THAMES & KOSMOS

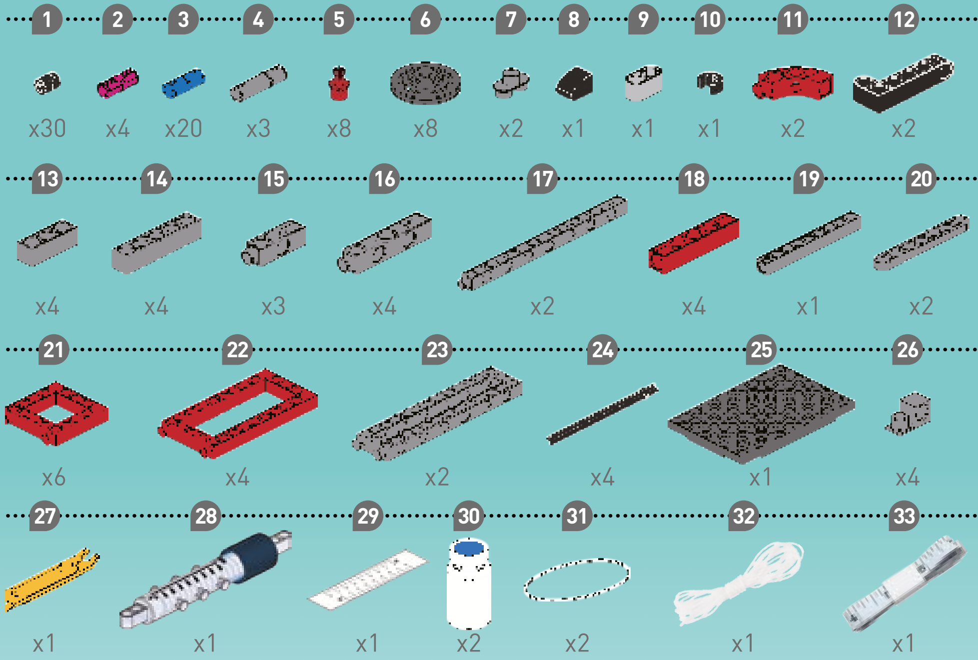
Forces, Motion & Energy

Experiment Manual

Franckh-Kosmos Verlags-GmbH & Co. KG, Pfizerstr. 5-7, 70184 Stuttgart, Germany | +49 (0) 711 2191-0 | www.kosmos.de
Thames & Kosmos, 89 Ship St., Providence, RI, 02903, USA | 1-800-587-2872 | www.thamesandkosmos.com
Thames & Kosmos UK LP, 20 Stone Street, Cranbrook, Kent, TN17 3HE, UK | 01580 713000 | www.thamesandkosmos.co.uk

KIT CONTENTS

What's in your experiment kit:



Checklist:

✓	No.	Description	Quantity	Item No.
◯	1	Short anchor pin, black	30	7344-W10-C2D
◯	2	Connector pin, magenta	4	1187-W10-E1K
◯	3	Axle connector, blue	20	7413-W10-T1B
◯	4	Asymmetrical joint pin, gray	3	7413-W10-U1S
◯	5	Shaft plug, red	8	7026-W10-H1R
◯	6	Wheel	8	7344-W10-O2S1
◯	7	Two-to-one converter	2	7061-W10-G1S2
◯	8	Nose cone	1	7402-W10-C2D
◯	9	2-hole wide rounded rod	1	7427-W10-A1S
◯	10	Gear fixing	1	3620-W10-A1D
◯	11	Curved rod	2	7061-W10-V1R
◯	12	5-hole L-shaped rod	2	7406-W10-B2D
◯	13	3-hole rod	4	7026-W10-Q2S1
◯	14	5-hole rod	4	7413-W10-K2S1
◯	15	3-hole dual rod	3	7413-W10-Y1S2
◯	16	5 -hole dual rod	4	7413-W10-X1S2
◯	17	15-hole dual rod	2	7413-W10-Z1S1
◯	18	5-hole cross rod, red	4	7413-W10-R1R
◯	19	9-hole cross rod	1	7407-W10-C2S
◯	20	7-hole flat rounded rod	2	7404-W10-C3S
◯	21	5x5 square frame	6	7413-W10-Q1R
◯	22	5x10 frame	4	7413-W10-I1R
◯	23	3x13 frame	2	7406-W10-A1S
◯	24	Axle	4	7413-W10-L2D
◯	25	Base grid	1	7125-W10-A1SK
◯	26	90-degree converter, X	4	7061-W10-X1S2
◯	27	Anchor pin lever	1	7061-W10-B1Y
◯	28	Spring scale	1	7428-W85-A
◯	29	Spring scale sticker	1	R20#7428
◯	30	Bottle weight	2	7428-W85-B
◯	31	Rubber band	2	R10-05
◯	32	Cotton string	1	R39-W85-200
◯	33	Measuring tape	1	R33#7092

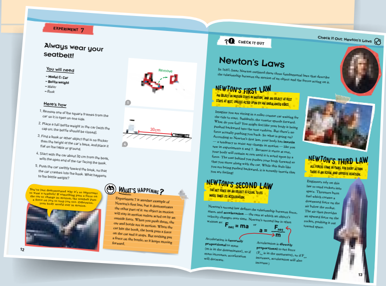
CONTENTS

Kit Contents .... **Inside front cover**
Table of Contents 1
Safety Information 2
NGSS Alignment 3

Assembling the Spring Scale (Model A) 4
Assembling the Sled (Model B) 5
Experiments 1–4: Force, Friction, and Work......... 6
Assembling the Car (Model C) 10
Experiments 5–7: Wheels and Inertia 10
Check It Out: Newton's Laws 13
Experiments 8–9: Potential and Kinetic Energy.. 14
Assembling the Spring Launcher (Model D) 16
Experiments 10–13: Spring Force, Mass, Acceleration, and Momentum 18
Assembling the Spring Car (Model E)................ 22
Experiments 14–15: Action / Reaction................. 24
Assembling the Impact Platform (Model F)........ 26
Experiments 16–18: Force of Impact................... 28
Assembling the Dropping Device (Model G)....... 30
Experiments 19–20: Terminal Velocity 32
Check It Out: Free Fall 33
Assembling the Elastic Launchers (Model H) 34
Experiments 21–22: Collisions 36

TIP

YOU WILL FIND ADDITIONAL INFORMATION IN THE CHECK IT OUT SECTIONS ON PAGES 13 AND 33.



YOU WILL ALSO NEED:

Water, books, thin board, stopwatch, paper

TIPS

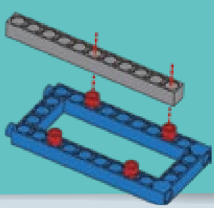
Woohoo!
Let's go!

