Kit Contents ............................................ 3
Tips and Additionally Required Materials ............... 6

Earth Attracts Us .................................... 7
Workshop 1: Potato Trap ............................. 7
Experiment 1: Potato Trap ............................ 9
Workshop 2: Center of Gravity Locator ............... 11
Experiment 2: Finding Your Center .................... 12
Workshop 3: Sail Car .................................. 14
Workshop 4: All-Terrain Vehicle with Treads ........... 16
Experiment 3: All-Terrain Vehicle Time Test .......... 18
Experiment 4: Fall Time ................................ 18
Workshop 5: Fall Speed Indicator ....................... 18
Experiment 5: Weight = Gravitational Force .......... 19
Experiment 6: Gravitational Force Increases Fall Speed..19
Workshop 6: Force Scale, 0 to 7.5 Newtons ............ 20
Workshop 7: Ship’s Lantern ........................... 22
Experiment 7: The Steady Tealight .................... 24
Experiment 8: Forces of Inertia ....................... 24
Workshop 8: Shot Put Device .......................... 25
Workshop 9: Numbered Target Board .................. 27
Experiment 9: The Trajectory Parabola ................. 28
Experiment 10: How Steep and How Far? .............. 28

Simple Machines ..................................... 29
Workshop 10: Force Scale and Type One Lever .......... 30
Experiment 11: Measuring Forces on a Lever .......... 32
Workshop 11: Force Scale and Type Two lever .......... 33
Workshop 12: Lever Postal Scale ...................... 35
Workshop 13: Fixed Pulley ............................ 37
Experiment 12: Testing the Fixed Pulley ............... 38
Experiment 13: The String Eater ........................ 39
Workshop 14: Simple Combination Pulley .............. 39
Workshop 15: Test Vehicle on an Inclined Plane ...... 40
Experiment 14: On a Slope Over a Precipice .......... 42
Experiment 15: Measuring Friction .................... 43
Workshop 16: Wheeled Sled, Runway, and Slide ...... 44
Experiment 16: Friction Makes it Happen ............... 46
Workshop 17: Wedge and Stuck Rack .................. 48
Experiment 17: Wedge Work ......................... 48
Experiment 18: Screw .................................. 49
Experiment 19: Wheels and Rollers .................... 51

Getting in Gear ....................................... 53
Workshop 18: Transmission of Force .................. 53
Experiment 20: Energy Transmission Equilibrium .... 55
Workshop 19: Two-Speed Crane with Gearshift ....... 56
Experiment 21: Power Test in Two Steps ............... 57
Workshop 20: Cogwheel Train .......................... 58
Workshop 21: Jumping Jack with Crank Drive ........ 60
Workshop 22: Hand-Crank Theater .................... 61
Experiment 22: The Caged Bird ....................... 63
Workshop 23: Mars Robot ............................ 63

Forces at Work ....................................... 66
Workshop 24: Water-Powered Sawmill ................. 67
Experiment 23: Energy in a Bottle ..................... 68
Workshop 25: Water-Powered Potter’s Wheel .......... 69
Workshop 26: Rubber Band Car ........................ 71
Workshop 27: Wind-Power Plant ....................... 73
Experiment 24: Wind-Power Plant Test 1 ............... 77
Experiment 25: Wind Power-Plant Test 2 ............... 79
Workshop 28: Pinball ................................... 81
Experiment 26: The Trajectory of the Pinball .......... 82
Workshop 29: Bowling Alley .......................... 83
Experiment 27: Momentum Propagates Itself .......... 84
Workshop 30: Electric Hammer Mill .................... 85
Workshop 31: Impact Gauge ........................... 86
Experiment 28: Big Fall, Big Bang ..................... 88
Experiment 29: Water Counteracts Swinging Motion ..88
Workshop 32: Oscillation Absorber .................... 89
Experiment 30: The Second Pendulum ................. 90
Experiment 31: Setting the Time ....................... 91
Workshop 33: Pendulum Clock ........................ 91

Turning Forces ....................................... 94
Experiment 32: Pebbles in Flight ....................... 94
Workshop 34: Centrifugal Force Station ................. 95
Experiment 33: Forces in Flight ....................... 97
Workshop 35: Centrifuge ............................. 97
Experiment 34: Spin-dry Principle ...................... 99
Experiment 35: Centrifuge Principle .................... 99
Experiment 36: Centrifugal Switch ..................... 99
Workshop 36: Automatic Centrifugal Switch .......... 100
Workshop 37: Spinning Top ........................... 103
Experiment 37: Top on a Sloping Path .................. 103
Workshop 38: Yo-Yo ................................. 104
# KIT CONTENTS

