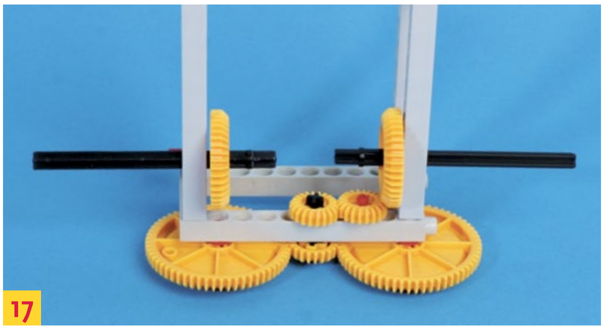
14. A short frame (3) makes the radiator. Three shaft plugs (25) and one short axle shaft (18) with two small gear wheels (8) are inserted into it.



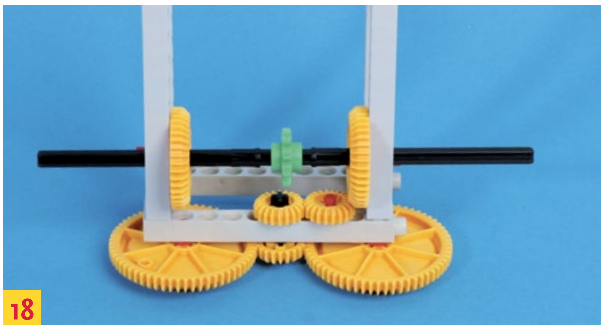
15. Mount two large gear wheels (6) on the front of the frame, and on the back mount one more small gear wheel (8). Check over the entire gear drive assembly.



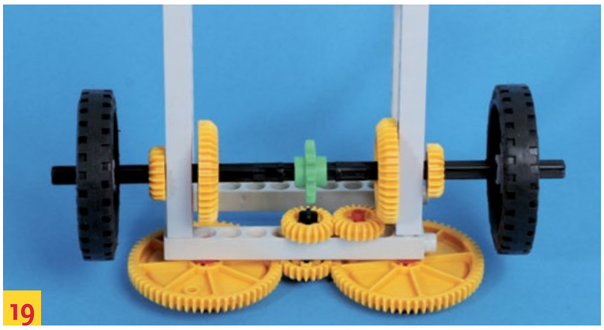
16. In each of two short frames (3), insert two anchor pins (26). In addition, insert two medium gear wheels (7) onto two long axle shafts (16).



17. Now attach the two short frames to the frame with the large gear wheels. The medium gear wheel on the inner right has to mesh with the small gear wheel shown below it.

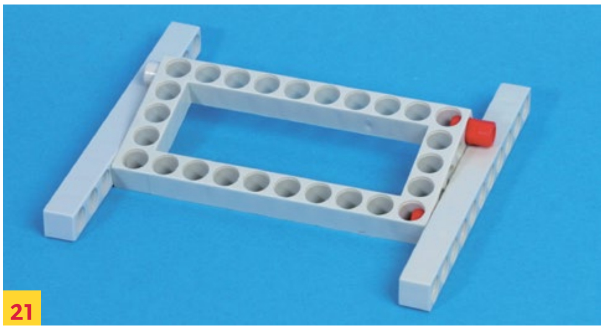


18. Now connect the two axle shafts with a small sprocket wheel (9) to form one long axle. Turn the axle to make sure that all the gears move smoothly.

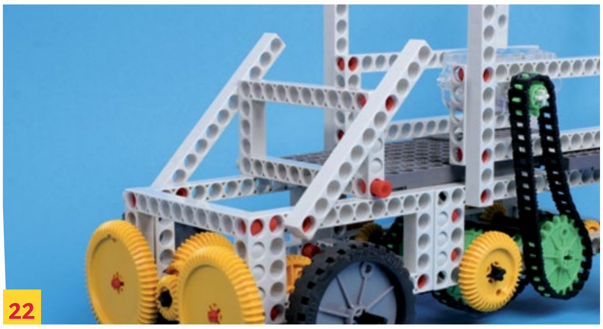


19. To complete the front of your truck, attach a small gear wheel (8) and a tire (15) to each end of the front axle.

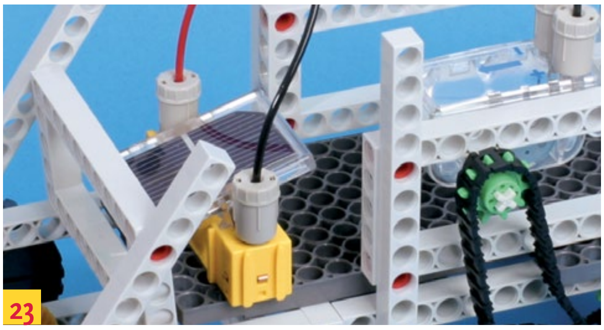
20. Now you will connect the front section to the cargo bed. Then attach two short rods (4) vertically to the front of the upper side frames.



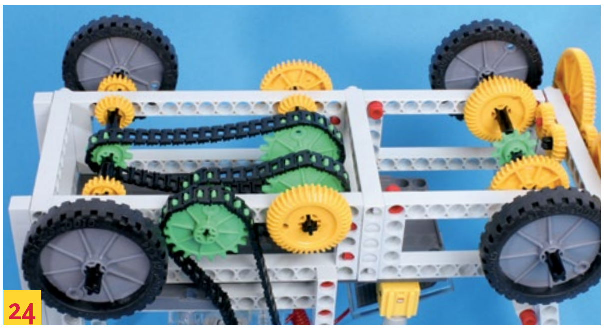
21. At the front, the truck still has to get its movable front section. It is constructed from two short rods (4), one short frame (3), and two anchor pins (26).



22. Attach this structure to the forward area of the two side sections with two anchor pins (26). When you attach it, you will have to push the two rods apart a little.



23. Now you just need the solar module (23) with holder (22) and cables (20/21). When you mount it, be careful not to push down on the cargo bed.



24. Finally, turn the model upside down again. Adjust the wheels and tires so that they form straight lines.

Large Drawbridge

Parts List	
2 x base plates **1**	4 x long frames **2**
4 x short frames **3**	8 x short rods **4**
4 x long rods **5**	4 x large gear wheels **6**
4 x medium gear wheels **7**	9 x small gear wheels **8**
3 x small sprockets **9**	1 x medium sprocket **10**
2 x large sprockets **11**	1 x medium pulley wheel **13**
5 x long axle shafts **16**	2 x medium axle shafts **17**
1 x short axle shaft **18**	1 x engine shaft **19**
1 x black cable **20**	1 x red cable **21**
1 x battery holder **22**	1 x solar module **23**
1 x solar engine **24**	4 x shaft plugs **25**
20 x anchor pins **26**	90 x chain links **29**
1 x attachment plate **27**	
1 x crane hook with spool and cord **28**	

Tall Bridge with Roadway

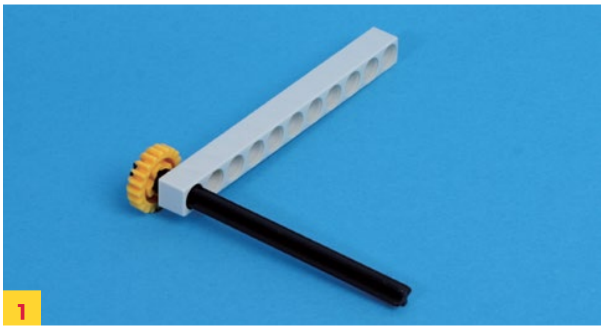
Drawbridges aren't just something found on medieval castles — they are still used today for roads that go over rivers and canals. When a large ship comes, the roadway can be raised up to let the ship pass through. Then, the bridge is lowered again so pedestrians and vehicles can cross over the river.

For our next project, we will be building this kind of drawbridge. The actual bridge is located at the front, and it can be raised and lowered with the help of the crane hook, spool, and cord. The cable is guided over a pulley wheel mounted high up the bridge. The bridge is just as wide as the roadway running through the lift machinery structure. This lift structure is built high in order to allow tall vehicles to use the road as well. The framework at the rear is needed to let you anchor the lift machinery securely to the base plate. The engine turns the cord pulley by way of a combination chain and gear drive.

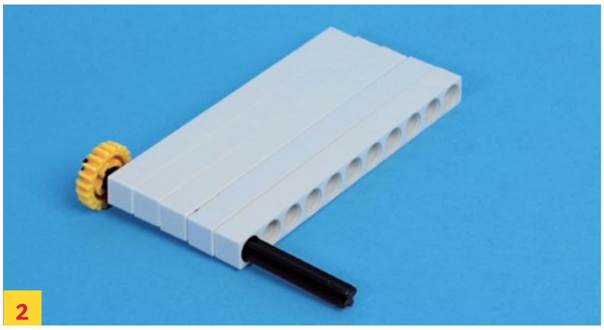
The direction of the solar engine's rotation determines whether the bridge is raised or lowered. The simplest way to change the direction of flow of the current is to reverse the position of the solar module in the holder.

When operating the bridge, be careful not to let the cord jiggle up and down too much. You can stop the bridge anytime by holding your hand over the solar module. The shadow of your hand will prevent enough light from getting to the solar cells. But the engine doesn't just wind and unwind the cord. At the front of the model, there is a medium gear wheel which is rotated by a reverse gear drive when the bridge is raised or lowered. It signals to ship traffic that the bridge is in movement. The large gear wheels at the top don't turn at all, however. They just serve to make the model look nicer.

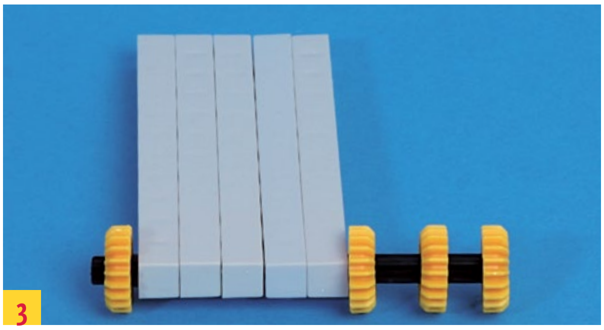
The model is actually easy to build. You first assemble the bridge itself and then you construct the lift machinery. Make sure that the sprocket wheels that are linked to each other are positioned in a straight line. Also, the chains should not sit too tightly or too loosely. Check periodically to see whether everything is moving smoothly and easily.



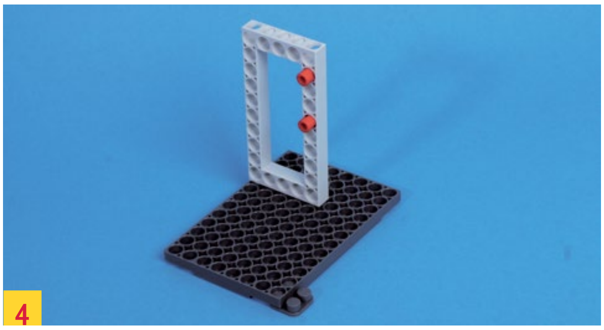
1. First you will build the bridge. Push a small gear wheel (8) onto the short end of a long axle shaft (16). Then push a short rod (4) onto the axle.



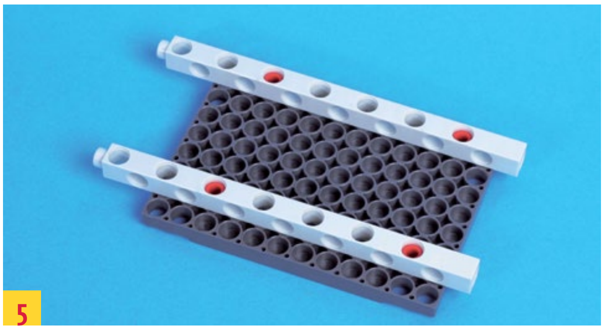
2. The bridge is the width of five short rods (4). Push all the short rods onto the long axle shaft.



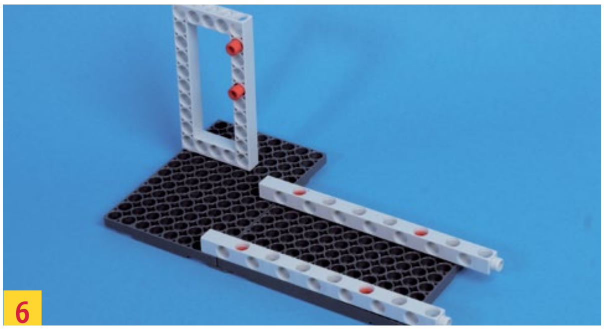
3. Then come three small gear wheels (8): One holds the rods in place, and the others will be needed as a guideway for the crane hook.



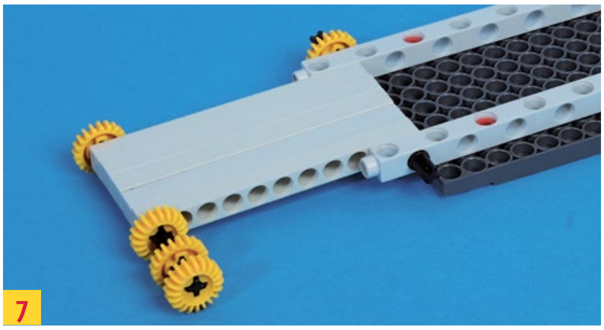
4. A short frame (3) with two anchor pins inserted into it goes on a base plate (1) with an attachment plate (27).



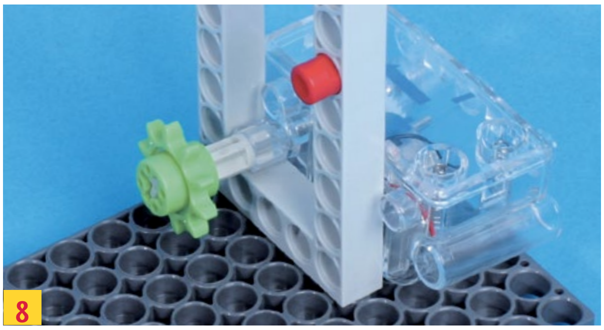
5. With the help of four anchor pins (26), attach two long rods (5) to the other base plate. Be careful to mount the rods correctly.



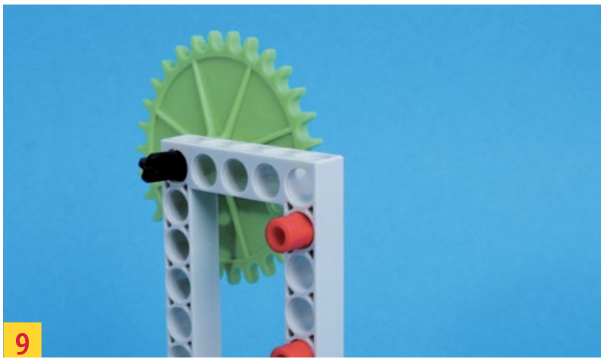
6. Now connect the two base plates together. They are held securely to one another by the attachment plate.



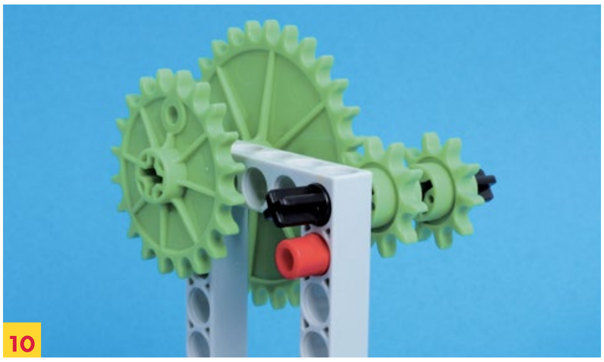
7. Now attach the drawbridge to the two rods. You will need a long axle shaft (16) and a small gear wheel (8). The short end of the shaft is to the front in the picture.



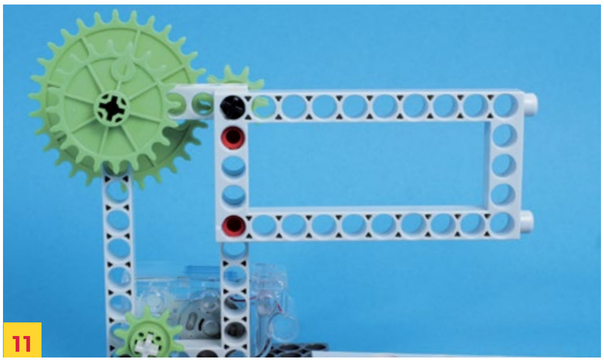
8. Next, mount the solar engine (24) with the engine shaft (19) and a small sprocket wheel (9) onto the base plate. The shaft fits precisely into the corner of the frame.



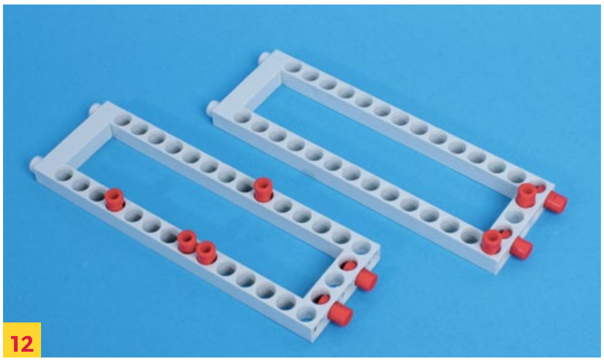
9. To the rear of the frame, attach a short axle shaft (18) with a large sprocket wheel (11).



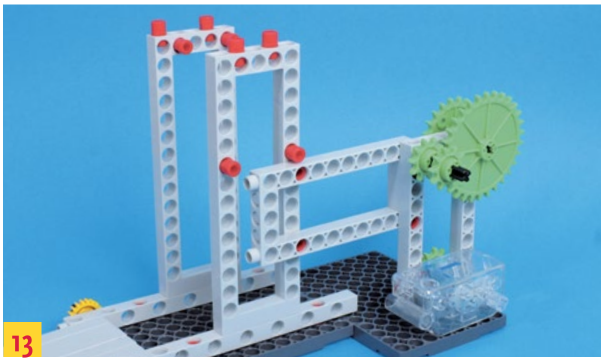
10. Then add a medium axle shaft (17) and two small (9) and one medium sprocket wheel (10) to the front.



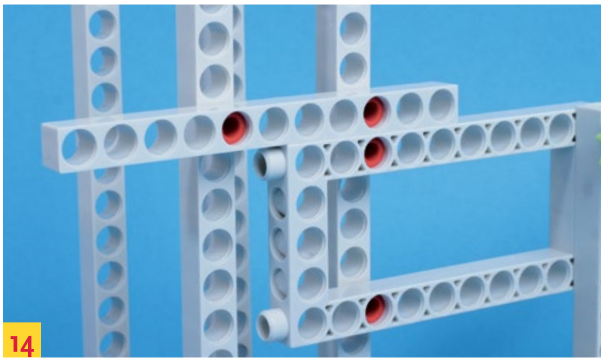
11. Now mount a second short frame (3) at right angles to the upright short frame.



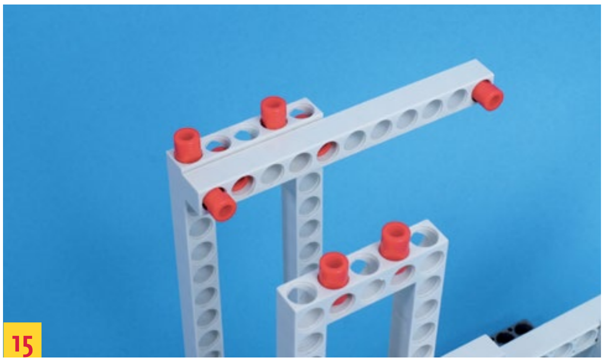
12. Insert a total of ten anchor pins (26) into two long frames (2). Pay close attention to the holes that the anchor pins go in.



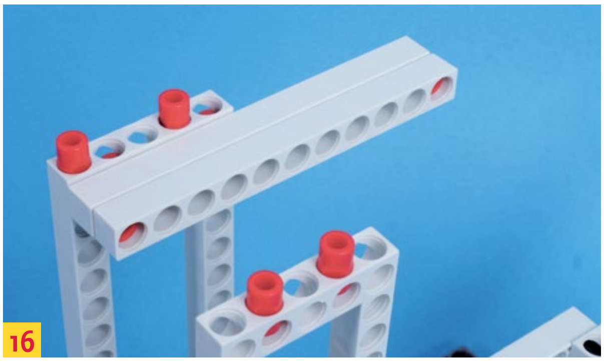
13. Mount the two frames on the two rods on the base plate.