ANCHOR PINS AND CONNECTORS

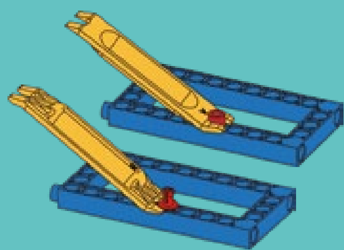
Take a careful look at the different assembly components. Red anchor pins, green anchor pins, joint pins, and shaft plugs all look pretty similar at first glance. When you assemble the models, it's important to use the right ones. The green anchor pins are shorter than the red ones.

CONNECTING FRAMES AND RODS

Use the anchor pins to connect frames and rods.



ANCHOR PIN LEVER



When you want to take your model apart again, you will need the anchor pin lever. Use the narrow end of the lever to remove the red anchor pins. You can use the wide end to pry out shaft plugs.

550076-02-090226

SAFETY INFORMATION

WARNING!

Not suitable for children under 3 years. Choking hazard — small parts may be swallowed or inhaled.

Strangulation hazard — long cords may become wrapped around the neck.

Keep the packaging and instructions as they contain important information.

Store the experiment material and assembled models out of the reach of small children.

Dear parents and teachers!

Children want to explore, understand, and create new things. They want to try things and do it by themselves. They want to gain knowledge! They can do all of this with Thames & Kosmos experiment kits. With every single experiment, they grow smarter and more knowledgeable.

Physics is an exciting and varied science that is not hard to understand, especially when you use fun models to demonstrate physics principles in action. It can be a lot of fun to figure out the astonishing physical phenomena that we encounter every day and to put this understanding to use.

This experiment kit and the working models you can build with it introduce your child to physics concepts including forces, work, acceleration and velocity, potential and kinetic energy, momentum, collisions, Newton's laws of motion, and more. Your child or student will gain basic insights into the world of physical units and laws — which will help them to understand the world around them and be ready to continue to expand their scientific knowledge and comfort with experimentation.

The individual experimental models are assembled step by step using an adjustable building system. It will require a little practice and patience at first. Children may need more support with the building system, but as with most things, their skills will improve with time and practice.

Some of the experiments will require a helping hand or some water to fill the bottle to be used as a weight. Please help your child each step of the way.

We wish you lots of fun experimenting and discovering!

STANDARDS ALIGNMENT

THIS KIT IS COMPATIBLE WITH NEXT GENERATION SCIENCE STANDARDS

NGSS Disciplinary Core Ideas

3-PS2-1 Motion and Stability: Forces & Interactions

Balanced and unbalanced forces; see experiments 1–2

3-PS2-2 Motion and Stability: Forces & Interactions

Observing motion; see experiments 3 & 5

4-PS3-1 Energy

Speed and energy; see experiments 8–9

4-PS3-3 Energy

Changes during collisions; see experiments 21–22

4-PS3-3 Energy

Converting energy; see experiments 3 & 5

5-PS2-1 Motion and Stability: Forces & Interactions

Gravitational force; see experiments 1, 19 & 20

MS-PS1-6 Matter and its Interactions

Collisions and Newton's Third Law; see experiments 14–15

MS-PS2-2 Motion and Stability: Forces & Interactions

Acceleration, force, and mass; see experiments 10–11

MS-PS3-1 & MS-PS3-5 Energy

Kinetic energy, mass, and speed; see experiments 8–9

HS-PS2-1 Motion and Stability: Forces and Interactions

Newton's second law; see experiment 11

HS-PS2-2 Motion and Stability: Forces and Interactions

Conservation of momentum; see experiments 21-22

Scan this QR for videos of the experiments:

Science & Engineering Practices

Asking questions

Planning & carrying out investigations

Analyzing & interpreting data

Using mathematics & computational thinking

Constructing explanations & designing solutions

Engaging in an argument from evidence

Obtaining, evaluating & communicating information

Cross-Cutting Concepts

Cause & effect

Scale, proportion & quantity

Energy & matter

Structure & function

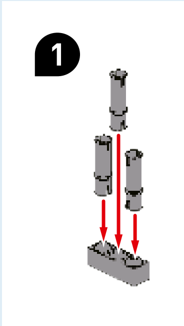
Patterns

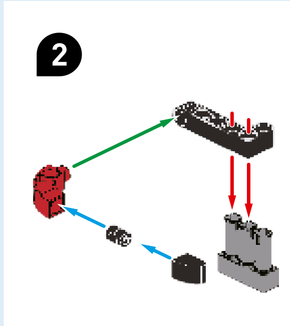
MODEL A: SPRING SCALE

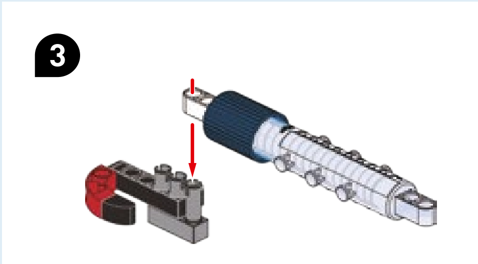
Measuring forces with a spring scale

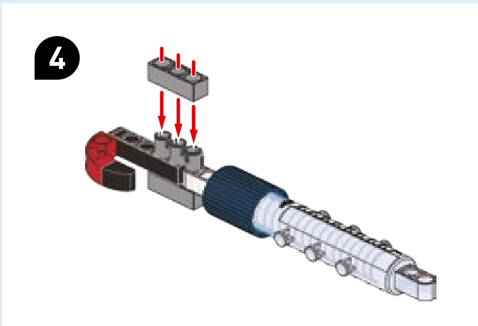
A spring scale is a simple tool that uses a metal spring to measure forces. The spring scale in this kit is specially designed to connect to the building system used in this kit (and other Thames & Kosmos kits).

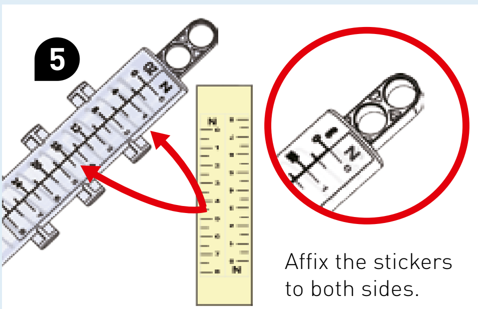
The theory behind the way a spring scale works is that the amount of force it takes to stretch the spring is proportional to the distance the force compresses the spring. In other words, a large force will compress the spring a lot and a small force will compress the spring only a little. By measuring the distance a spring is compressed, we can approximate the force being exerted on the spring.