## What’s inside your experiment kit:

<table>
<thead>
<tr>
<th>No.</th>
<th>Description</th>
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## Checklist: Find – Inspect – Check off

- **No.**
- **Description**
- **Qty.**
- **Item No.**

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

## For some experiments, you will also need:
- Scissors, match stick, blank paper, large plastic bag, wooden skewer, tape, sewing needle, thread, tealight candle, plastic water bottle, paper clips, heavy book, wooden board, extra rubber bands, cup or mug, C batteries or similar-sized objects for weights, small cylindrical container with lid, wire cutter, pliers
In this kit, you will find a large number of colored plastic components. You will use these pieces to build all the structures, machines, and mechanical models used in the experiments. Screws, nuts, bolts, and glue are not included because all of the models are held together with plastic pieces.

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

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

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

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

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

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

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

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

10-12. **Axles: 35-mm (x4), 60-mm (x4), 100-mm (x4)**
   The black axles come in different lengths. They have plus-sign-shaped cross sections, so that gears and wheels inserted onto them turn with the axles. You will be using them mostly as drive axles. They have two different ends. At one end of each axle you will see a ring, which ensures that the axle does not push through the hole of a frame or rod while at the same time leaving enough room to insert a wheel onto it. You will also notice that the axle is thicker on the inside of the ring—small enough to rest inside a hole, but too large to push a wheel onto.
13. Shaft Plug (x20)
This red-colored piece will hold fast when its thick end is inserted into a hole. If you press a wheel into its other end, the prongs will hold the wheel securely while still allowing it to rotate freely. You can also use this piece to attach cardboard and other pieces to frames or rods. When the shaft plug is inserted in a hole, its thin rim will protrude a little, allowing it to be pried out with the part separator tool.

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

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

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

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

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

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

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

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

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

23. Large Pulley Wheel (x2)
Like the two other sizes of pulley wheels, this one is yellow. A rubber band or cord can go along the groove around its rim. On its inner side, you will see a ring with an opening. If you push the inner sides of two equal-sized pulley wheels together and then slide them onto an axle, it creates a drum with room for the knot and an exit hole for the cord. Near its edge, the pulley wheel has a crank-hole for a shaft pin.

Pulley wheels, like sprocket wheels, are used to transmit forces or movements, in order to increase or reduce them. Instead of a fixed interlocking chain, the pulley wheel uses a drive belt made of rubber, leather, or cloth, which can slip and still turn in the groove with fluctuations of force or overloads. Drive belts therefore afford a soft and elastic means of transmission.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Dunkin’ shot put

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

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

You will get a curve that bends only a little bit at first and then more strongly. But what accounts for the curve? It’s simple. The physical trajectory is due to two individual forces: the force with which the ball is shot and the force of gravity. The force with which the object is shot gives it an initial speed and a direction. The initial upward-angled velocity of the object “fights” with the acceleration of its fall. What is the outcome of the fight? Both forces come together in a smooth curve, with no bumps or bruises. The flight path from the takeoff point to ground impact is called a trajectory parabola. The path forms a high arch with a steep shooting angle and a flat arch with a low shooting angle. In addition, the path is flatter and more elongated the greater the initial force is. Because the force is only applied initially, it can only give the ball an initial velocity, and cannot accelerate it. Earth's gravity, on the other hand, acts on the ball during its entire flight — causing the speed of the ball’s fall to the table surface to increase by the gravitational acceleration of 9.81 m/s².

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

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

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

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

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

The Lever

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

One-Armed and Two-Armed Levers

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

Resistance Arm and Effort Arm

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

- **effort force x effort arm length = resistance force x resistance arm length**
body rolls on a surface, and is considerably less than kinetic friction. If you move the crate forward on two rolling broomsticks, it’s easier than just shoving it along the floor. That’s why it’s easier to move furniture if you use a furniture dolly, a platform with wheels beneath it.

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

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

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

**WORKSHOP 16: WHEELED SLED, RUNWAY, AND SLIDE**

1. [Image of a sled]
2. [Image of build steps 1-2]
3. [Image of build steps 3-4]
4. [Image of 100-mm axle]
WORKSHOP 16: WHEELED SLED, RUNWAY, AND SLIDE

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

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

Place the vehicle on the model.

Now try Experiment 16.

Done!