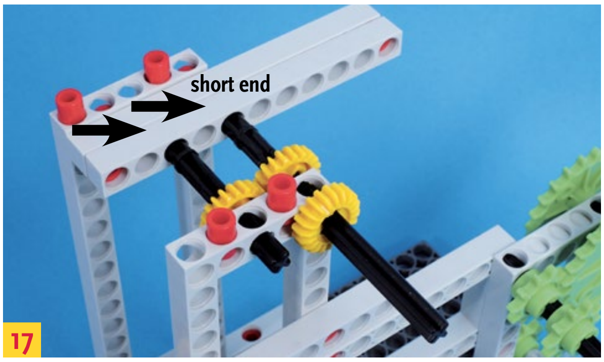
14. Directly over the horizontal frame, attach a short rod (4).



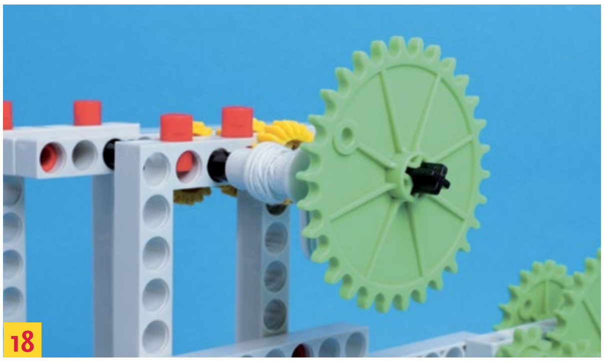
15. Next, attach a short rod (4) to the rear frame. Then insert two more anchor pins (26).



16. Now mount another short rod (4) onto the two anchor pins.

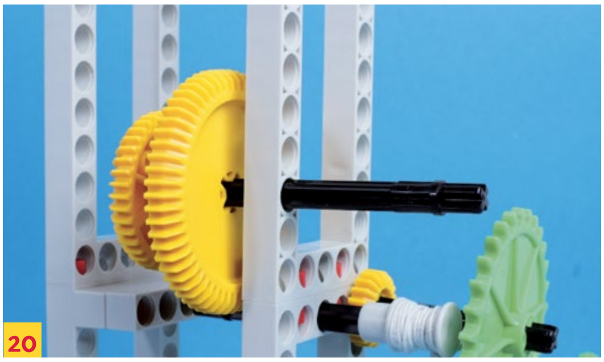


17. Now add a medium (17) and a long axle shaft (16) along with three small gear wheels (8).

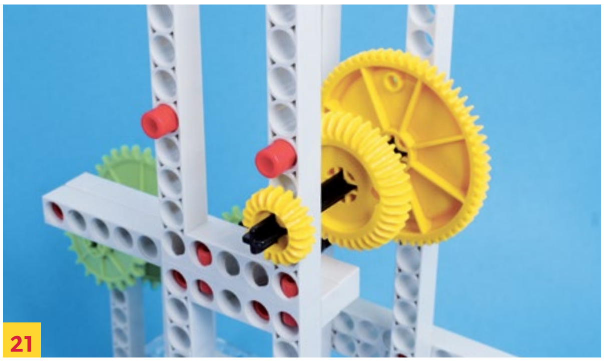


18. The spool with the cord and crane hook goes on the short axle, and a large sprocket wheel goes on the long one.

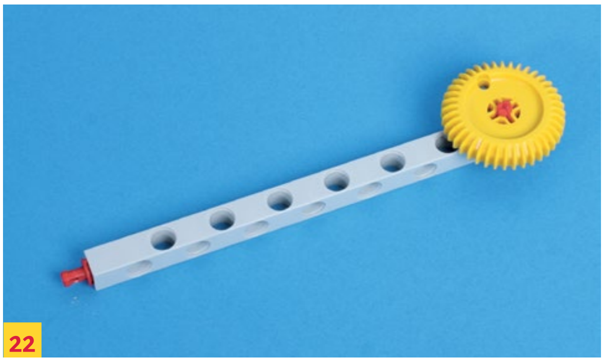
19. Now, lengthen the structure with two long frames (2).



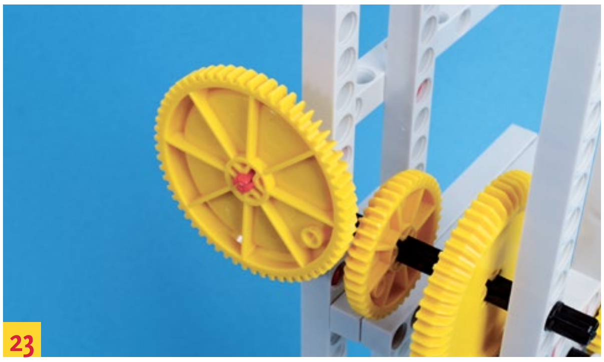
20. Insert a long axle shaft (16) with one large (6) and one medium gear wheel (7) into the frame.



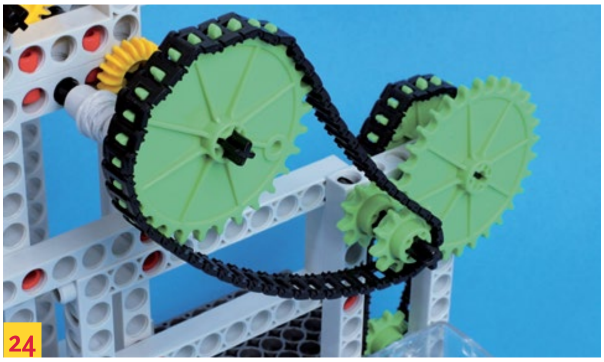
21. On the other side, secure the axle shaft with a small gear wheel and insert two anchor pins (26).



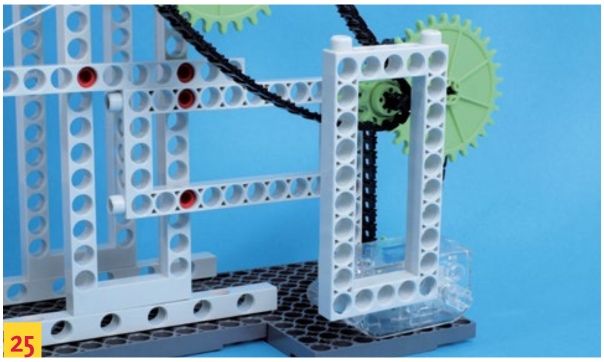
22. Insert two shaft plugs (25) into a long rod (5) and mount a medium gear wheel (7) on one shaft plug.



23. Place a large gear wheel (6) on the other and mount the rod so that the large gear meshes with the medium one.

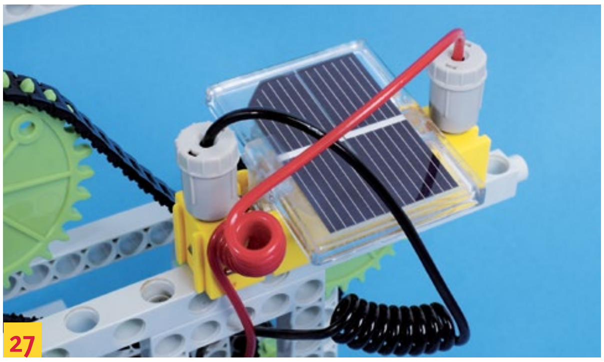


24. Now mount the drive chains. They are composed of 41 and 49 chain links.

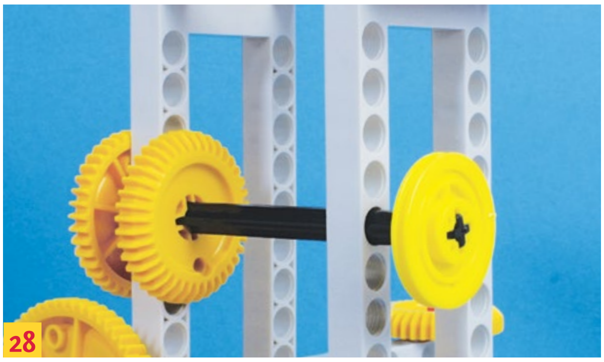


25. To secure the battery holder, we will now attach a short frame (3) to the solar engine.

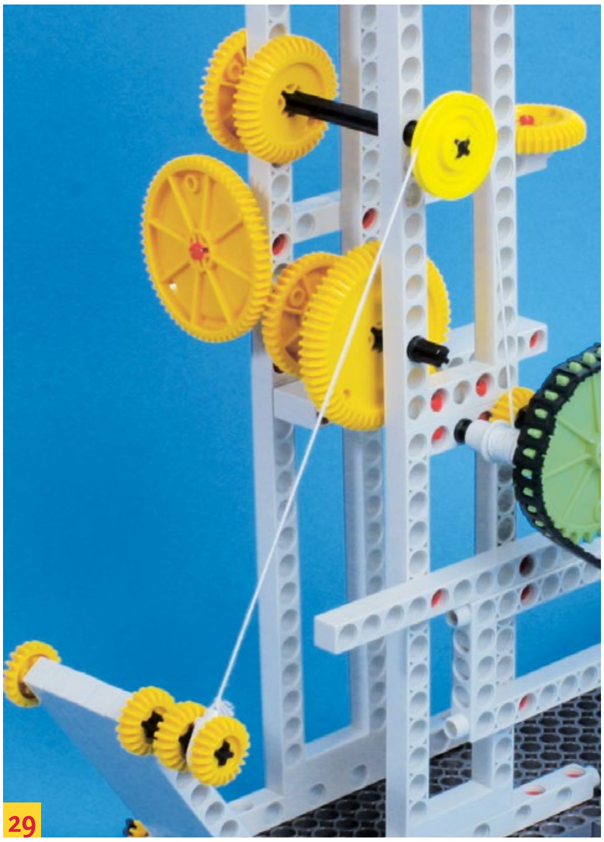
26. A long rod (5) goes on the frame and the battery holder (22) goes on the rod.



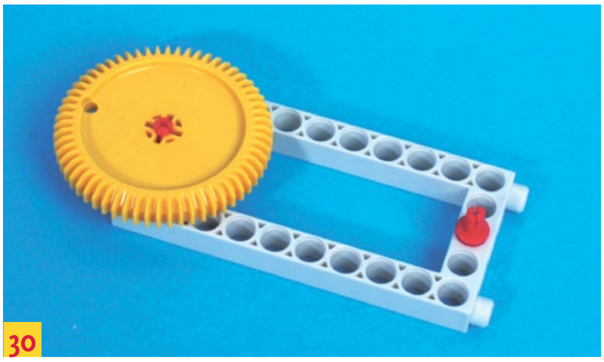
27. Now you just have to mount the solar module (23) and attach the cables (20/21).



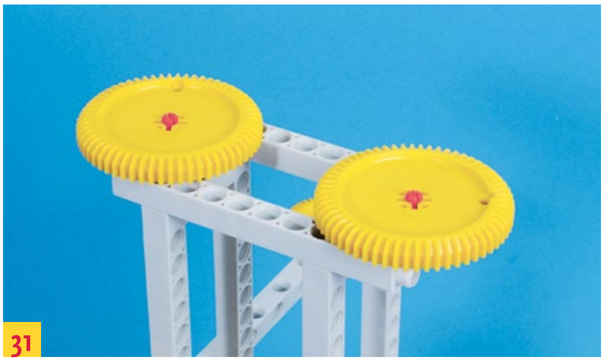
28. A long axle shaft (16) with two medium gears (7) holds the medium pulley wheel (13) that guides the cord.



29. Guide the cord over the medium pulley wheel to the drawbridge and attach the hook to the long axle shaft.



30. Insert two shaft plugs (25) into a short frame (3). A large gear wheel (6) is mounted on each one.



31. Finally, mount the frame on top of the model and check to make sure everything works properly.

“Iron Annie” Airplane

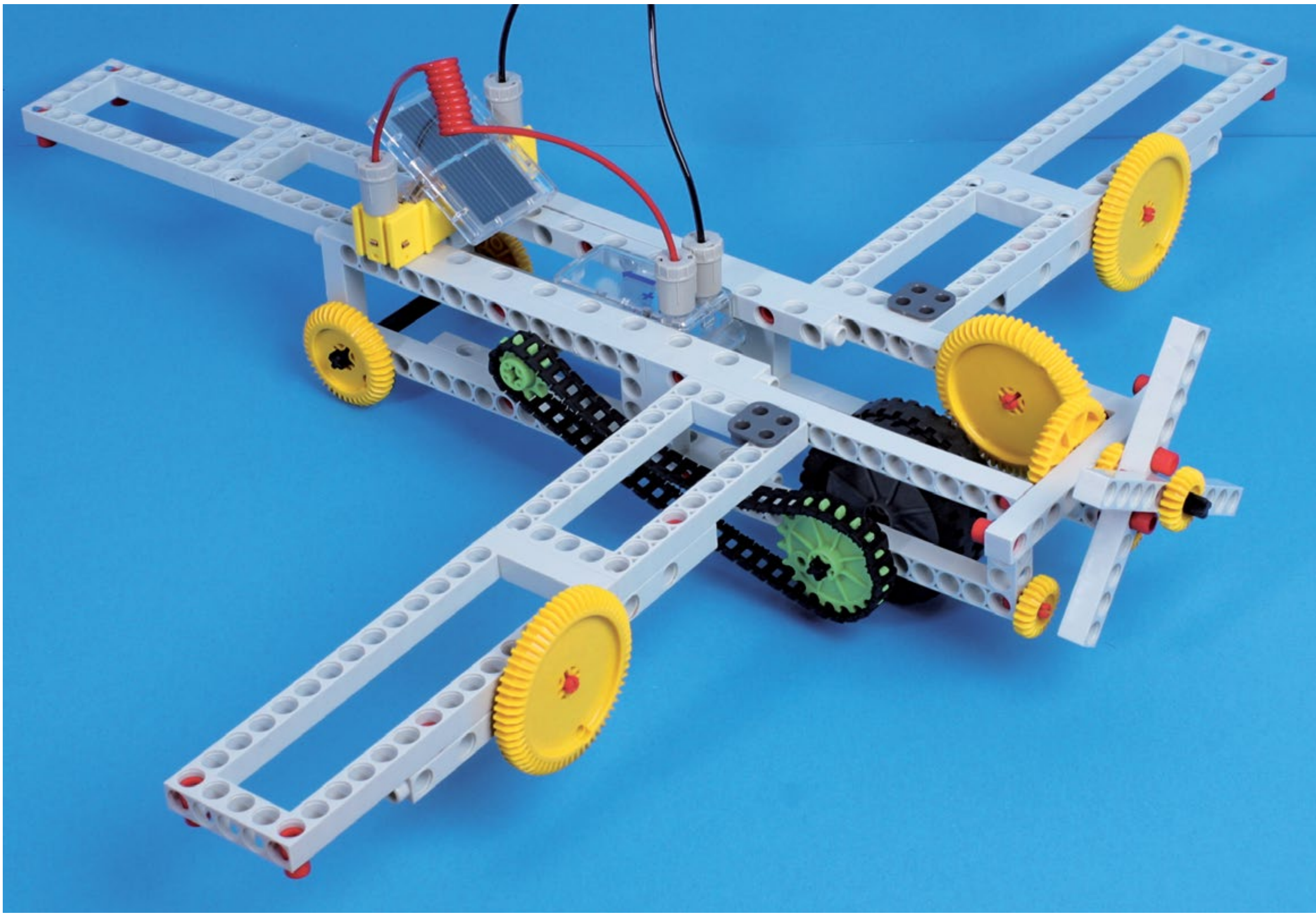
Two Directions of Movement

The “Iron Annie” is one of the most famous passenger planes in the world. In Germany, it was called the “Tante Ju” — or “Auntie Ju” — with the “Ju” part of its name being short for German aircraft engineer Hugo Junkers. It was technically known as the “Ju 52/3m,” but it got its affectionate nickname because of its reliability.

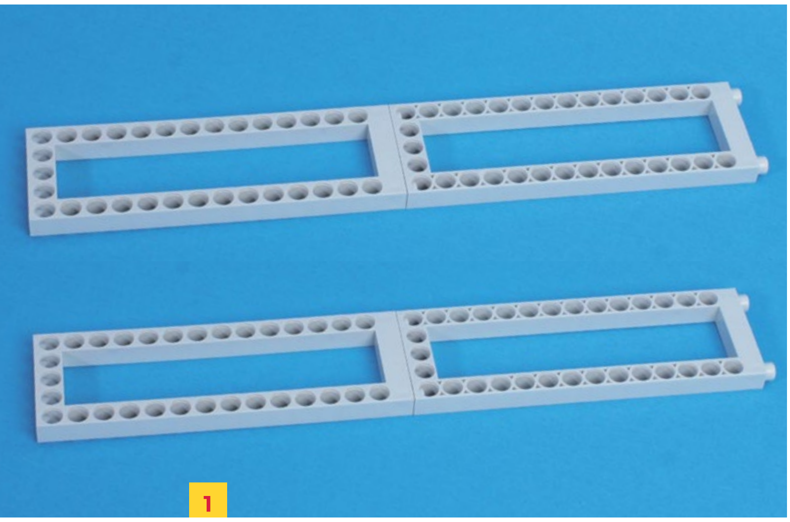
Iron Annie was the inspiration for this model. In this design, the solar engine moves the wheels as well as the propeller in the center. So there are different directions of movement: while the wheels move forward or backward, the propeller moves at right angles to them. This is made possible by a gear drive that redirects the movement.

Parts List

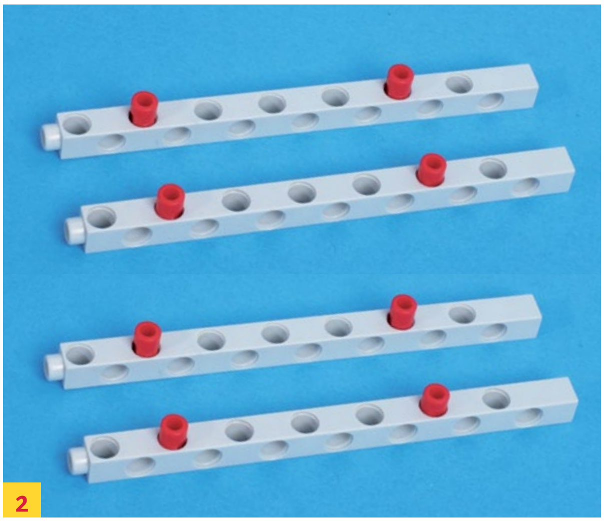
6 x long frames **2**	4 x short frames **3**
3 x short rods **4**	6 x long rods **5**
3 x large gear wheels **6**	4 x medium gear wheels **7**
4 x small gear wheels **8**	1 x small sprocket **9**
1 x medium sprocket **10**	2 x tire wheels **15**
2 x long axle shafts **16**	1 x medium axle shaft **17**
1 x engine shaft **19**	1 x black cable **20**
1 x red cable **21**	1 x battery holder **22**
1 x solar module **23**	1 x solar engine **24**
5 x shaft plugs **25**	26 x anchor pins **26**
57 x chain links **29**	
2 x attachment plates **27**	



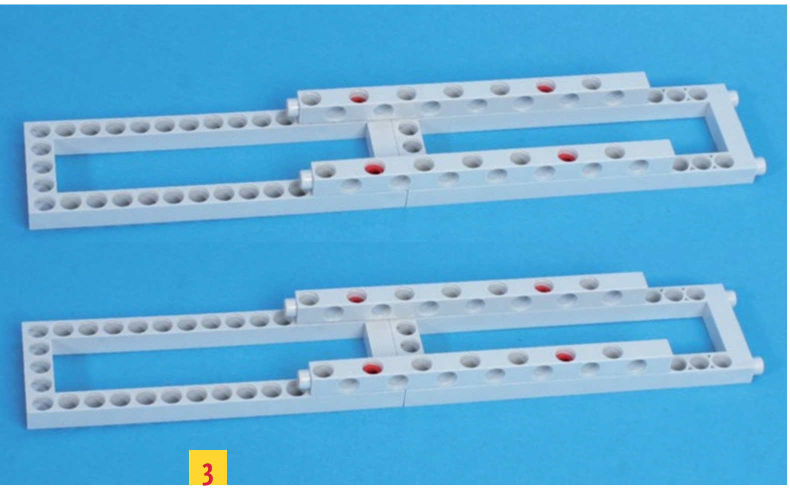
On your airplane, the motor doesn’t just turn the propeller up front, it also turns the front wheels. If you switch the direction of current flow, not only does the airplane move backwards, its propeller turns the opposite direction too.