Affix the stickers to both sides.

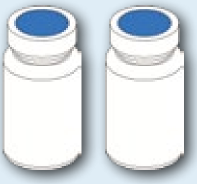
Test the Spring Scale

This spring scale measures forces in grams and Newtons, which is the standard unit of force in physics. Hold the spring scale by the clear plastic cylinder, with the hook at the bottom, and try hanging some objects from around your house or classroom from the hook.

Do not hold the spring scale by the blue collar when taking measurements.

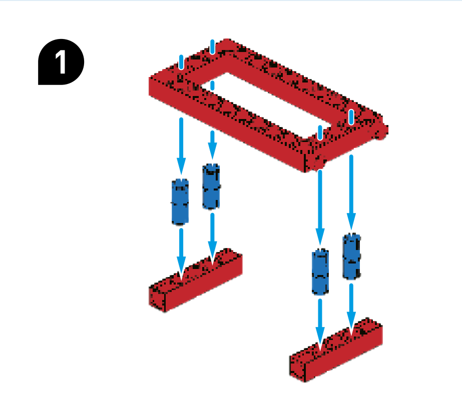
Do not measure weights of more than 800 grams.

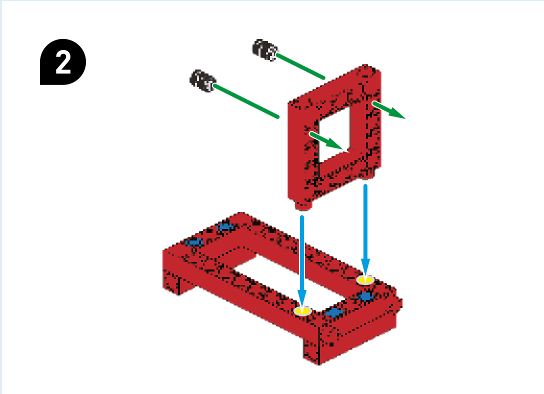
WATER BOTTLE WEIGHTS

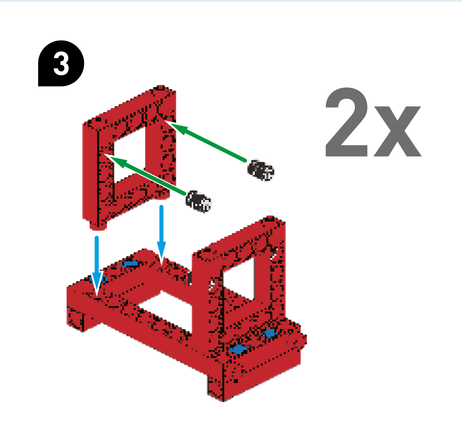


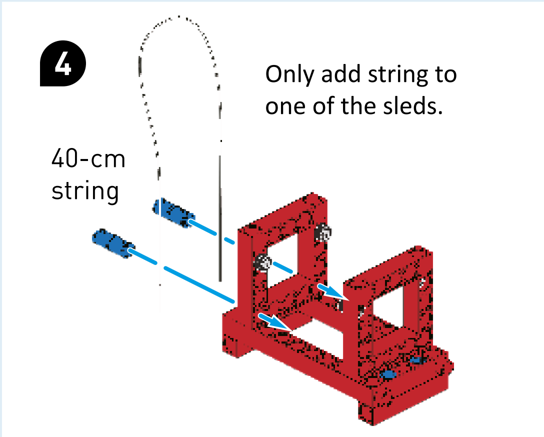
In many of the experiments, you will need to vary the mass of an object to see physics in action. Two 200-milliliter bottles are included. You can fill them with water or sand to create a weight — also called a load. The mass contained in one milliliter of water is equal to one gram, so the mass of a completely full bottle weight is 200 g.

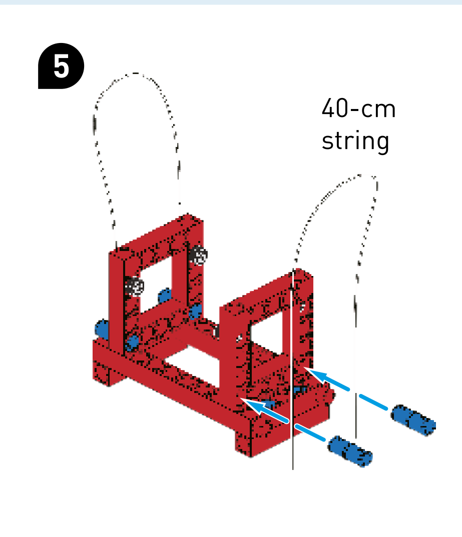
MODEL B: SLED

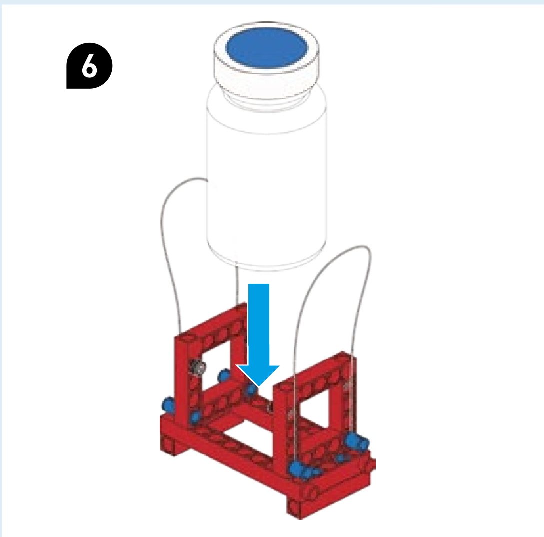

1


2


3
2x


4
Only add string to one of the sleds.
40-cm string


5
40-cm string


6

EXPERIMENT 1

Weight of water

You will need

- **Model A: Spring scale**
- **Model B: Sled with strings**
- **2 Bottle weights**
- *Water*

Here's how

1. Place an empty bottle weight in the sled that has strings attached.
2. Place both loops of string around the hook of the spring scale and lift the object into the air.

   Record the force exerted by the object on the spring scale:

   $F_{\text{gravity empty}} =$ ______ Newtons

3. Fill the other bottle weight with water.
4. Repeat step 2 and record the force exerted by the object on the spring scale:

   $F_{\text{gravity full}} =$ ______ Newtons

5. Calculate the difference between the two force measurements to find the **weight** of the water. If you divide the weight by 9.8 m/s^2, you will get the mass of water in grams. (For water, this also equals the number of milliliters.)