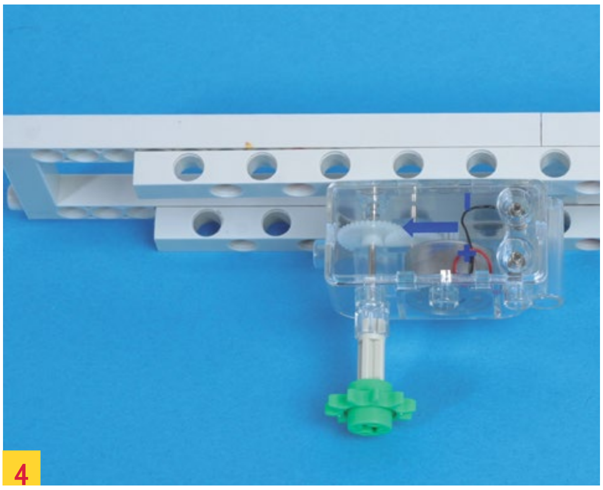
1. First build the two side pieces by combining four long frames (2) into two large side sections.



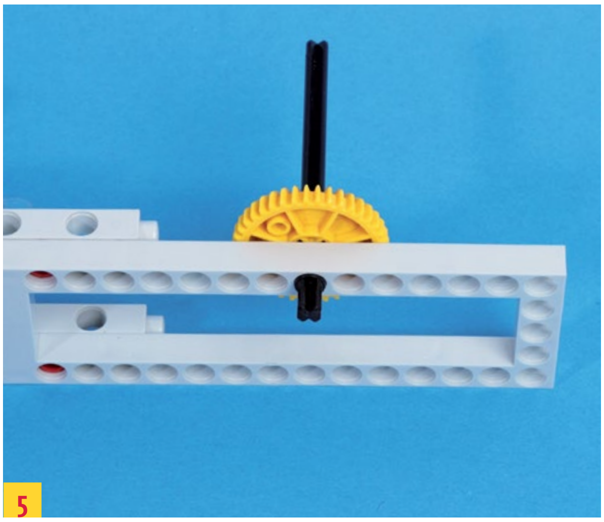
2. To strengthen the double frames, insert eight anchor pins (26) into four long rods (5).



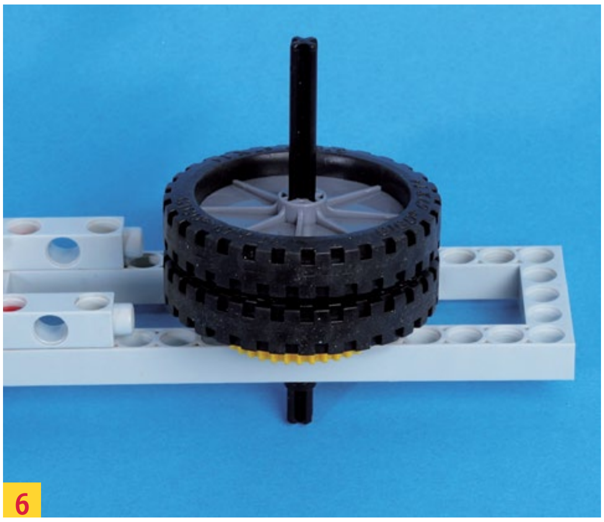
3. Now attach the four rods with the anchor pins to the two double frames, as shown in the picture.



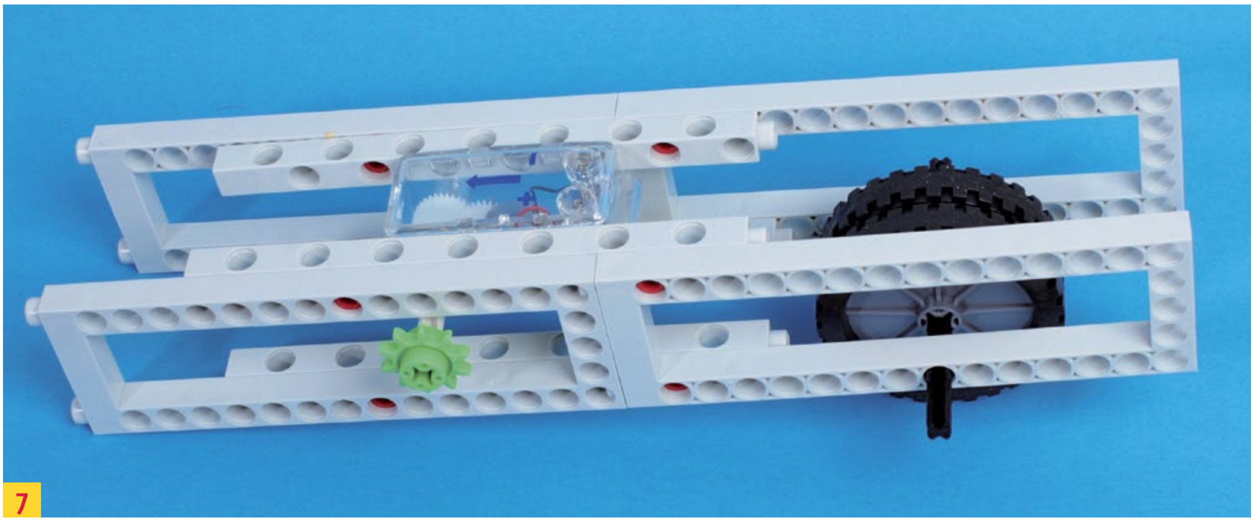
4. Next, mount the engine (24) with engine shaft (19) and small sprocket wheel (9) onto one double frame.



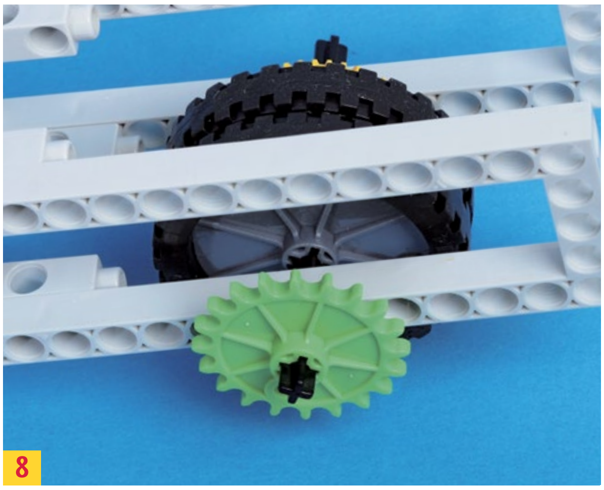
5. On the other side of the same double frame, attach a long axle shaft (16) with a medium gear wheel (7).



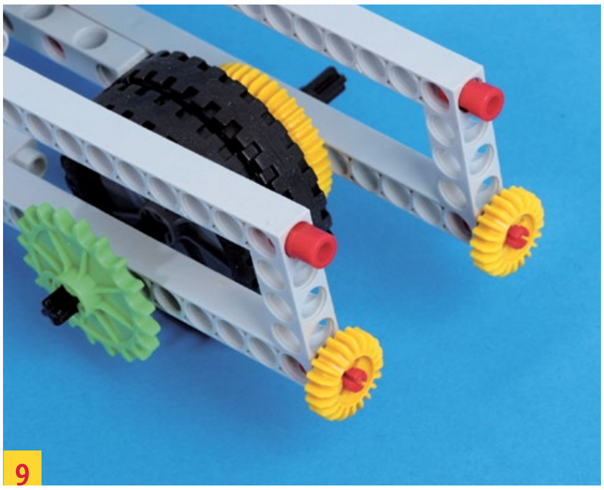
6. The long axle shaft will serve as the front axle. Next, mount two tires (15) onto the axle shaft.



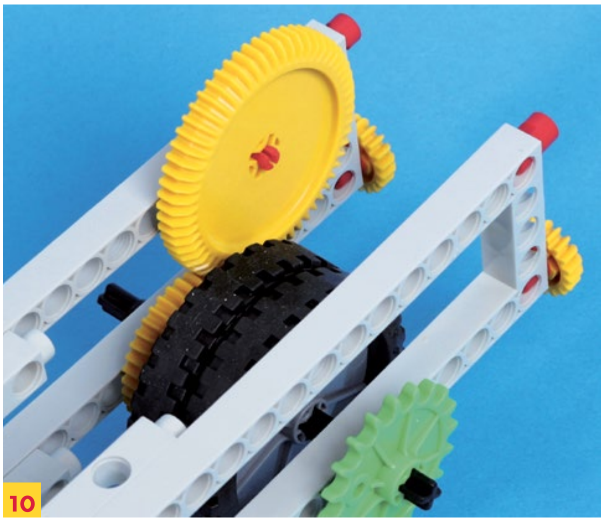
7. Now attach the two double frames together. The engine's anchor pins will help to secure it. Make sure that the two frames sit exactly across from each other and that the front axle sits in the right hole in the new fame.



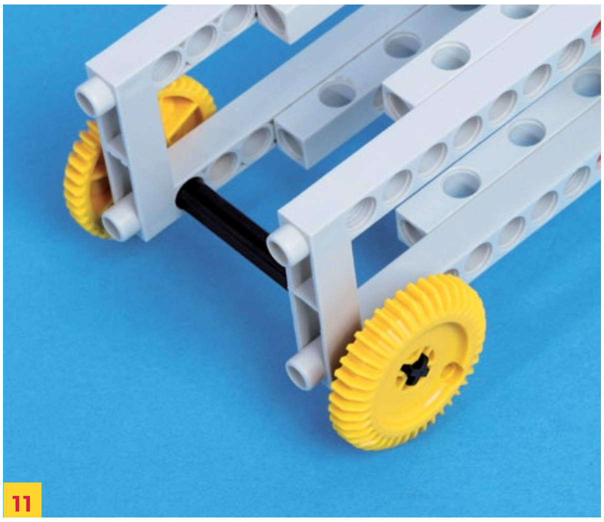
8. For the drive transmission, place a medium sprocket wheel (10) on the outside of the front axle.



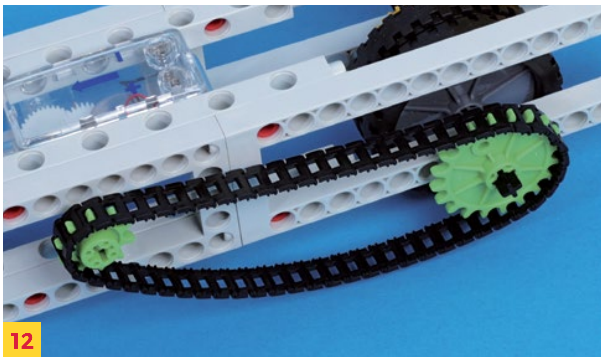
9. For looks, your airplane gets two anchor pins (26) and two small gear wheels (8) with two shaft plugs (25) in front.



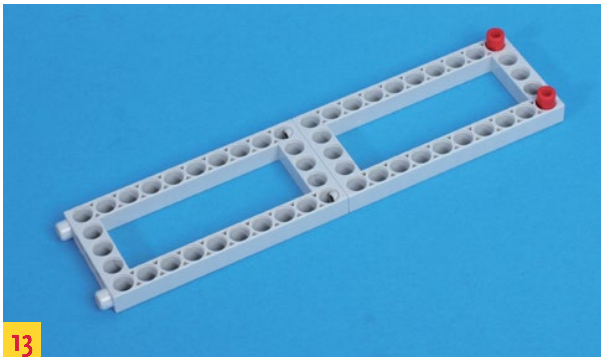
10. The power is conveyed to the propeller by a large gear wheel (6). Secure the gear wheel with a shaft plug (25).



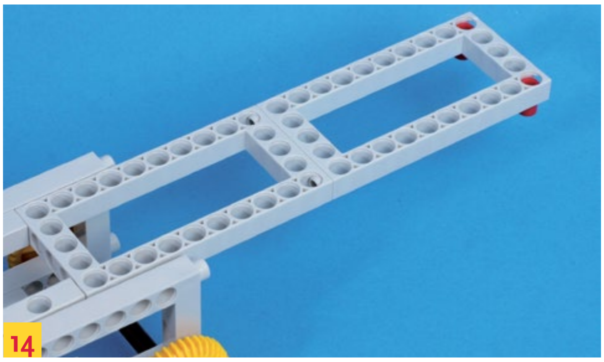
11. For the rear axle, insert a long axle shaft (16) into the double frame and add two medium gear wheels (7).



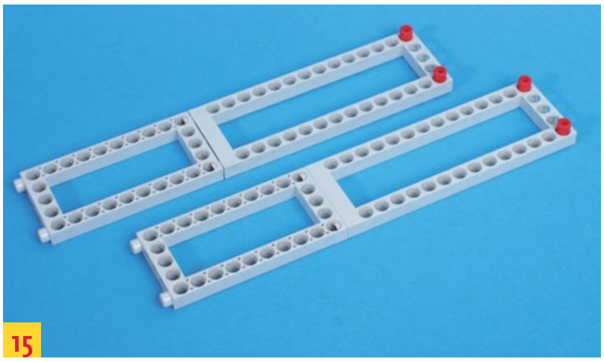
12. Now assemble the drive chain from 57 chain links (29) and wrap the chain around the two sprocket wheels.



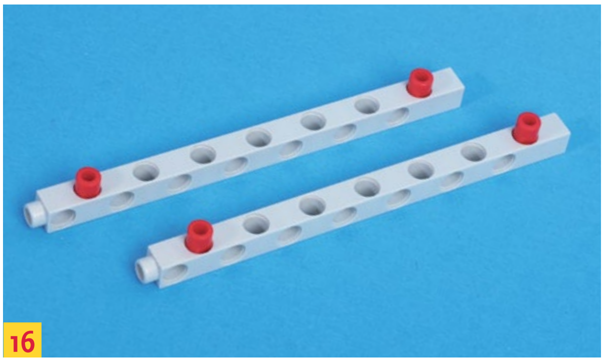
13. To lengthen the tail of the plane, combine two short frames (3) and insert two anchor pins (26).



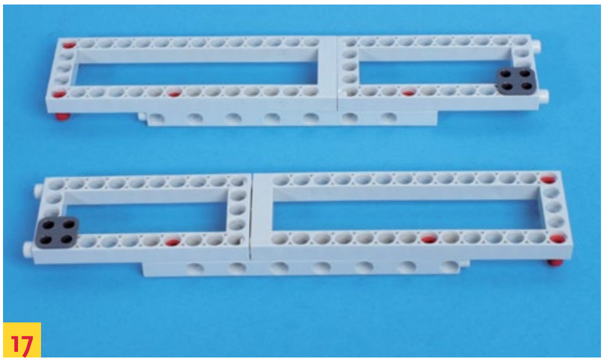
14. Mount this double frame on the rear of the plane between the two long axle shafts.



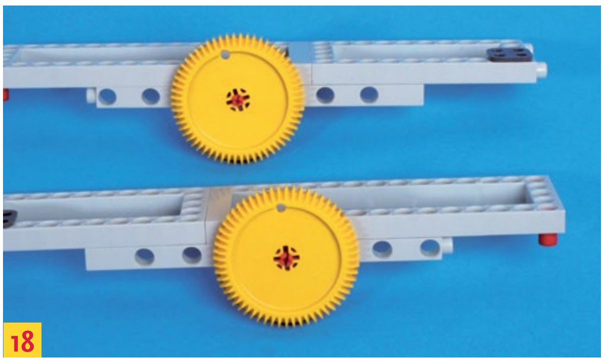
15. Attach together two short (3) and two long frames (2) for the wings. Then insert four more anchor pins (26).



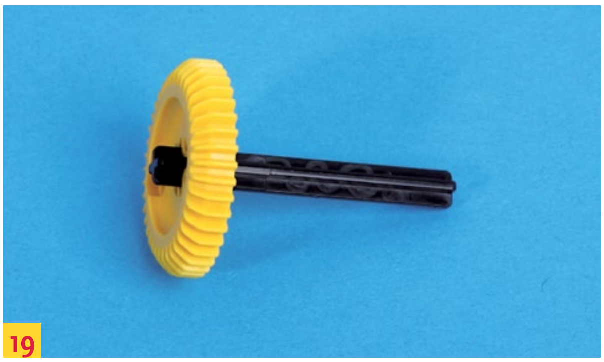
16. Next, insert four anchor pins (26) into two long rods (5).



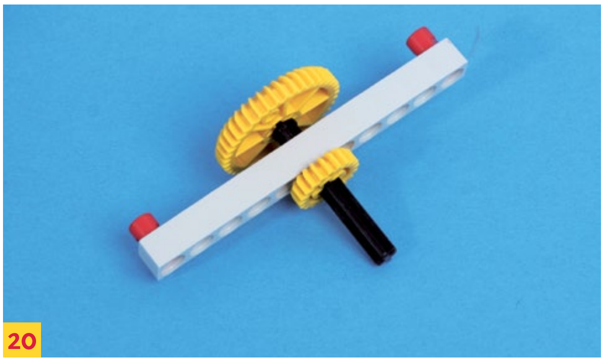
17. Attach the rods to the two double frames. The two attachment plates (27) will serve as decoration.



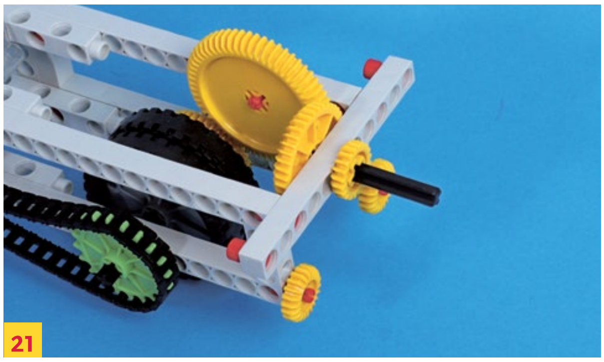
18. Two large gear wheels (6) — attached with two shaft plugs (25) — will make the wings look nicer.



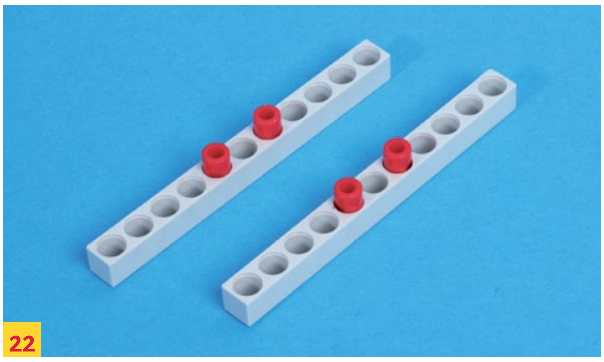
19. A medium axle shaft (17), with a medium gear wheel mounted on its short end, will drive the propeller.



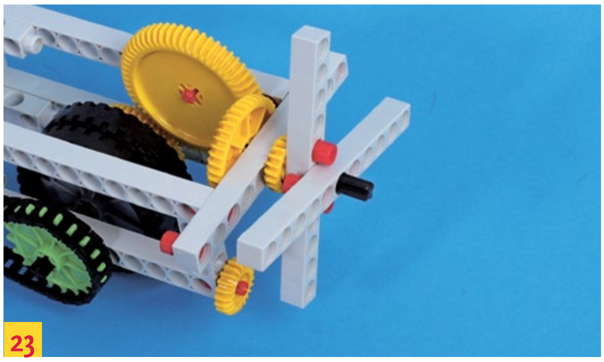
20. Insert the axle shaft along with a small gear wheel into the center of a short rod (4) with two anchor pins (26).



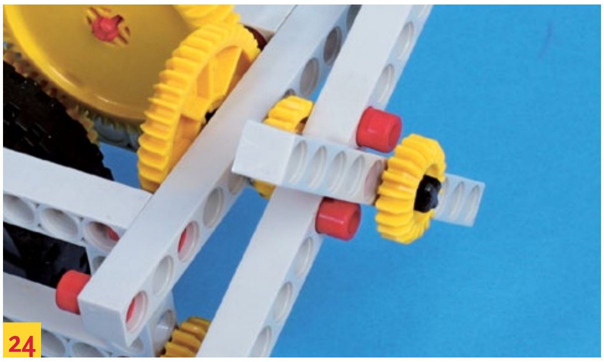
21. Attach the rod to the front of the airplane. Adjust tires and gears and make sure that everything moves easily.



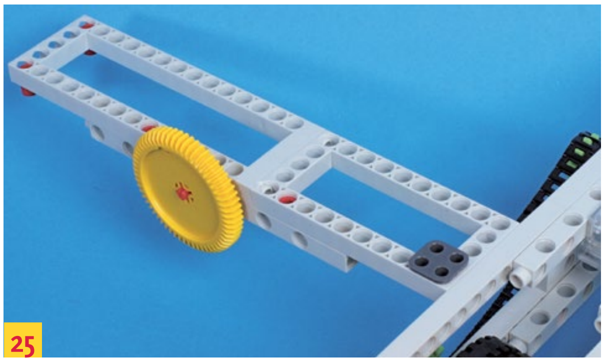
22. For the propeller, you will need two short rods (4) with four anchor pins (26) inserted into them.



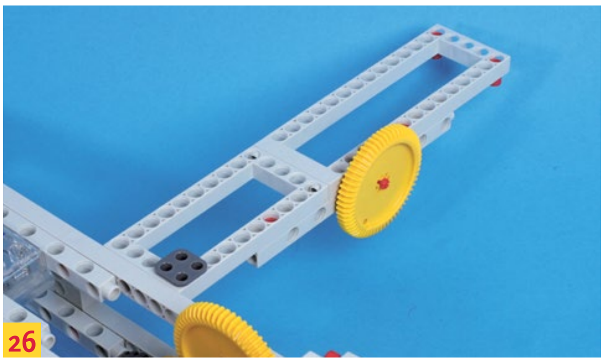
23. Now mount the two rods on the center drive shaft of the propeller.



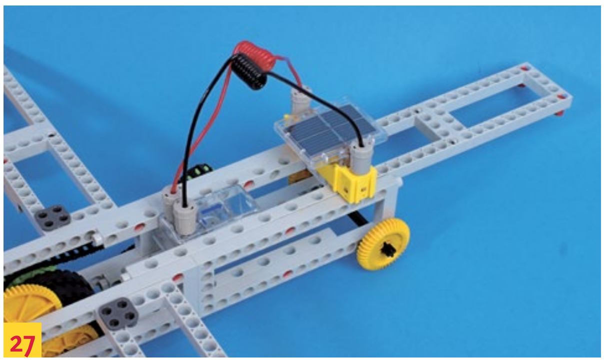
24. Now push on a small gar wheel (8). Push the two gars together so that the propeller is mounted securely.



25. Now attach the first wing. When you mount it, orient yourself by the holes on the long rod.



26. Now mount the other wing directly across from the first one on the tail's double frame.



27. Finally, mount the holder (22) with the solar module (23) on top of the double frame and attach the cables (20/21).

Windmill with Wind Wheels

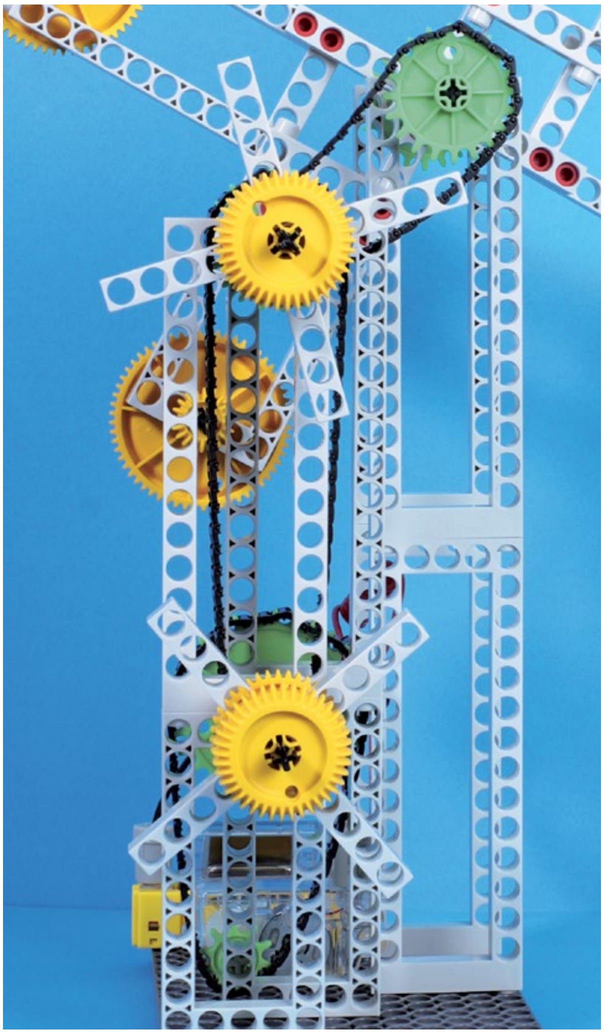
Power Over Great Distances

This very large model demonstrates how a chain drive can be used to bridge great distances between sprocket wheels. In this case, there are three chains moving three wind wheels. **The construction is by no means simple, and it requires precise work.**

The solar engine sits down below on the foundation, which is made out of two base plates. At the back are two large frames attached together. In each of these frames, there is a small wind wheel. The first chain drive turns the lower wheel. On the axle that turns this wind wheel is another sprocket wheel, which drives the other small wind wheel mounted above.

From that second small wind wheel, the power is further transferred to a larger wind wheel mounted higher on the front side.

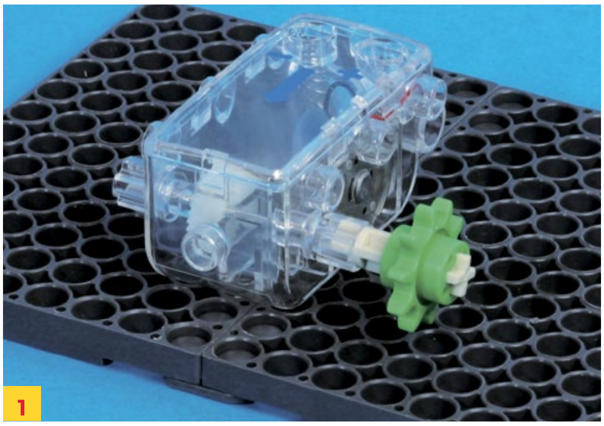
So the large wind wheel is the one that is farthest away from the solar engine. If you wanted to drive it directly — without the axles in between, on the small wind wheels — you would have to use a very long chain indeed. But long chains can easily slip, and they are not very sturdy. The little wind wheels have a technical purpose: They let you use shorter chains, and thus help to ensure a more dependable operation.



The solar engine drives not only the large windmill wheel in front, but also two small mill wheels on the rear side of the model.

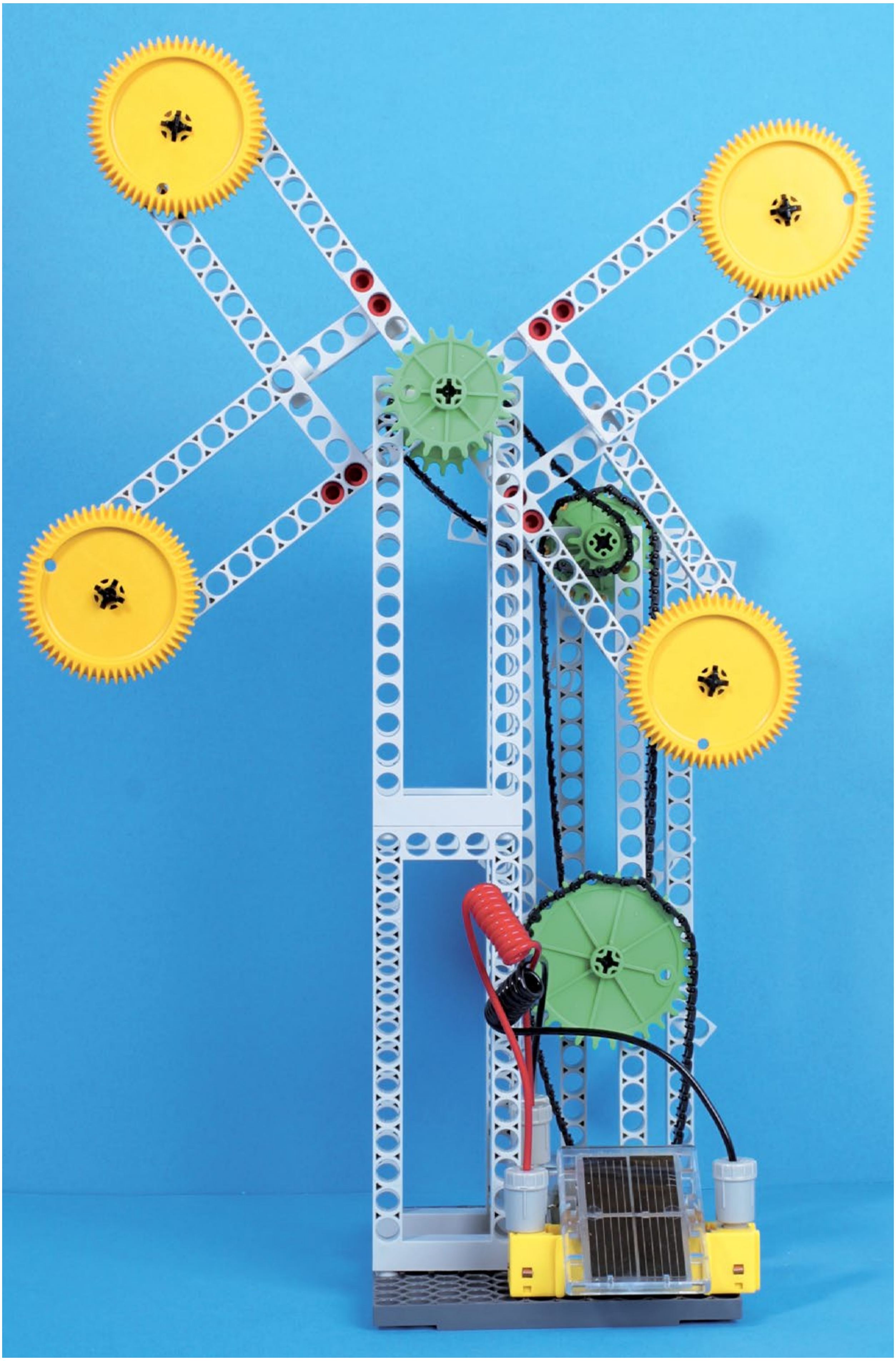
Parts List

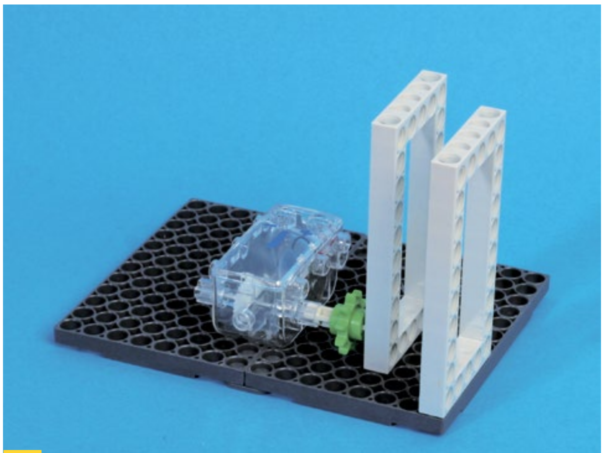
2 x base plates **1**	6 x long frames **2**
6 x short frames **3**	6 x short rods **4**
4 x large gear wheels **6**	4 x medium gear wheels **7**
10 x small gear wheels **8**	3 x small sprockets **9**
3 x medium sprockets **10**	1 x large sprocket **11**
3 x long axle shafts **16**	4 x short axle shafts **18**
1 x engine shaft **19**	1 x black cable **20**
1 x red cable **21**	1 x battery holder **22**
1 x solar module **23**	1 x solar engine **24**
20 x anchor pins **26**	147 x chain links **29**
2 x attachment plates **27**	



1

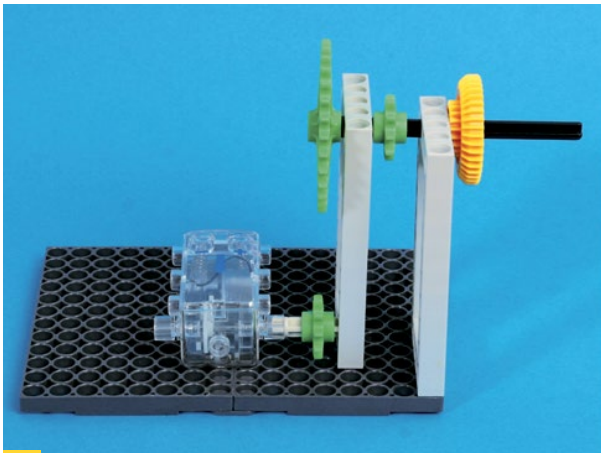
1. Connect two base plates (1) with the help of the attachment plates (27). Attach the engine (24) with engine shaft (19) and small sprocket wheel (9) to the base plates.





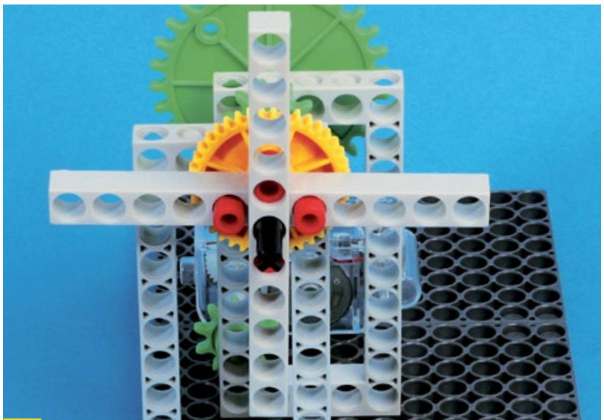
2

2. Now mount two short frames (3) to the base plate. They will serve as a support structure for the two small wind wheels.



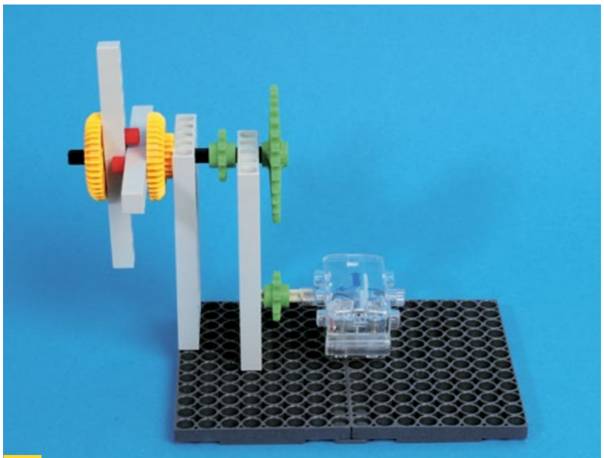
3

3. A long axle shaft (16) with small (9) and large sprocket wheel (11) and small (8) and medium gear wheel (7) goes through the second hole of each of the frame stands.



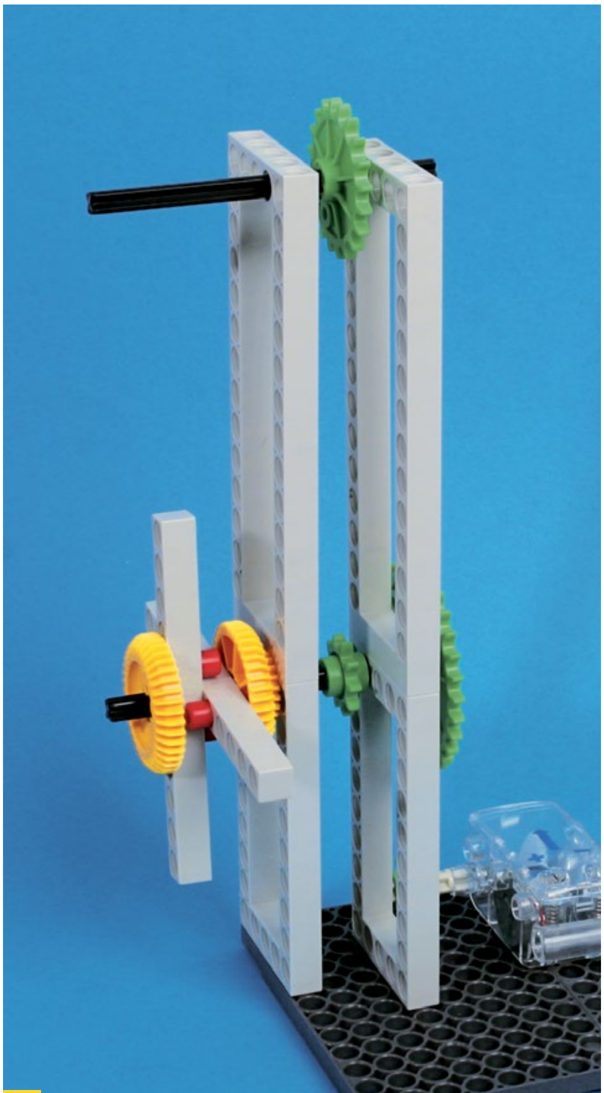
4

4. Insert two anchor pins (26) into two short rods (4), to the left and right of the center hole. Mount one rod on the axle shaft with the anchor pins sticking out to the front, and mount the other rod with the anchor pins the other way around.



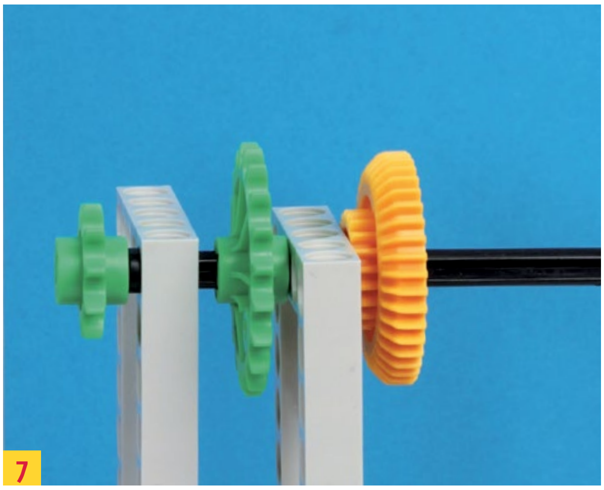
5

5. A second medium gear wheel (7) goes on the outside. The rods form a small wind wheel held by the two medium gear wheels.

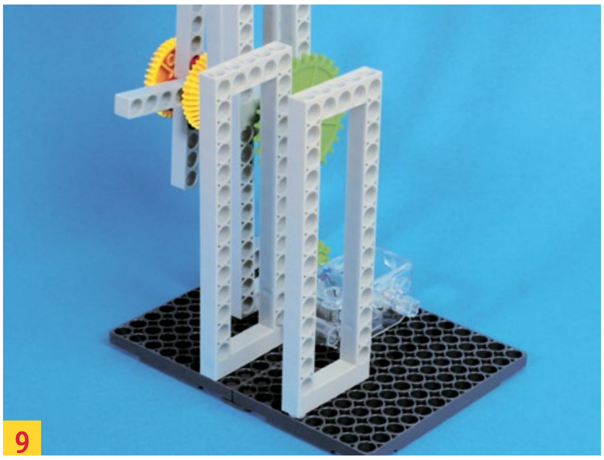


6

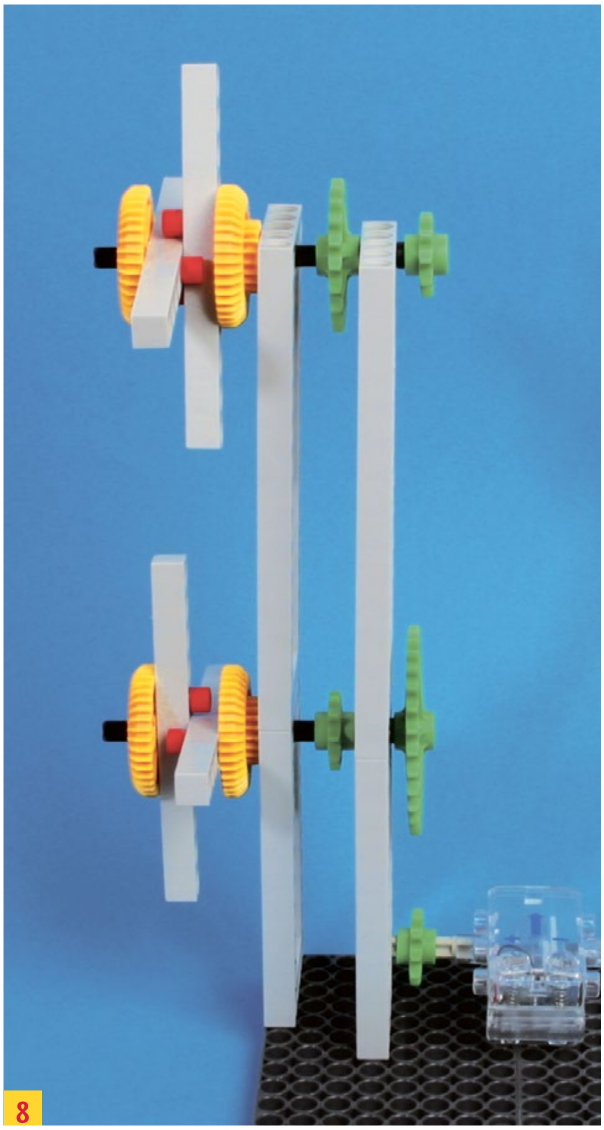
6. Now mount two long frames (2) on the short frames and insert a long axle shaft (16) with a medium sprocket wheel (10) on top.