   $F_{\text{gravity full}} - F_{\text{gravity empty}} =$ ______ Newtons

Force of Gravity

(also known as: weight)

$$F_{\text{gravity}} = mg$$

mass (a measure of stuff, measured in kilograms)

gravitational constant on Earth (9.8 meters/second^2)

2

Force is measured in a unit called a newton (N), named after Isaac Newton (see page 13). A newton is defined as the force required to accelerate — or speed up — a mass of 1 kilogram by 1 meter per second squared (1N = 1 kg*m/s^2)

WHAT'S HAPPENING?

All objects have a weight, which is due to the **force of gravity** acting on them. Gravity is a fundamental **force** in the universe that is generated by mass. Since our planet, Earth, is a big mass, it generates a big force of gravity, pulling all objects on its surface down toward its center. On the Moon, which has a small fraction of Earth's mass, we would weigh less. That's because the **acceleration due to gravity** on the Moon is lower than the acceleration due to gravity on Earth.

When the spring scale is holding up the sled, the spring compresses, and the scale shows how much the force of gravity is pulling down.

EXPERIMENT 2

Friction and forces

You will need

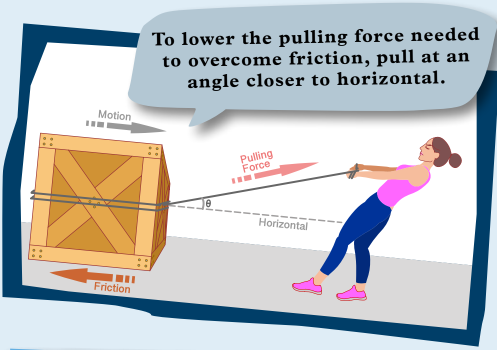
- Model A: Spring scale
- Model B: Sled
- Bottle weight with water

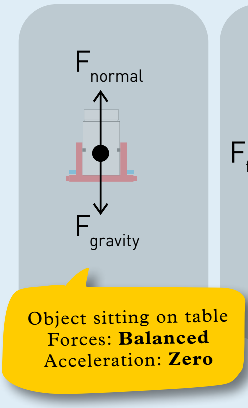
Here's how

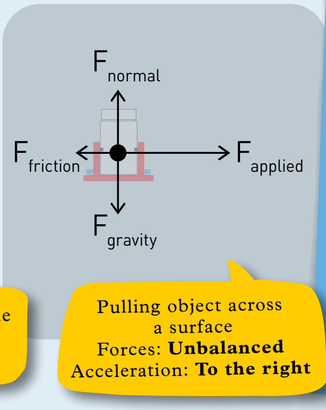
1. Place a bottle weight filled with water in the sled.
2. Place this object on a table top and attach the hook of the spring scale to one of the loops.
3. Pull the sled across the table.
4. Record the amount of force required to move the sled by looking at the spring scale.
5. Repeat steps 1–4 on different surfaces (carpet, wood floor, tile, etc.).
6. Try pulling the spring scale at different angles.

WHAT'S HAPPENING?

Friction is a force that works against the direction of movement of an object. Friction occurs when two surfaces touch. Even on seemingly smooth surfaces, there are lots of uneven spots that look like canyons and mountains under a powerful microscope. When two surfaces meet, these microscopic uneven spots will catch on one another and push against each other, causing friction. Materials like carpet have rougher surfaces, therefore there is more friction between carpet and the object than there is with wood.







Free Body Diagrams

It's helpful in physics to think about the forces acting on a particular object. We do this with **free body diagrams,** in which an object is represented as a dot or simple box. Arrows start at the object and point outward, showing each force acting on the object. The **magnitude,** or size, of the force is represented by the length of the arrow. If the forces are **balanced,** the object is stationary or moving at a constant velocity. If the forces are **unbalanced,** it means the object must be **accelerating** (see page 13).

When the sled is sitting on a table, the force of gravity pushes down on the table. The table pushes back on the object with an **equal and opposite** force, often called a **normal force.** If there was no normal force, the sled would fall through the table toward the center of the Earth!

EXPERIMENT 3

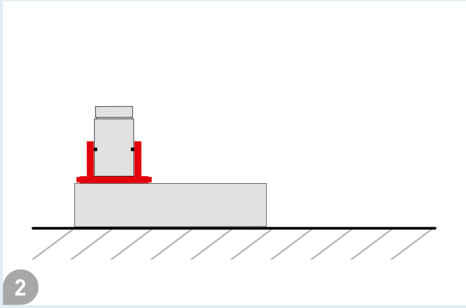
When will it slide?

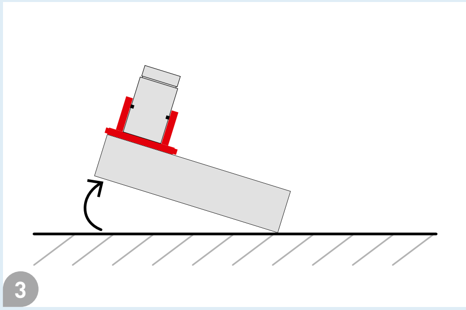
You will need

- **Model B: Sled**
- **Full bottle weight**
- *Kit box and other flat surfaces*

Here's how

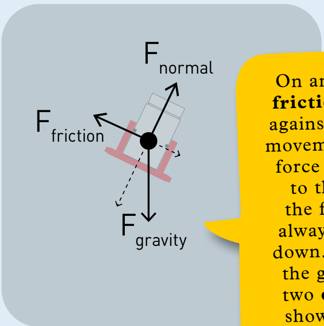
1. Place a full bottle weight in the sled.
2. Place the sled on one edge of the box that this kit came in.
3. Slowly raise the end of the box that has the sled on it, making the angle of the surface steeper and steeper.
4. Observe when the sled starts to slide. How steep is the angle? (Optional: hold the box steady and use a protractor to measure the angle between the box and the horizontal surface.)
5. Repeat the experiment with other flat surfaces, for example: a wood plank, plastic cutting board, large book, etc.





WHAT'S HAPPENING?

An object on an **inclined plane accelerates** down the incline because of the force of gravity. The acceleration of the object depends on the angle of the incline and the amount of friction between the surface and the object. A steeper angle and/or a more slippery surface will result in greater acceleration.



On an inclined plane, **friction** points uphill, against the direction of movement. The **normal** force is perpendicular to the surface, and the force of **gravity** always points straight down. You can think of the gravity **vector** in two **components**, as shown. The sled will not accelerate until the component that opposes friction is greater than the friction.