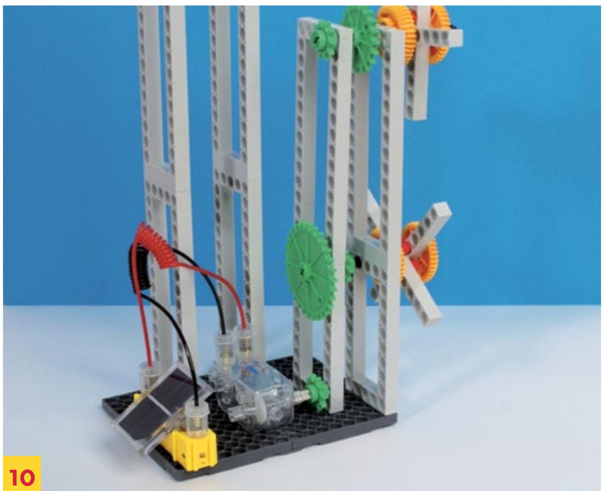
7. This is where the drive for the second small wind wheel will be. You will need a small sprocket wheel (9) as well as a small (8) and medium (7) gear wheel.



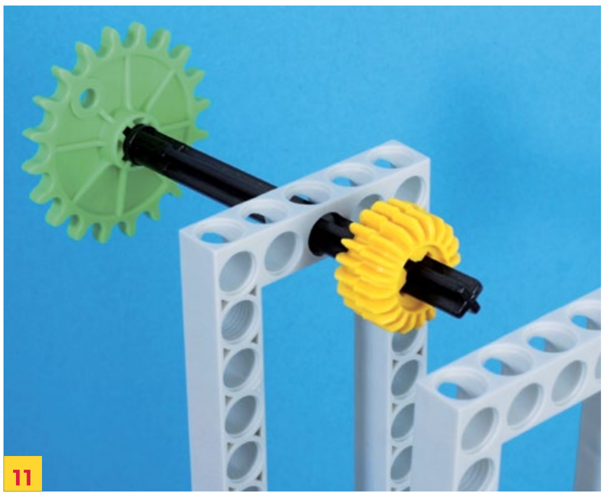
9. Now it's time to build the support structure for the large wind wheel. First, attach two more long frames (2) to the base plates.



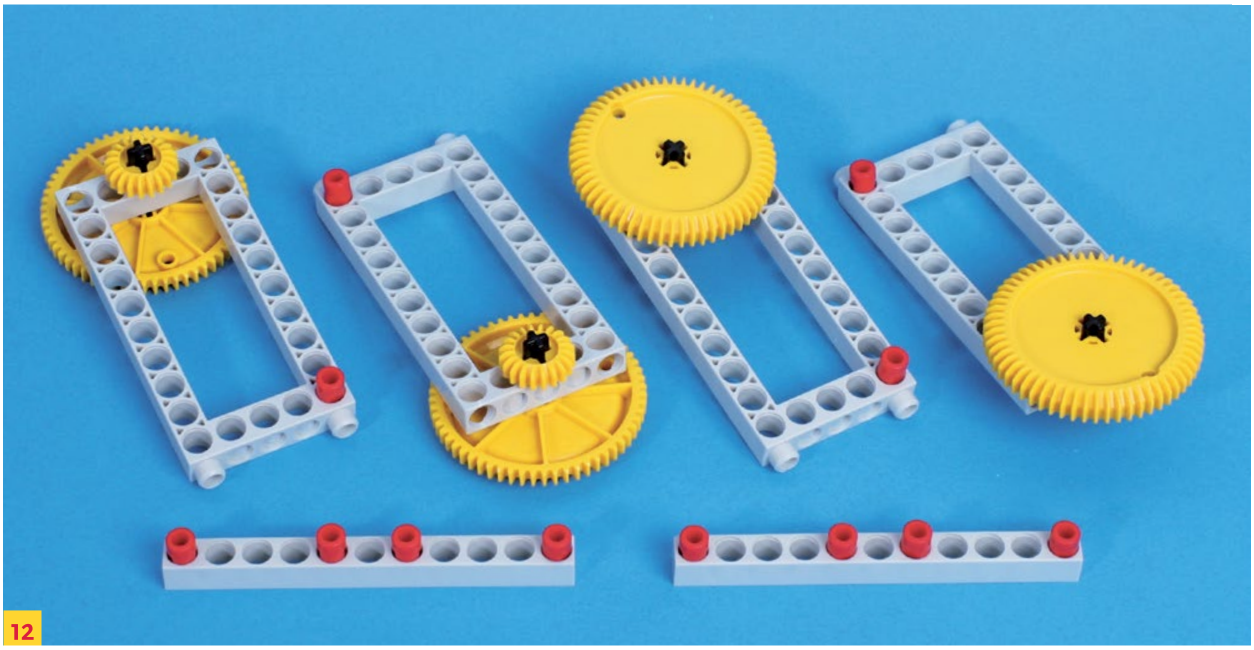
8. Construct another small wind wheel with two short rods (4) and four anchor pins (26), and secure it to the axle with a medium gear wheel (7).



10. Lengthen the support structure with two long frames (2). Then mount the holder (22) with solar module (23) on the base plate below, and hook up the cables (20/21).

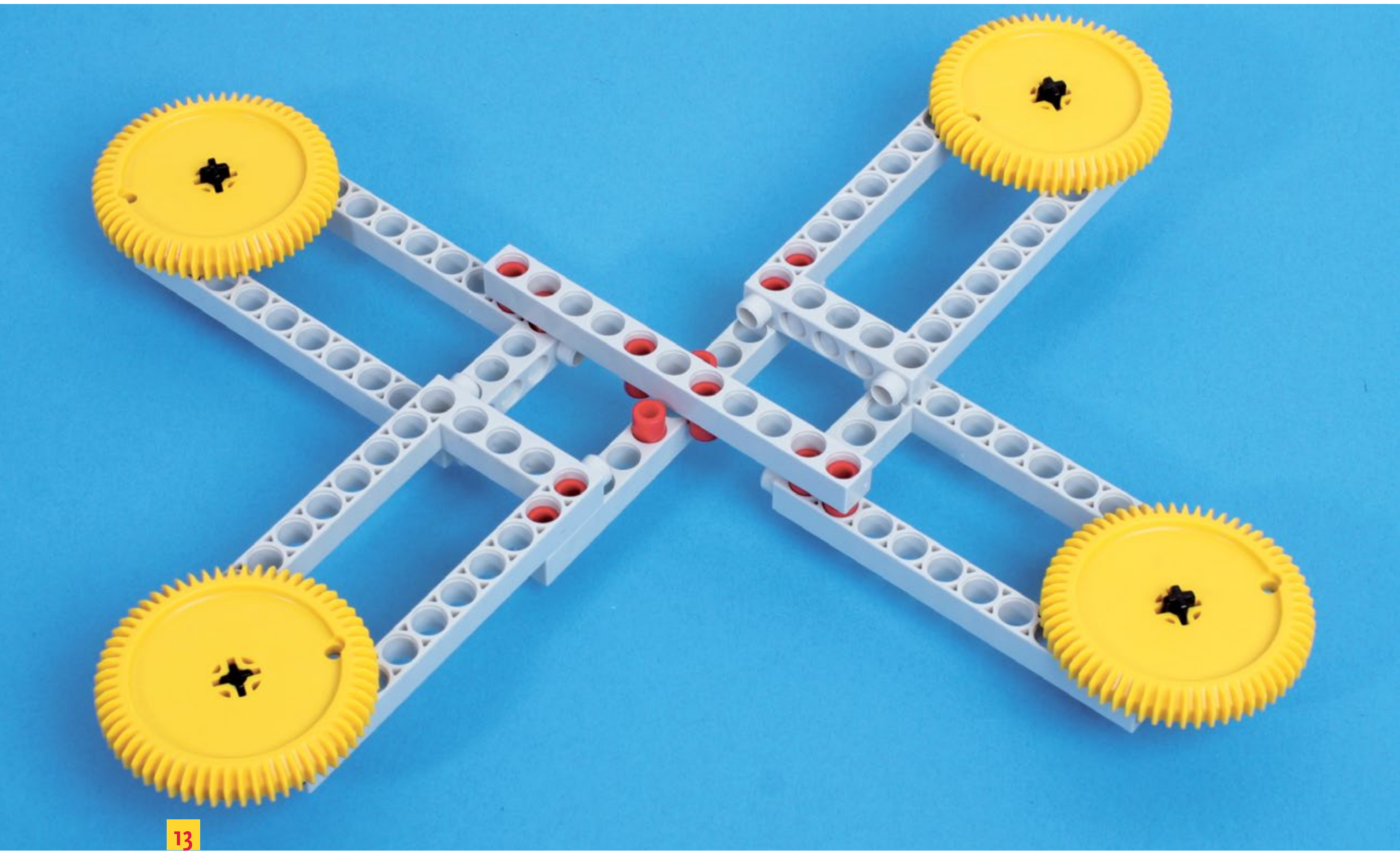


11. Up top, through the center hole of the two frames, insert a long axle shaft (16) with two small gear wheels (8), plus a medium sprocket wheel (10) on the outside.



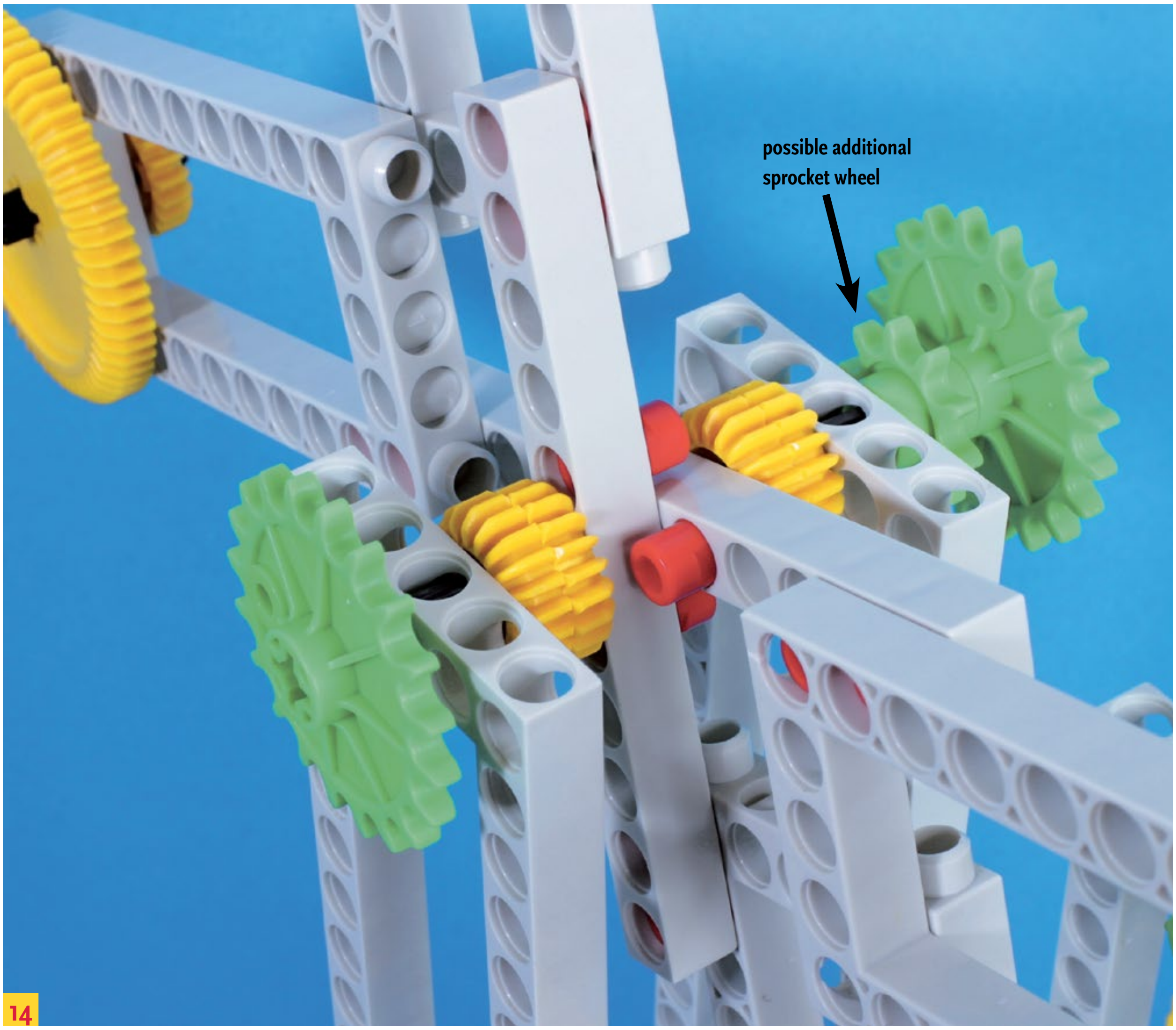
12

12. Prepare the assembly for the large windmill wheel by first building four identical blades. Build each of them out of one short frame (3), one short axle shaft (18), one small (8) and one large gear wheel (6), as well as one anchor pin. To connect the blades to one another, you will need two short rods (4), each with four anchor pins (26).

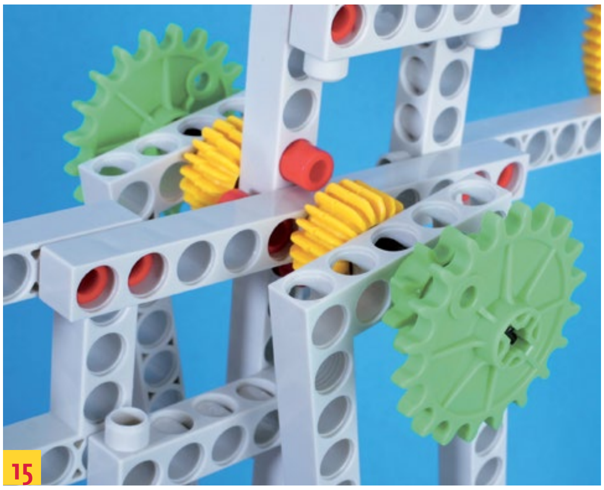


13

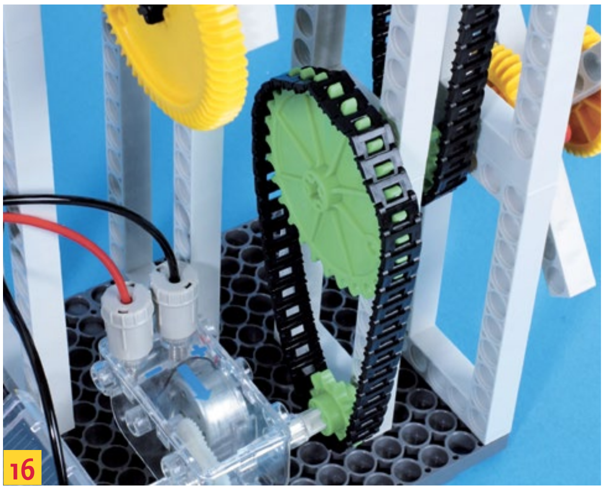
13. The wind wheel is composed of two pairs of blades, with each pair consisting of two single blades connected together. The lower double blade is already assembled, and you can see how the rod is supposed to connect the two blades of the other double blade. In the center, four anchor pins mesh in such a way as to loosely connect the two double blades to each other. The entire wind wheel is mounted through the hole in the middle.



14. The two double blades are attached to the already-mounted axle shaft. Set them against the two gear wheels that are already there. Then add two more small gear wheels (8), so the blades are clamped between the gear wheels. On the outside, a medium sprocket wheel (10) completes the assembly. Depending on how precisely you assembled the pieces, you may also need a small sprocket wheel (9).



15. This picture shows you from the other side how the blades are attached. The double blades have to sit firmly between the gears so they don't slip.



16. Finally, attach the drive chains. They are made of 39, 62, and 46 chain links (29), as shown in the picture on page 49.

Mobile Crane Car

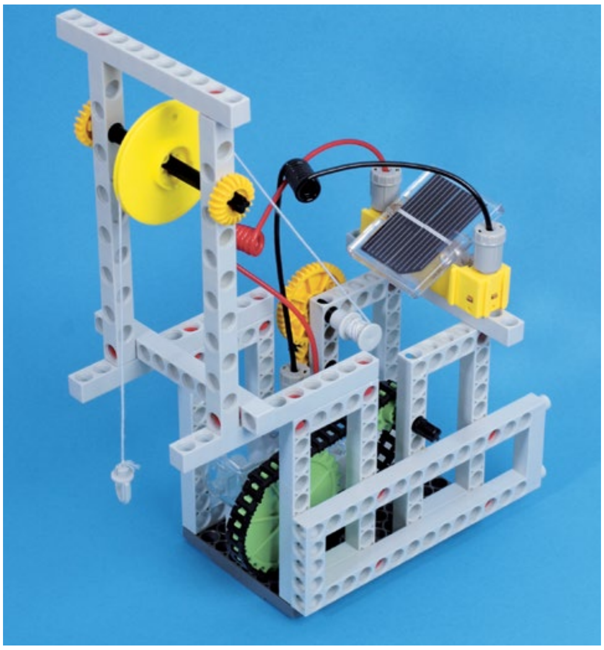
Removable Crane Assembly

This crane car is actually made out of two separate models: the crane assembly and the vehicle mount. That lets you transport the crane wherever it may be needed.

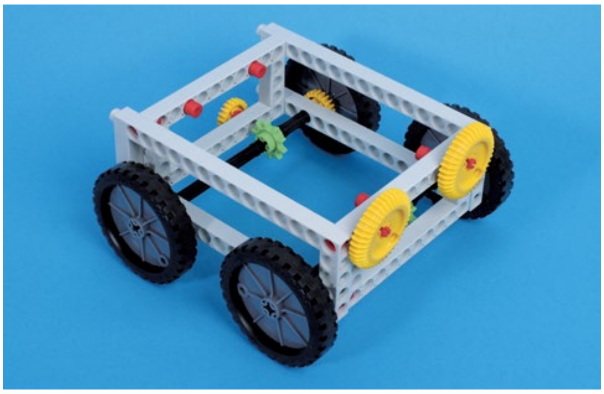
You dismount the crane assembly on site, so that it can sit securely while lifting loads. Once you have lifted them, you remount the assembly onto the car so that you can carry the cargo to another location.

The heart of the heavy crane car is the actual crane assembly, which can lift and lower a variety of loads with the help of the solar-driven engine and a crane hook that is raised and lowered by the cord and spool. A large pulley wheel mounted on its own framework serves as a guide for the cord. This framework has two functions. First, its height makes it possible to lift large items (for example, a long rod). Without the tall framework, the distance between pulley and crane hook would be too small, and many items couldn't be lifted properly off the ground.

The crane car consists of two separated models: the crane assembly and the chassis it sits on.



The crane hook extends far enough over the front of crane so that it can raise loads without interference.

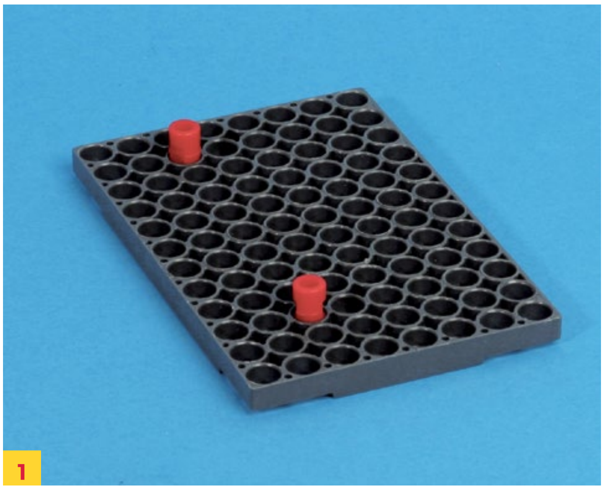


The chassis serves to transport the crane assembly to where it is needed.

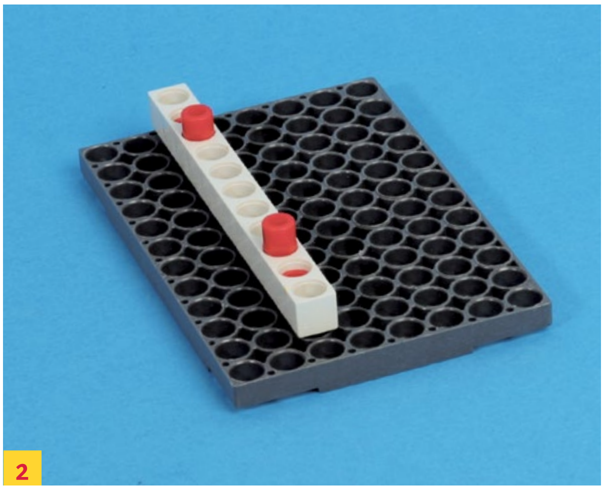
The frame structure also makes it possible to lift loads without banging them against the car or the gear wheels. If the long rods holding the cord pulley were to sit directly on the short frame in front, the hook would always be hitting the assembly.
The drive machinery is held by four short frames. A large frame mounted on one side serves to hold the other frames steady. The technical way to say it is that the large frame "reinforces" the construction. The short rod holding the solar unit in the rear, as well as the two cross-rods on the front framework, also contribute significantly to the reinforcement of the drive mount framework, and therefore to the crane assembly as a whole.

Parts List

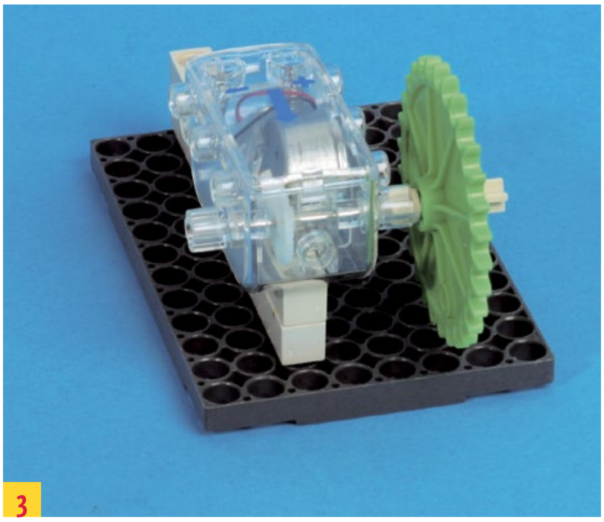
1 x base plate 1	3 x long frames 2
6 x short frames 3	7 x short rods 4
2 x long rods 5	3 x medium gear wheels 7
9 x small gear wheels 8	3 x small sprockets 9
1 x large sprocket 11	1 x large pulley wheel 12
4 x tire wheels 15	4 x long axle shafts 16
2 x medium axle shafts 17	1 x short axle shaft 18
1 x engine shaft 19	1 x black cable 20
1 x red cable 21	1 x battery holder 22
1 x solar module 23	1 x solar engine 24
4 x shaft plugs 25	26 x anchor pins 26
42 x chain links 29	1 x anchor pin lever 30
1 x crane hook with spool and cord 28	



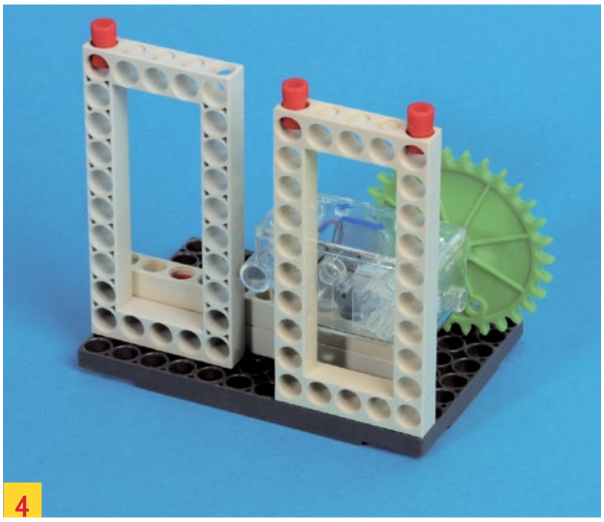
1. A base plate (1) with two anchor pins (26) serves as a foundation for the crane.



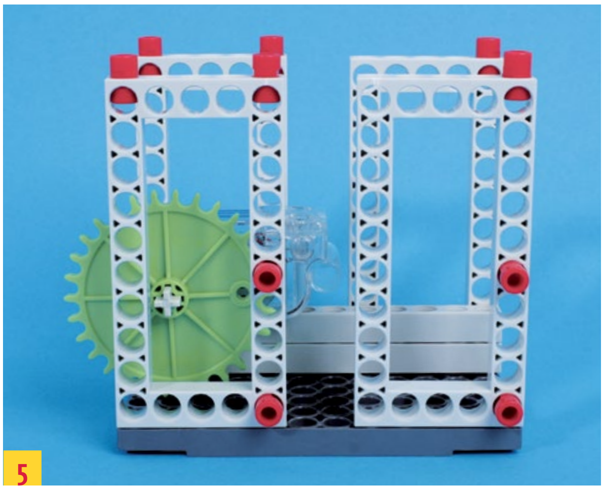
2. Mount a short rod (4) on the anchor pins, and insert two more anchor pins (26) into the rod.



3. Now add a short rod (4) and the solar engine (24) with engine shaft (19) and a large sprocket wheel (11).

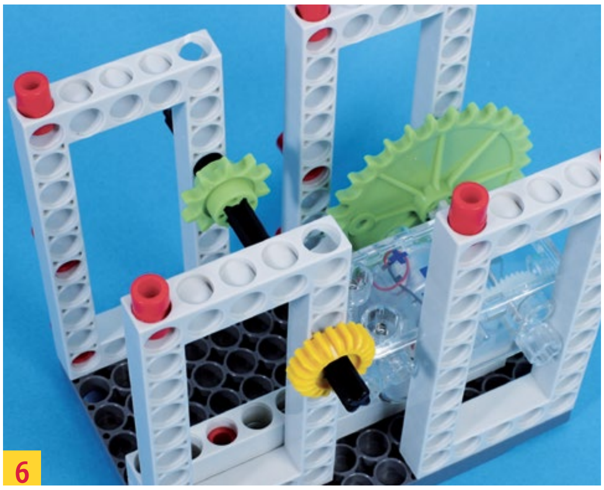


4. The next step is to add two short frames (3) with three anchor pins (26).



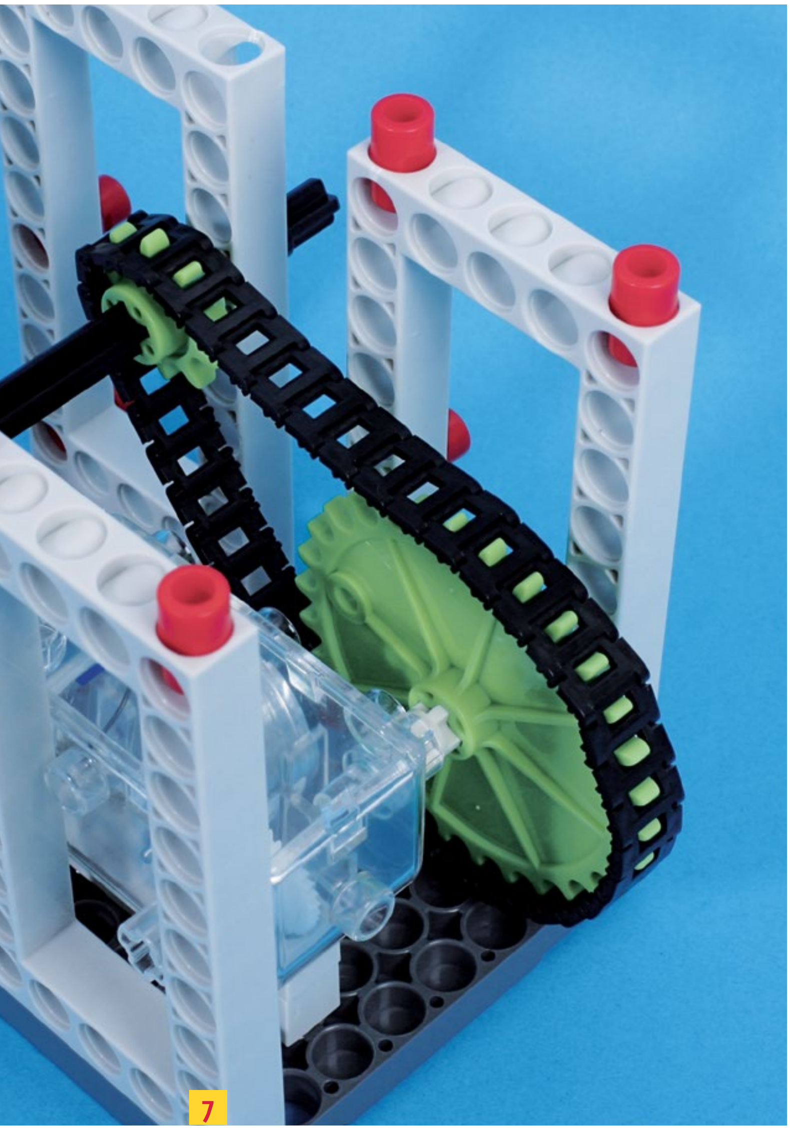
5

5. On the other side of the base plate, mount another two short frames (3) with three anchor pins (26) on top and four on the side.



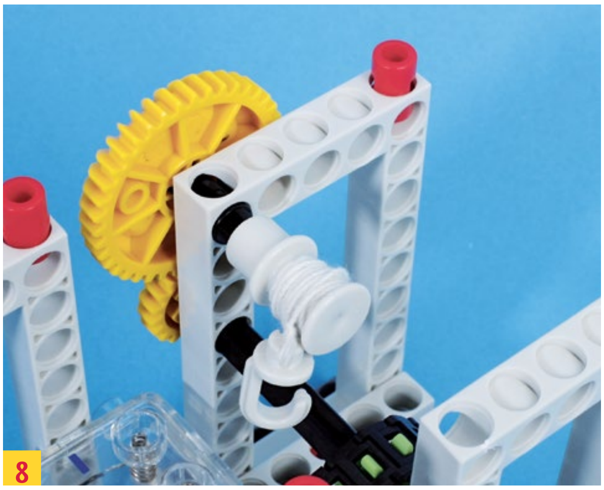
6

6. A long axle shaft (16) with small gear wheel (8) and small sprocket wheel (9) goes through the fourth hole from the top in the frames that have just one anchor pin on the top.



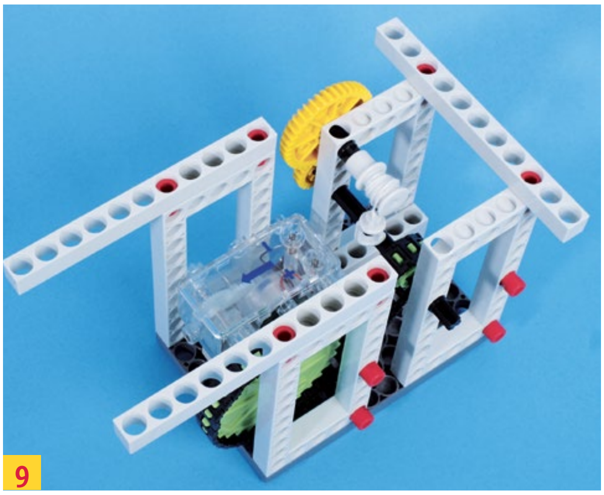
7

7. Now adjust the two sprocket wheels so that they are aligned and attach a chain made out of 42 chain links (29).



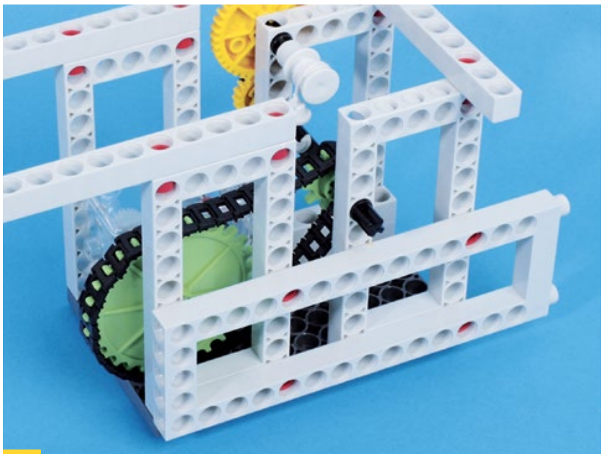
8

8. Insert a small axle shaft (18). Attach a medium gear wheel (7) to one side, and the spool with cord and hook (28) to the other.



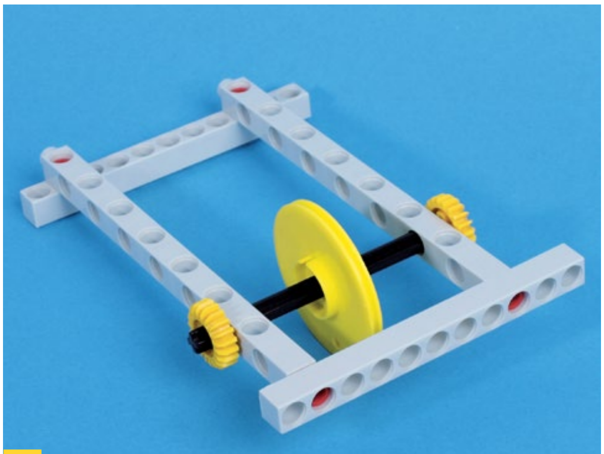
9

9. For the front framework, you will need to mount two short rods (4) onto the anchor pins on the top of the front frames. Also mount a short rod (4) on the rear frames.



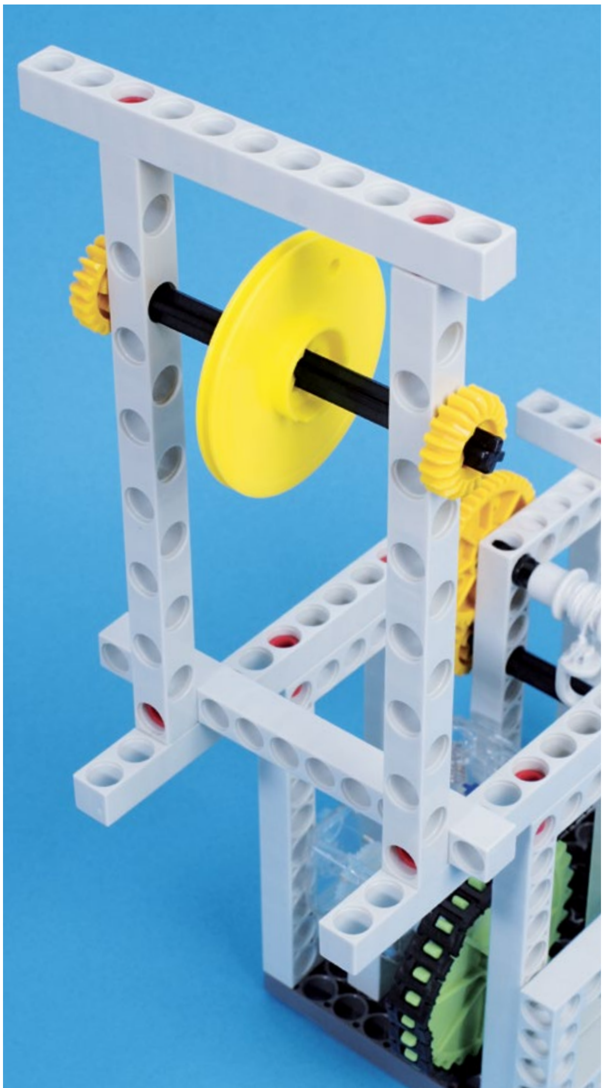
10

10. Mount a long frame (2) on the four free anchor pins on the side away from the engine. This serves to stabilize the construction.



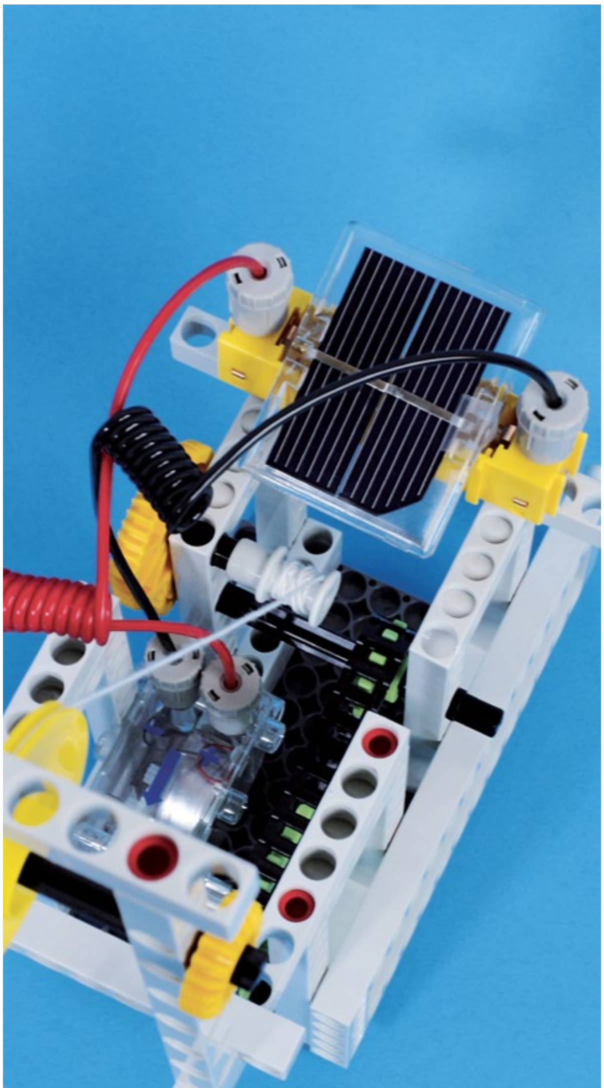
11

11. The large pulley wheel (12) is held by two short (4) and two long rods (5) with four anchor pins (26), along with a long axle shaft (16) with two small gear wheels (8).



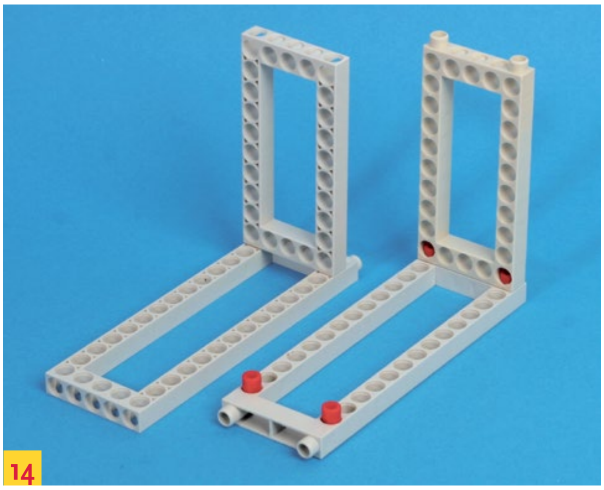
12

12. Now mount the already-assembled framework to the front of the crane assembly. Adjust the pulley wheel so it is aligned with the cord spool.