EXPERIMENT 4

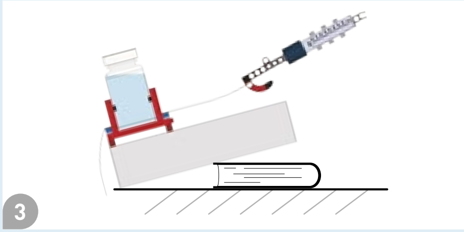
Doing work

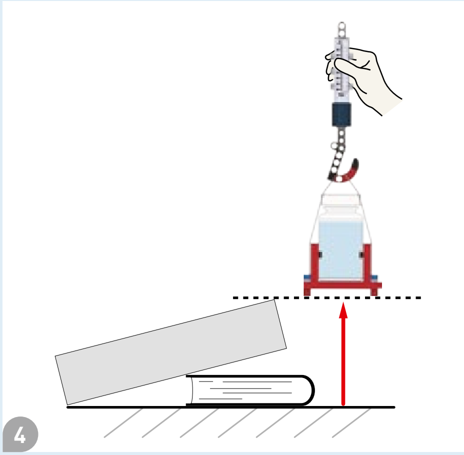
You will need

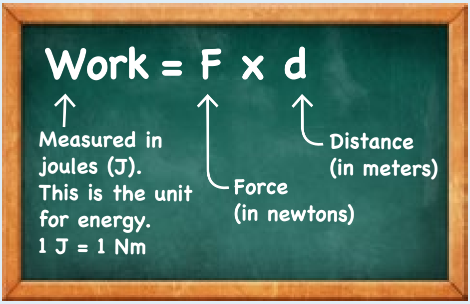
- **Model A: Spring scale**
- **Model B: Sled**
- **Full bottle weight**
- *Kit box or other flat surface*
- *Book or other object*

Here's how

1. Place a full bottle weight in the sled.
2. Create an inclined plane with a flat surface propped up on a few books.
3. Place one of the strings onto the hook of the spring scale. Pull the sled up the incline, and note how much force is required to pull the sled up the incline.
4. Place both strings onto the hook of the spring scale. Lift the sled straight up from the table to the top edge of the incline. How much force is required to lift the box vertically?


3


4



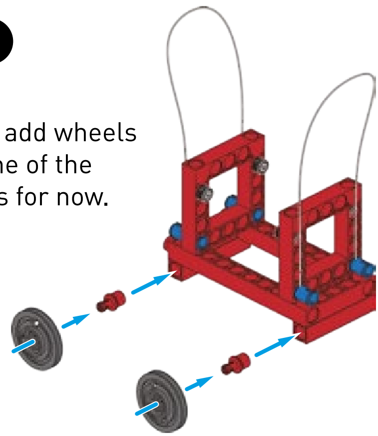
WHAT'S HAPPENING?

You may think of work as the chores your parents make you do or the assignments you do in school, but to a physicist, **work** is the amount of **energy** exerted when a **force** moves an object a certain **distance.** When you carry a box of toys up the stairs, you are doing work equal to the amount of force it takes to move that box the distance from the bottom of the stairs to the top. Moving an object up an inclined plane requires less force than moving it straight up vertically. However, you do the same amount of work to get the object to the top of the ramp, whether it goes up the incline or you lift it straight up. In the case of the incline, you apply a smaller force over a greater distance.

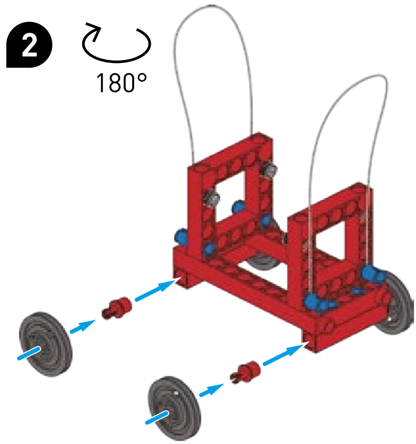
MODEL C: CAR

1

Only add wheels to one of the sleds for now.

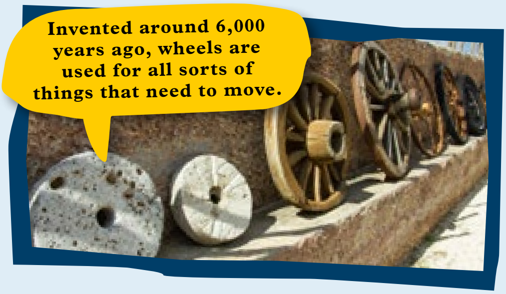


2



EXPERIMENT 5

The power of wheels

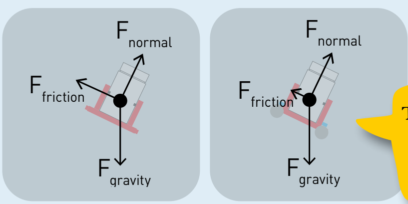


You will need

- **Model B: Sled**
- **Model C: Car**
- *Kit box or other flat surface*

Here's how

1. Place the car and the sled next to each other on one edge of the flat surface.
2. Slowly raise the end of the surface that has the car and sled on it, making the angle of the surface steeper and steeper.
3. Observe which object moves first.



The force of friction is much smaller for the car than the sled, so it accelerates at a lower angle.

WHAT'S HAPPENING?

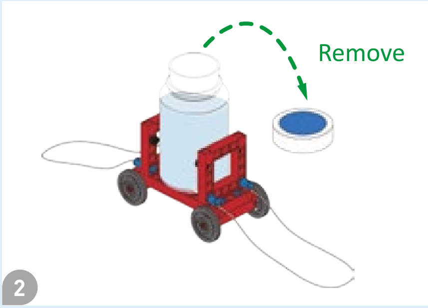
Wheels reduce the amount of friction because there is less surface area touching the surface. However, there is still some friction; if there were no friction, the wheels would slide instead of roll. Wheels also act as levers; a small force applied at the edge of the wheel has a larger force at the axle. You only need to tilt the box a tiny bit to get the car to move.

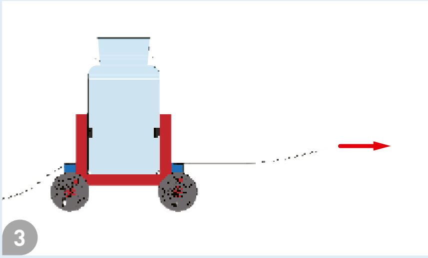
EXPERIMENT 6

Sloshing around

You will need

– **Model C: Car**
– **Bottle weight**
– *Water*
– *Area that can get wet*



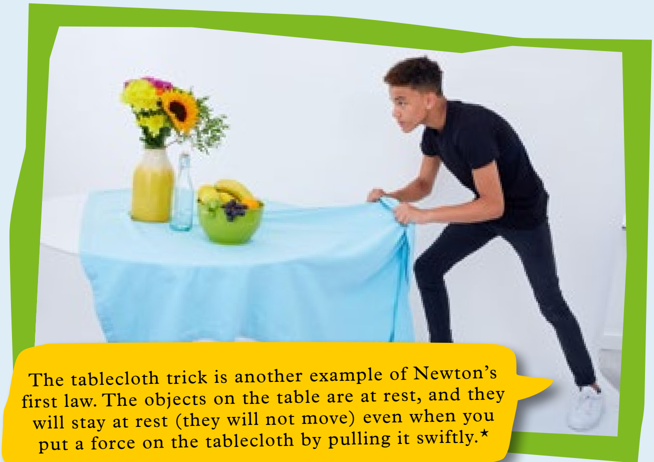


Here's how

1. Find a large surface (table or floor) that can get wet.
2. Place a full bottle weight in the car and then remove the cap from the bottle. Make sure the bottle is filled to the top with water.
3. Swiftly pull the string of the car so that the car moves fast toward you.
4. What do you observe in the pattern of the water on the surface?

WHAT'S HAPPENING?

You will notice that the water sloshes out of the back of the bottle, leaving a puddle **behind** the car. This is an example of **Newton's first law of motion,** the law of **inertia.** This says that an object at rest stays at rest, and an object in motion stays in motion, unless an outside force acts on it. When you pull the car forward you put a force on the car, but not on the water inside of the bottle. The water in the bottle, therefore, stays where it is, and when the car moves, it spills out the back and falls down.



The tablecloth trick is another example of Newton's first law. The objects on the table are at rest, and they will stay at rest (they will not move) even when you put a force on the tablecloth by pulling it swiftly.*

*There is friction between the tablecloth and the objects on the table, which depends on their weight and the materials of the surfaces that are touching. That's why this trick works best with a slippery tablecloth and a forceful tug on the cloth to overcome the force of friction.

EXPERIMENT 7

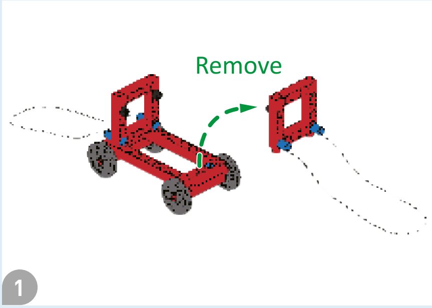
Always wear your seatbelt!

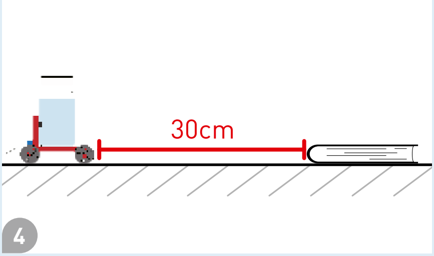
You will need

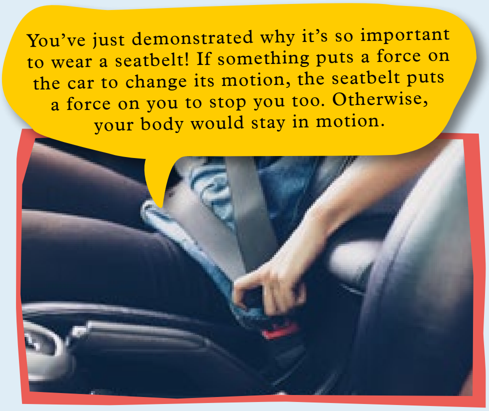
- **Model C: Car**
- **Bottle weight**
- *Water*
- *Book*

Here's how

1. Remove one of the square frames from the car so it is open on one side.
2. Place a full bottle weight in the car (with the cap on; the bottle should be closed).
3. Find a book or other object that is no thicker than the height of the car's base, and place it flat on the table or ground.
4. Start with the car about 30 cm from the book, with the open end of the car facing the book.
5. Push the car swiftly toward the book, so that the car crashes into the book. What happens to the bottle weight?



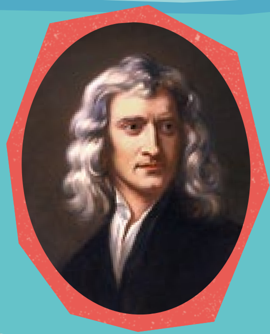




WHAT'S HAPPENING?

Experiment 7 is another example of Newton's first law, but it demonstrates the other part of it: an object in motion will stay in motion unless acted on by an outside force. When you push them, the car and bottle are in motion. When the car hits the book, the book puts a force on the car and it stops. But nothing put a force on the bottle, so it keeps moving forward.

CHECK IT OUT



Newton's Laws

In 1687, Isaac Newton outlined these three fundamental laws that describe the relationship between the motion of an object and the forces acting on it.

NEWTON'S FIRST LAW

AN OBJECT IN MOTION STAYS IN MOTION, AND AN OBJECT AT REST STAYS AT REST, UNLESS ACTED UPON BY AN UNBALANCED FORCE.

Imagine you are sitting in a roller coaster car waiting for the ride to start. Suddenly, the coaster speeds forward. What do you feel? You might feel like your body is being pushed backward into the seat cushion. But there's no force actually pushing you back. So what is going on? According to Newton's first law, your body has **inertia** — a tendency to resist any change in motion — like you saw in experiments 6 and 7. Because it starts at rest, your body will remain at rest until it is acted upon by a force. The seat behind you pushes your body forward so that you move along with the car. While this feels like you are being pushed backward, it is actually inertia that you are feeling!

NEWTON'S SECOND LAW

THE NET FORCE ON AN OBJECT IS EQUAL TO ITS MASS TIMES ITS ACCELERATION.

Newton's second law defines the relationship between force, mass, and **acceleration** — the rate at which an object's velocity changes over time. Newton's second law is often written as: $F_{net} = ma$ or $a = \frac{F_{net}}{m}$

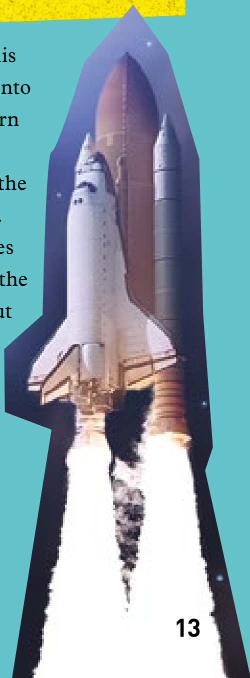
Acceleration is **inversely proportional** to mass (m is in the denominator), so if mass increases, acceleration will decrease.

Acceleration is **directly proportional** to net force (F_{net} is in the numerator), so if F_{net} increases, acceleration will also increase.)

NEWTON'S THIRD LAW

ALL FORCES COME IN PAIRS. FOR EVERY ACTION THERE IS AN EQUAL AND OPPOSITE REACTION.