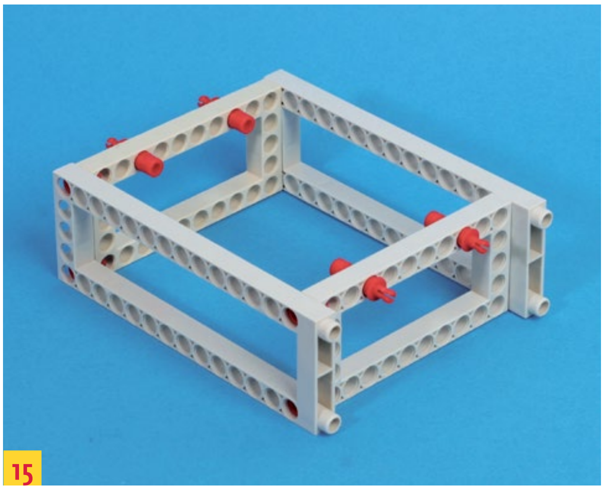


13

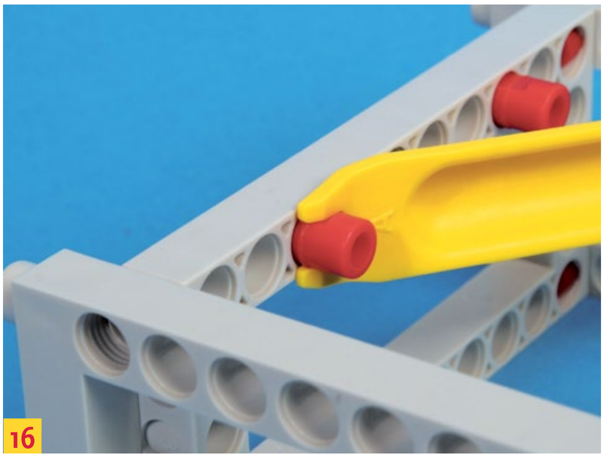
13. Finally, guide the cord over the pulley wheel, mount the holder (22) with the module (23) and attach the cables (20/21). Be sure that the cables don't interfere with the cord.



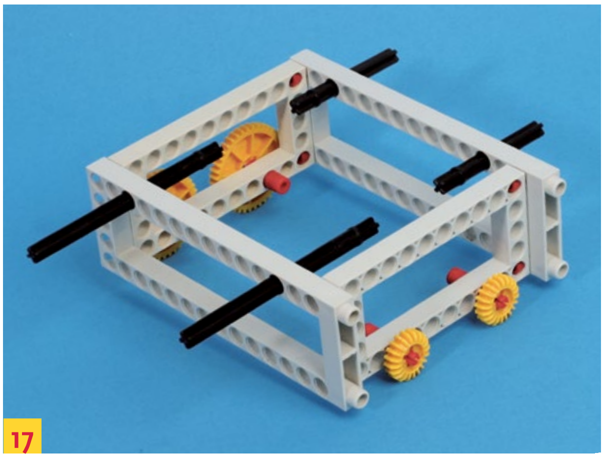
14. The framework for the vehicle mount is made of two short (3) and two long frames (2). You will need four anchor pins (26) in order to combine the frames into a rectangle.



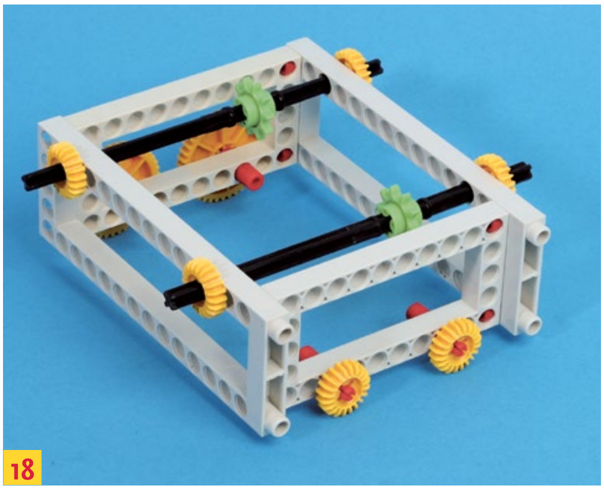
15. Once the frames are connected, attach four anchor pins (26) on the inside and four shaft plugs (25), which are going to hold decorative wheels, on the outside.



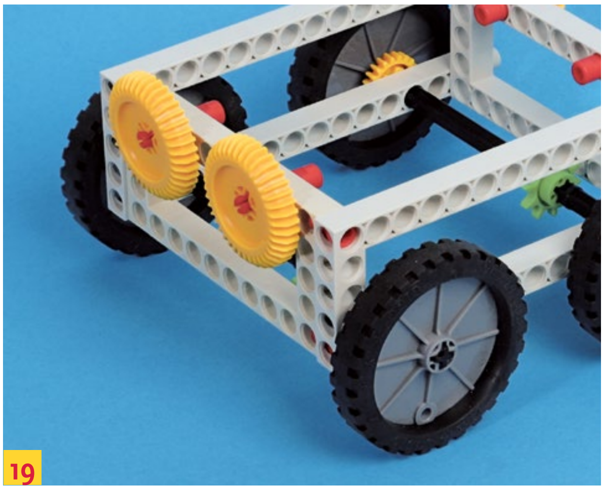
16. The four anchor pins on the inside serve to support the base plate of the crane assembly. Use the anchor pin lever (30) to adjust them so they sit horizontally.



17. Each of the vehicle mount's axles is built out of one medium (17) and one long axle shaft (16). Two small (8) and two medium gear wheels (7) serve as headlights.



18. The axles are connected by two small sprocket wheels (9). Put four small gear wheels (8) on the outer ends of the axles so that the axles do not shift.



19. Now you just have to attach the four tires (15). Test the axles to make sure they turn easily. Then you can simply place the crane assembly on the vehicle mount.

Heavy Duty Construction Crane

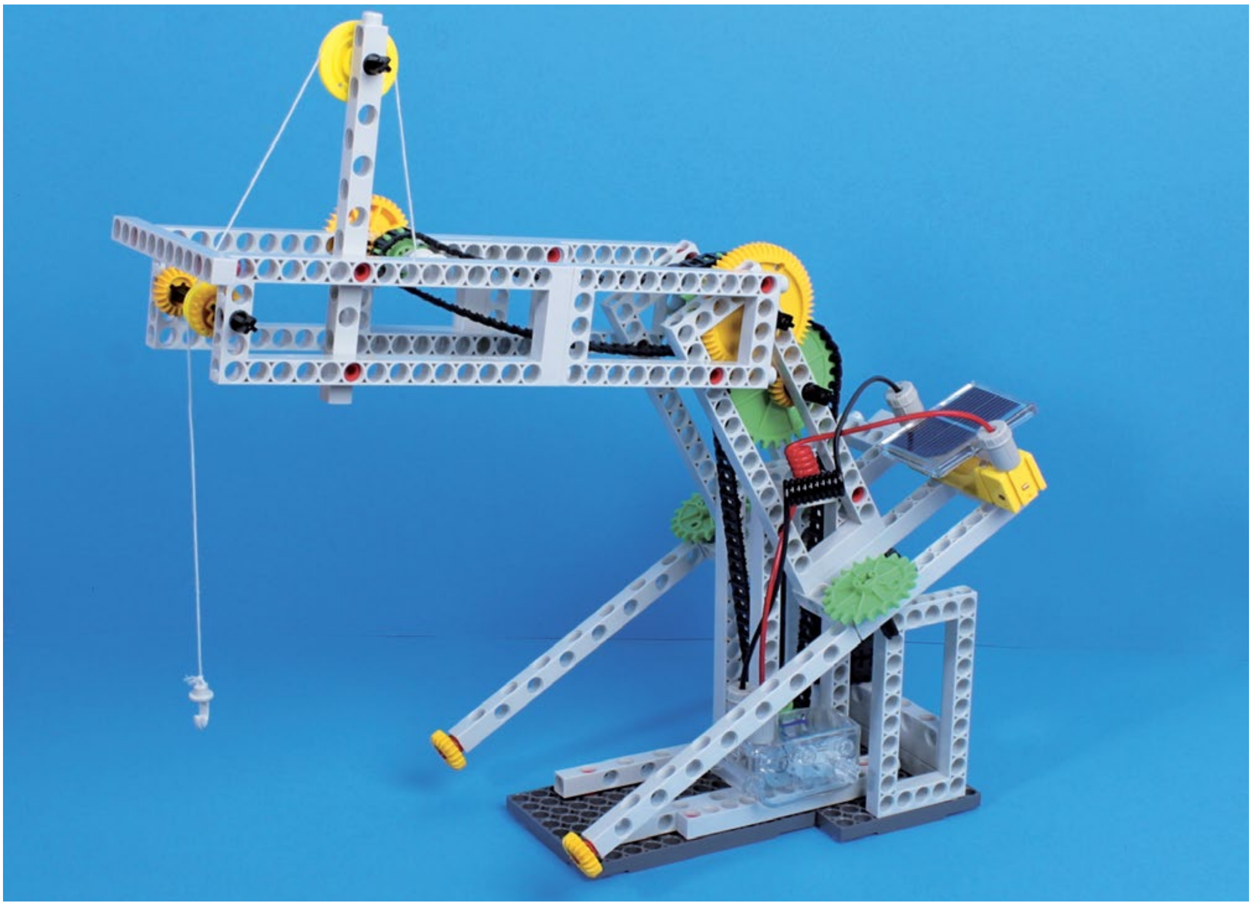
"Crooked" Construction

For our final project, we will build a heavy construction crane. The unusual thing about it is that the frame sections are assembled a little crookedly, rather than at a right angle. This is made possible by anchor pins arranged so that they are offset from one another, with large and small frames mounted on these anchor pins.

This crane is a very large model. That makes it all the more crucial that you assemble everything carefully and that you make sure that everything is attached securely. Wheels, pulleys, and chains have to turn easily. The chains are very long, so be sure that their sprocket wheels are precisely aligned. Otherwise, they will get twisted. The crane spool and the pulleys have to guide the cord reliably, so adjust all the wheels and pulleys carefully.

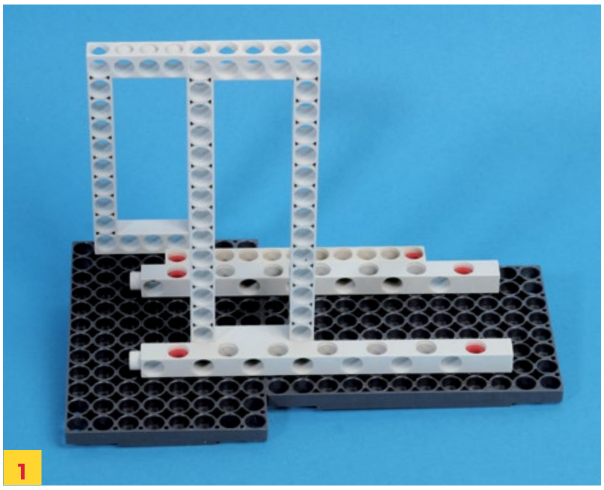
Parts List

2 x base plate 1	6 x long frames 2
6 x short frames 3	5 x short rods 4
6 x long rods 5	1 x large gear wheel 6
1 x medium gear wheel 7	8 x small gear wheels 8
2 x small sprockets 9	3 x medium sprockets 10
1 x large sprocket 11	1 x medium pulley wheel 13
1 x small pulley wheel 14	4 x tire wheels 15
4 x long axle shafts 16	1 x medium axle shaft 17
3 x short axle shafts 18	1 x engine shaft 19
1 x black cable 20	1 x red cable 21
1 x battery holder 22	1 x solar module 23
1 x solar engine 24	2 x shaft plugs 25
26 x anchor pins 26	142 x chain links 29
1 x crane hook with spool and cord 28	

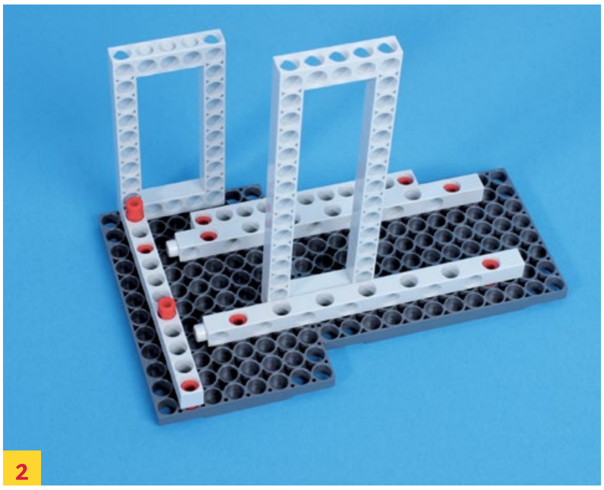


The arm of this heavy construction crane is mounted at a slight angle. The hook is all the way at the front of the model, while the engine is all the way down on the base plate, with the drive train passing through two very long chains. That is how the great distance is bridged from one end to the other.

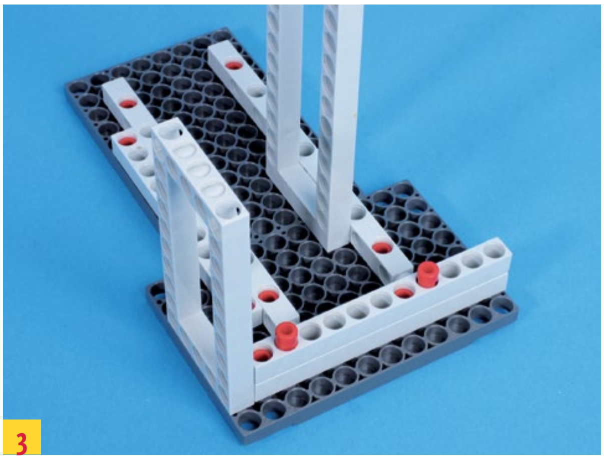
When you assemble the crane, it is crucial that the drive wheels are precisely mounted and the chain and gear drives work perfectly.



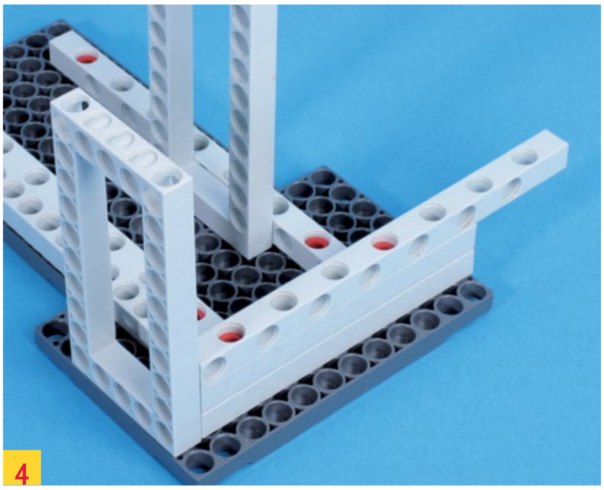
1. Connect the base plates (1) with two long (5) and one short rod (4) along with six anchor pins (26). Then attach one short (3) and one long frame (2) to the plates.



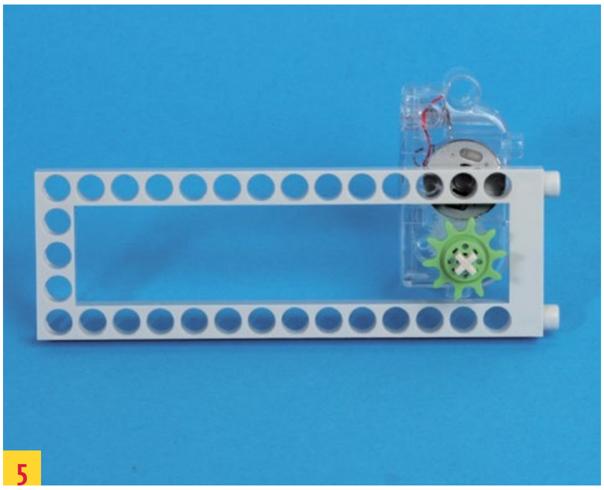
2. Insert four anchor pins (26) into one short rod (4) and attach the rod to the left base plate. Look at the picture to see where to put the anchor pins.



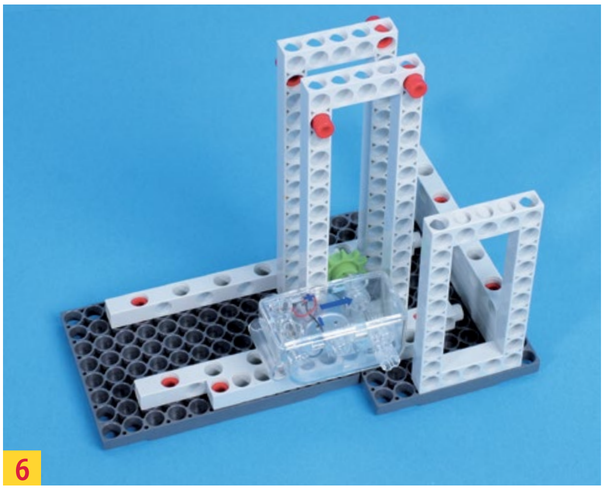
3. Attach one more short rod (4) to the rod you just mounted. Insert two anchor pins (26) into this one as well.



4. Now, a long rod (5) goes on the two short rods. The permanent pin on the end of this rod goes into the short frame on the left.



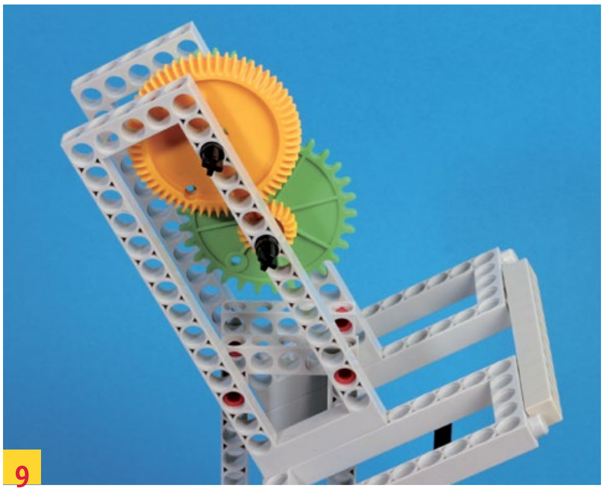
5. The solar engine (24) with engine shaft (19) and small sprocket wheel (9) sits at the lower end of a long frame (2).



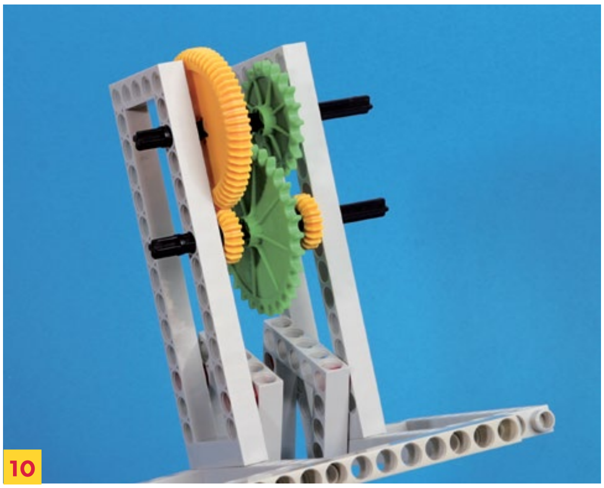
6. Now mount the frame with the engine on the base plate. Four anchor pins (26) go into the two long frames sticking up vertically.

7. Now, attach two long frames (2) to the anchor pins. Attach a short frame (3) to the bottom of each of them, and connect the short frames at the rear with a short rod (4).

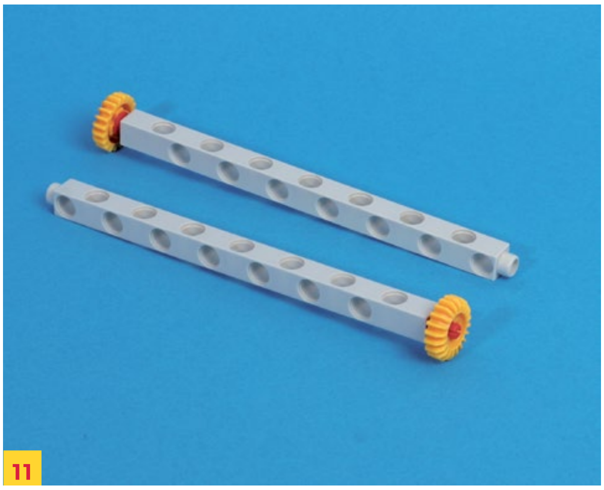
8. For looks, attach two medium sprocket wheels (10) with two short axle shafts (18) along with a long axle shaft (16) with four tires (15) and a small gear wheel (8).



9. In the long frames, insert two long axle shafts (16) with two small gear wheels (8), a medium (10) and a large sprocket wheel (11), and a large gear wheel (6).