Engineers rely on this law to send rockets into space. Thrusters burn fuel which creates a downward force on the air below the rocket. The air then provides an upward force on the rocket, pushing it out toward space.



EXPERIMENT 8

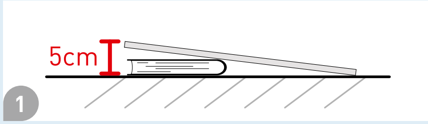
Potential and kinetic energy: velocity

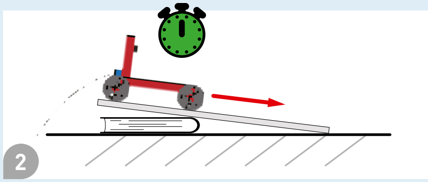
You will need

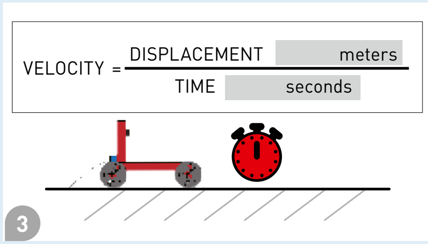
- **Model C: Car**
- **Tape measure**
- *Thin ramp, like foam core*
- *Books or other objects to prop up ramp*
- *Stopwatch*

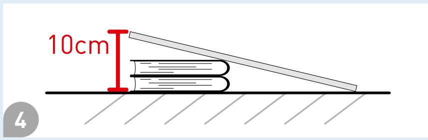
Here's how

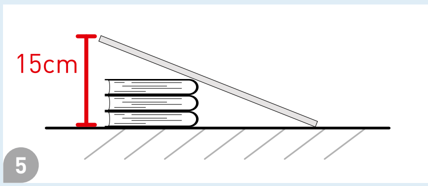
1. Set up the thin ramp so that the **top of the ramp is approximately 5 cm** off the ground. (Use the tape measure to measure.)
2. Get your stopwatch ready. Start the stopwatch and release the car with no bottle weight from the **top of the ramp.**
3. Stop the stopwatch when the car stops and measure the distance traveled by the car (displacement). Calculate velocity by dividing displacement by time.
4. Increase the **height of the ramp to 10 cm** and repeat steps 2–3.
5. Increase the **height of the ramp to 15 cm** and repeat steps 2–3.











Gravitational Potential Energy

$$PE = m\ g\ h$$

PE (joules)
m: mass (kilograms)
g: gravitational constant on Earth (9.8 meters/second²)
h: height (meters)

WHAT'S HAPPENING?

Velocity is a measure of an object's speed, which also takes into account the direction it's traveling. To calculate the car's **average velocity** during the trial, divide the displacement — distance traveled — by the time it took to travel.

You should see that the higher the starting point of the ramp, the higher the average velocity. That's because a car that starts higher up has more **gravitational potential energy.** As you release the car, potential energy is converted into **kinetic energy** — the energy of motion — as the car rolls down the ramp.

EXPERIMENT 9

Potential and kinetic energy: does mass matter?

You will need

- **Model C: Car**
- **Tape measure**
- **Bottle weight**
- *Water*
- *Thin ramp, like foam core*
- *Books or other objects to prop up ramp*
- *Stopwatch*

Here's how

1. Set up the ramp so that the **top of the ramp is approximately 10 cm** high.
2. Place an **empty bottle weight** in the car.
3. Get your stopwatch ready. Start the stopwatch and release the car from the top of the ramp.
4. Stop the stopwatch when the car stops and measure the car's displacement. Calculate velocity by dividing displacement by time.
5. Place a **full bottle weight** in the car and repeat steps 3–4. Which car traveled faster (had a higher velocity): the car with the full bottle weight or the car with the empty bottle weight? Or did they have the same velocity?

A gravity light converts **gravitational potential energy** (from a heavy weight suspended above the ground) into **kinetic energy** (setting gears in motion) to generate **electrical energy** to power an LED light.

WHAT'S HAPPENING?

The **conservation of energy** principle says that energy cannot be created or destroyed. Therefore, under ideal conditions, **total mechanical energy** (potential + kinetic) remains constant. Because mass is a factor in both equations, the mass cancels out, and is not actually a factor in the final velocity of the car.