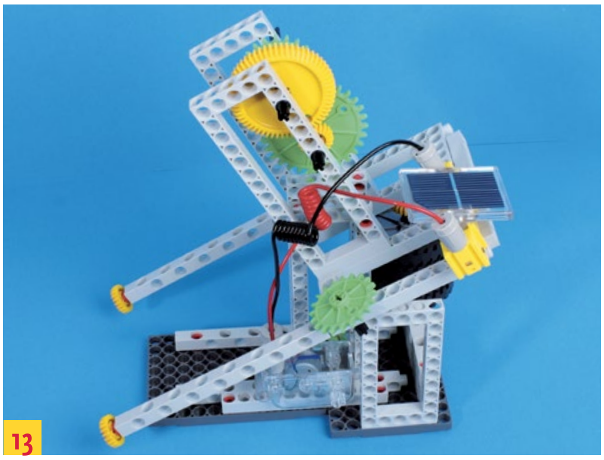


10. Adjust the wheels so the large gear wheel meshes with the small one. The two sprocket wheels shouldn't sit too close to other components. Check to see if the wheels turn well.



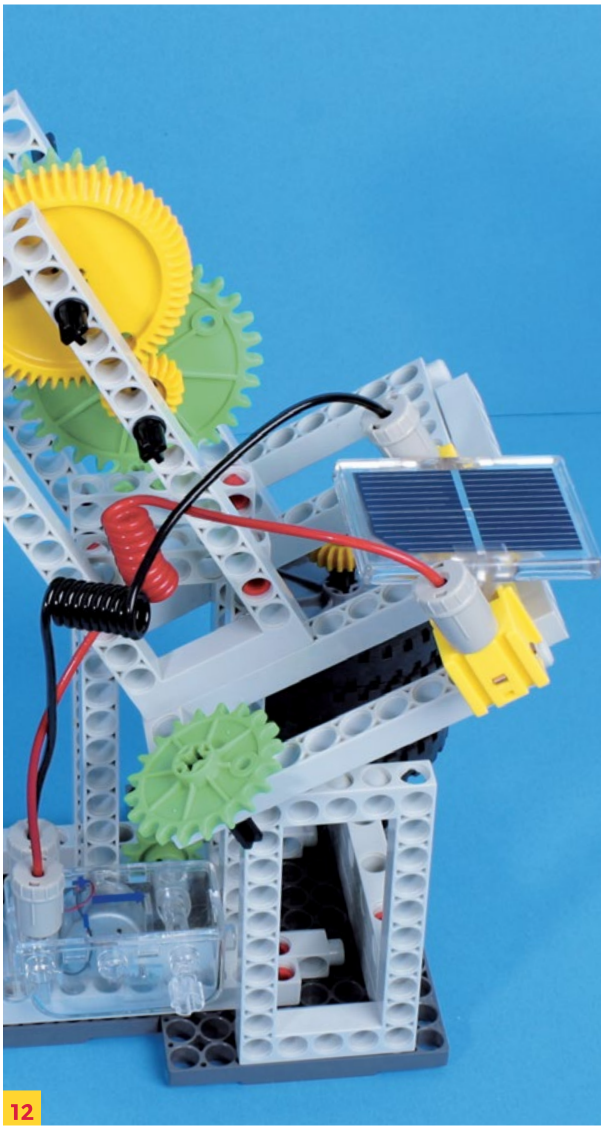
11

11. For extra decoration, take two long rods (5) and attach a shaft plug (25) and small gear wheel (8) to the end of each.



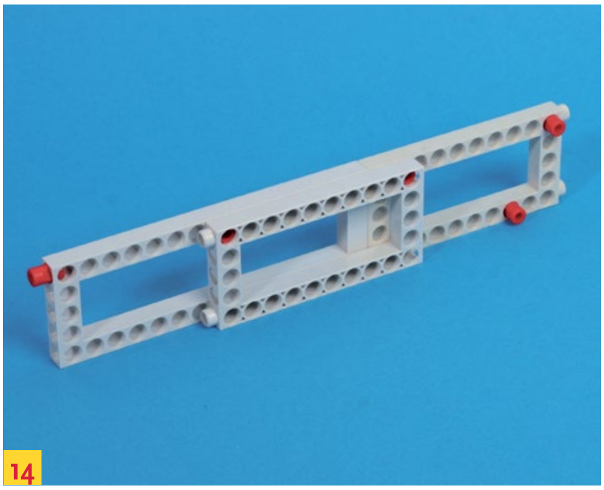
13

13. Now mount the two long decorative poles on the outer frames. Check that all the parts sit tightly and don't wobble.



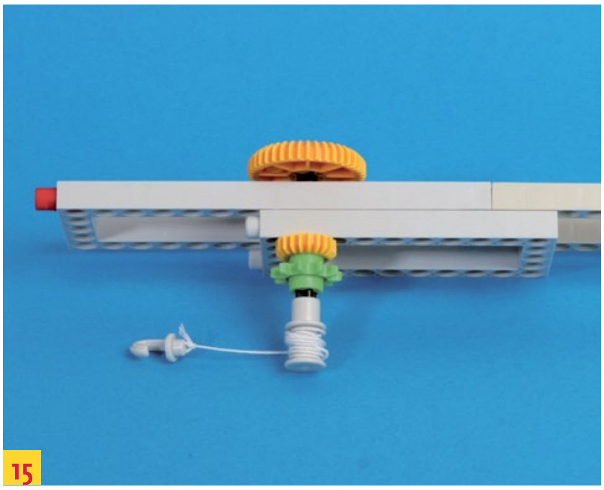
12

12. Mount the holder (22) with the solar module (23) on the rear small frame. Then attach the cables (20/21) so that they don't interfere with the drive machinery.



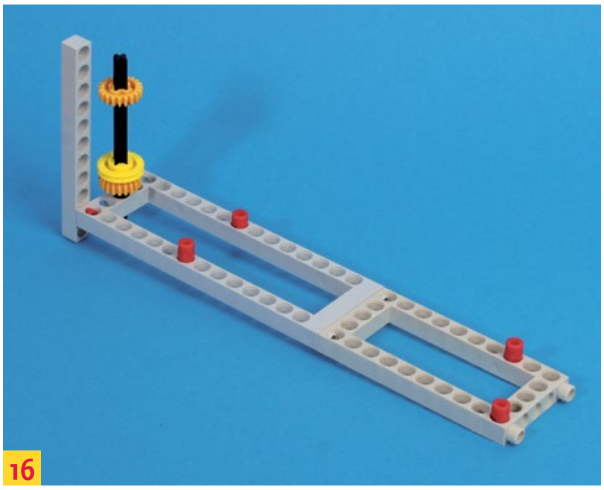
14

14. Build the first side section of the arm. Connect two short frames (3) and one long frame (2) with two anchor pins (26). Then attach three more anchor pins (26).

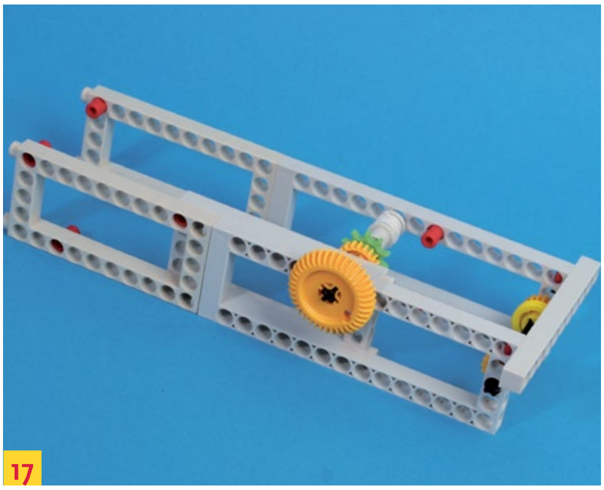


15

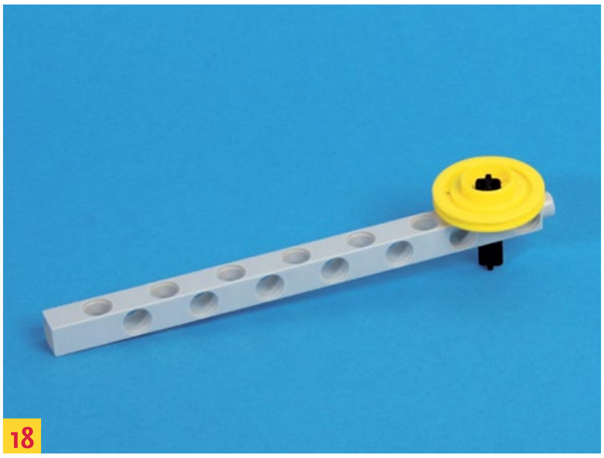
15. Mount the crane spool on a medium axle shaft (17) with a small gear wheel (8) and a small sprocket wheel (9). A medium gear wheel (7) secures the shaft.



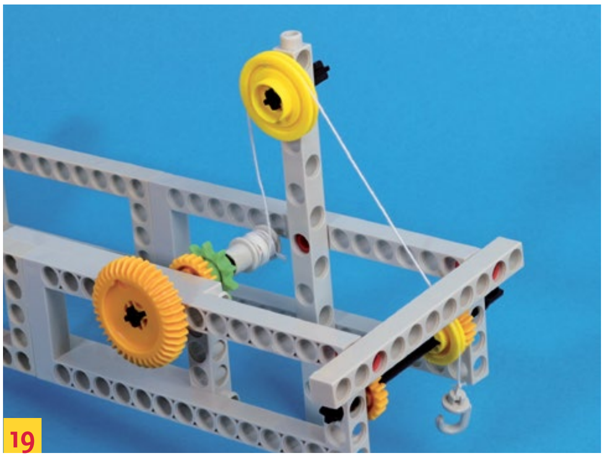
16. Now you'll need a short (3) and a long frame (2), a short rod (4), a long axle shaft (16), two small gear wheels (8), a small pulley wheel (14), and five anchor pins (26).



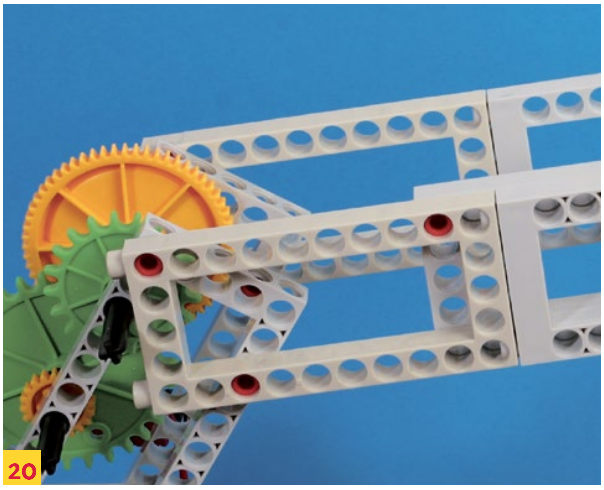
17. Now combine the two sections of the arm. Adjust the position of the small pulley wheel so that it is aligned with the crane spool.



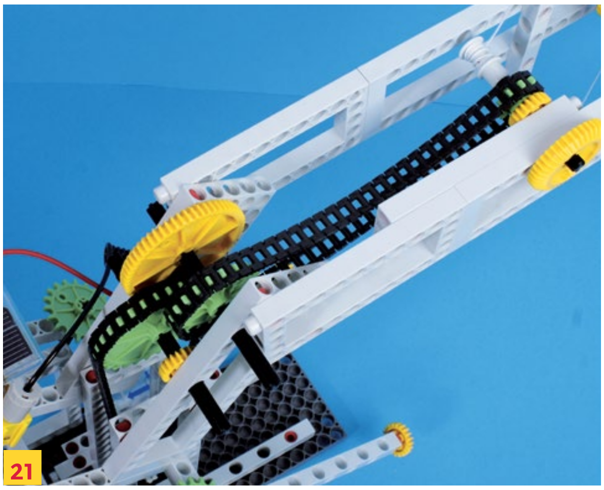
18. In order to be able to run the cable even higher, mount the medium pulley wheel (13) on a long rod (5) with a short axle shaft (18).



19. Attach this rod to the arm and guide the cord over both pulley wheels. Make sure that the top and forward axles turn easily.



20. Now mount the arm onto the crane. The arm is positioned at an angle with the help of the offset anchor pins.



21. Finally, mount chains made of 74 and 68 links (29). For the model to work well, all the chains and wheels have to move easily.

Designing Your Own Solar Models

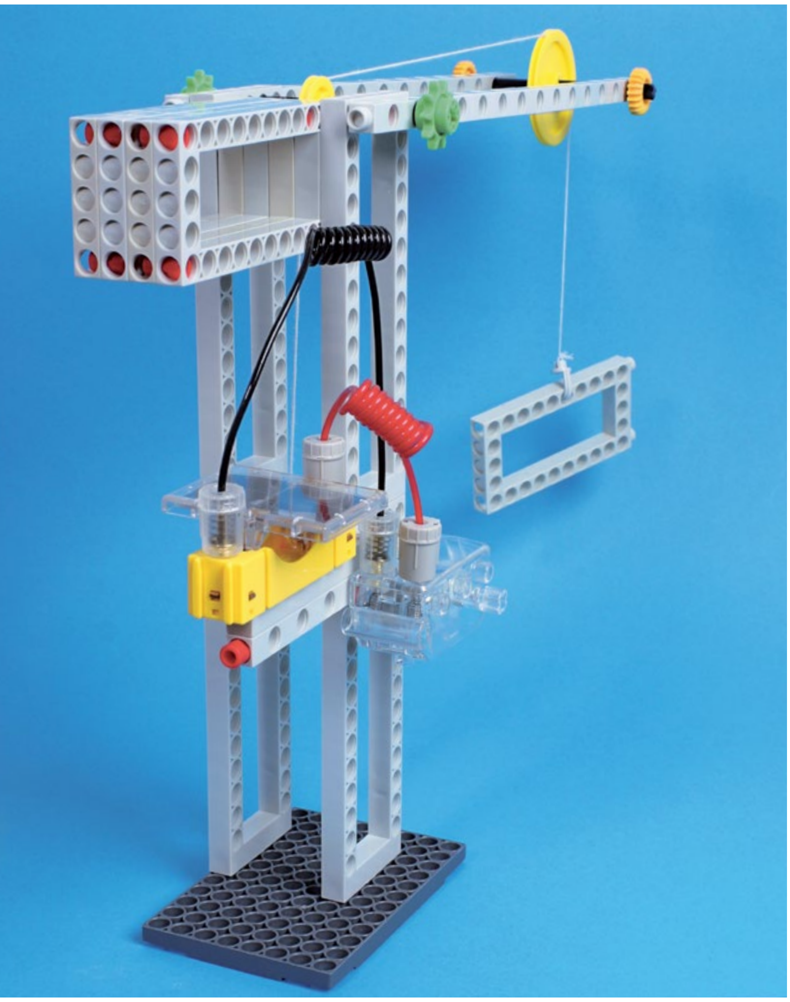
Multiple Possibilities

If you have built all the models in this book, you are a real solar engineer. You know lots of ways the solar engine can be used and you have learned the function of all the components in the kit.

But the models that you have built are by no means all the things you can make with the solar engine and the other components. You could also, for example, build a tall crane, a fan, or a spaceship. Let your imagination run free and invent your own models. In all cases, the important things are that the construction is stable and the drive systems run smoothly.

Stable Construction

Above all, be sure that your models have a stable construction. Nothing is more frustrating than when a model falls apart as soon as you try to use it. That is particularly true for large models. Be sure to stabilize the building components sufficiently (see p. 55). For models that are not mobile, it is always a good idea to use a base plate as a foundation. It gives the model stability. When assembling a model, it goes without saying that you should never try to jam components together by force or bend them. If two pieces aren't connecting or inserting easily, then you've constructed something wrong. You can always find a different way to do it.



You can design and build an almost endless number of solar vehicles and devices, such as this tower crane.

Smooth-running Drive Systems

With all drive systems, it is important that they run smoothly. Chains must be neither too loose nor too tight. The sprockets holding a chain should be lined up exactly. Otherwise, the chain will easily twist and your model won't work well.

The same goes for gear drives: the gear wheels have to mesh with the right distance between them. Only then will everything work well and utilize the solar engine's full power.

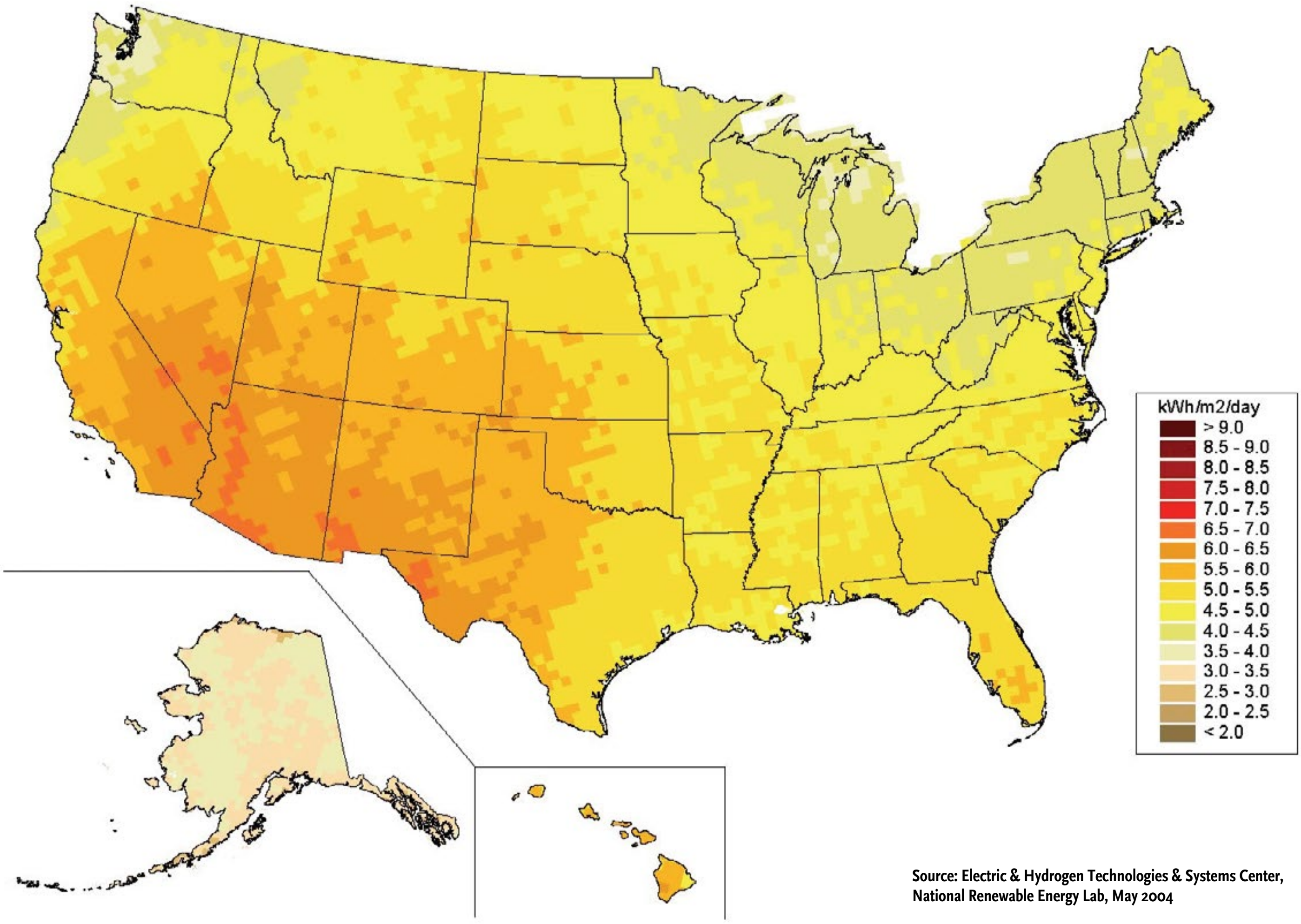
Once you have finished constructing your drive system, before building anything else you should check to make sure that everything runs well. Hold the engine up to the light and make sure that some construction detail or other isn't placing too heavy a load on it. That can happen, for example, with a car design that has ended up carrying too much weight.

Drivable models run well when they drive on four tires (15) or on a caterpillar track (see p. 24). Gear and sprocket wheels don't work well as driving wheels, because the solar engine would have to expend too much force to move them over the ground.

That's it! Have fun constructing and building!

US Annual Average Solar Energy

received by a photovoltaic cell



Source: Electric & Hydrogen Technologies & Systems Center, National Renewable Energy Lab, May 2004