Kinetic Energy

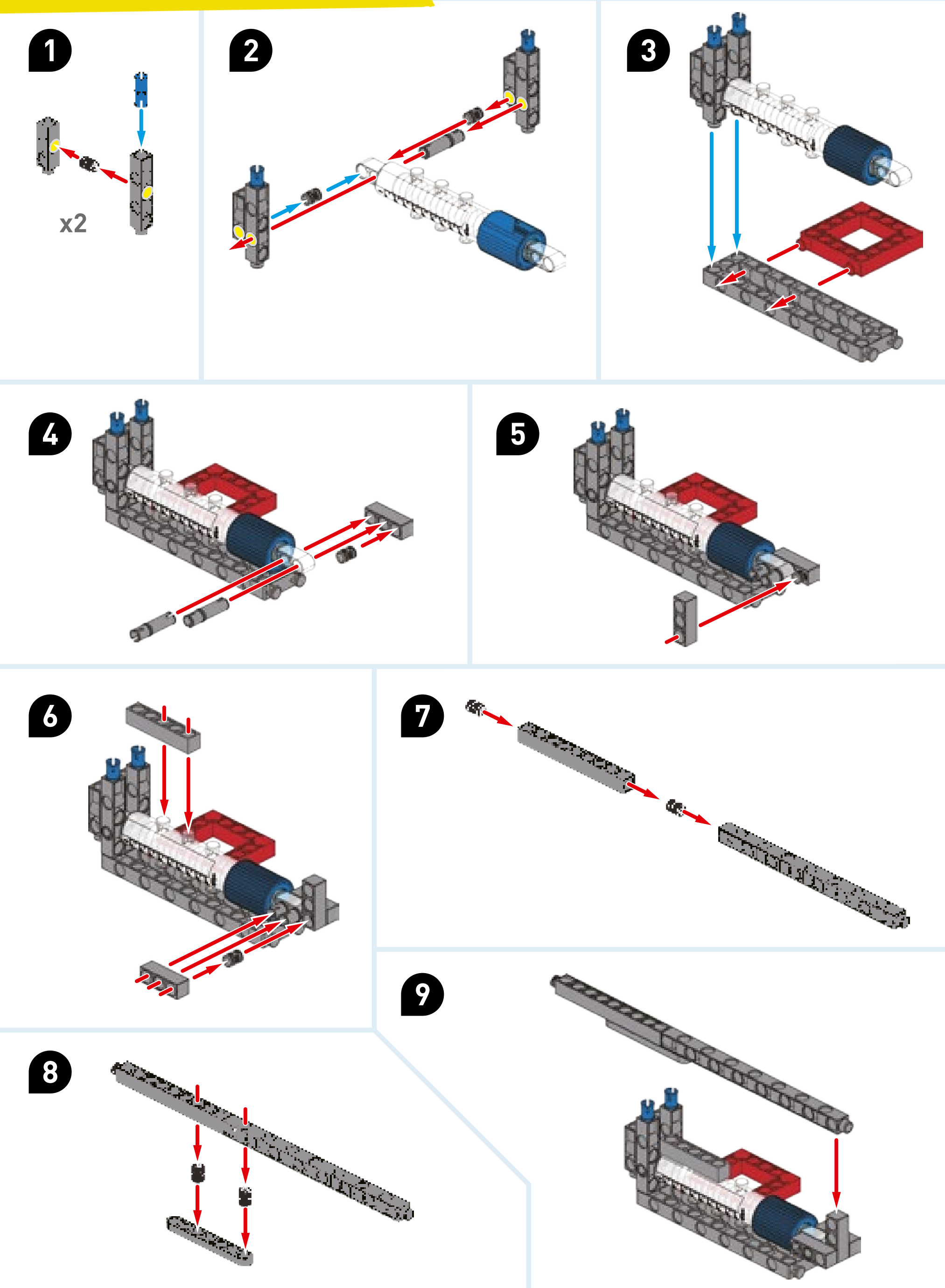
$$KE = 1/2\ m\ v^2$$

(joules)

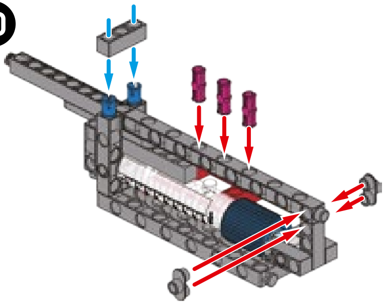
mass (kilograms)

velocity (meters/second)

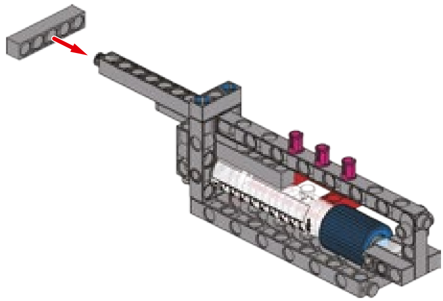
MODEL D: SPRING LAUNCHER



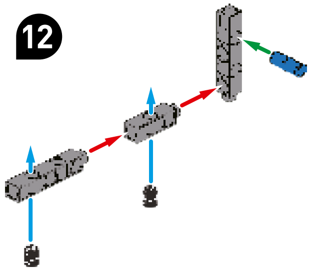
10



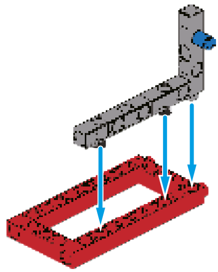
11



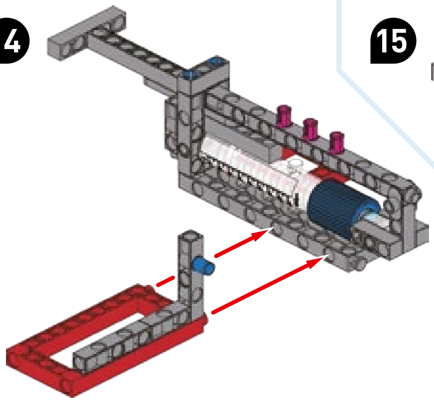
12



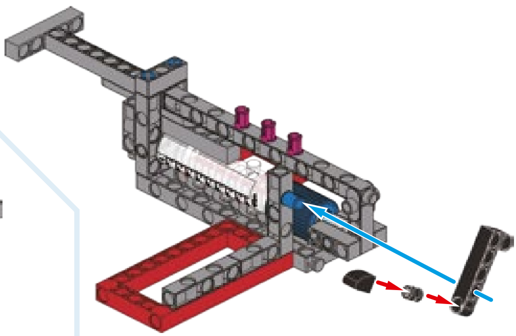
13

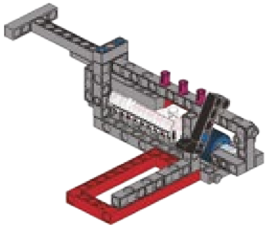


14



15





Done!

EXPERIMENT 10

Spring force

You will need

- **Model C: Car**
- **Model D: Spring launcher**

Here's how

1. Compress the spring launcher a little bit, and place the latch against the first pink pin.
2. Place the T-bar of the launcher against the car.
3. Release the latch.
4. Repeat steps 1–3, but this time compress the spring a little more, so that the latch rests on the second pink pin.
5. Repeat steps 1–3, but this time compress the spring even more, so that the latch rests on the third pink pin.

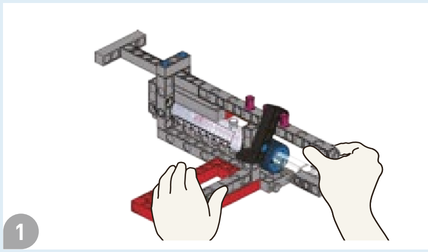
Hooke's Law

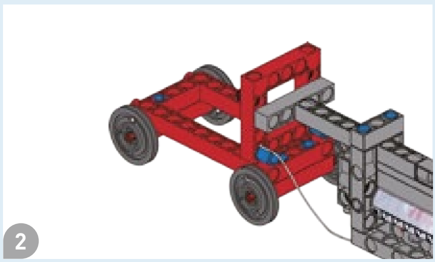
$$F_{spring} = -k\,x$$

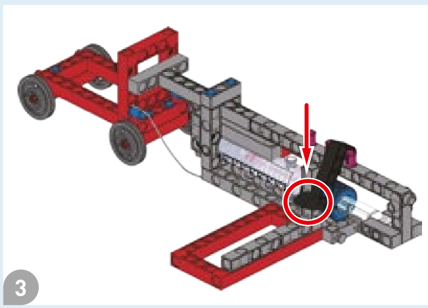
(newtons)

spring constant (relates to stiffness of spring)

displacement of the spring from rest (meters)







WHAT'S HAPPENING?

You disassembled the spring scale which measured force, and now you're using the spring to generate force. Hooke's law states that the force exerted by a spring is directly proportional to the displacement of that spring from its resting position. The more you compress (or stretch) an elastic object, like a spring or rubber band, the more force it will exert.

Experiment 10 shows Newton's second law in action. The more **force** you exert on the car, the greater its **acceleration** will be. That means, when you push a car with more force, it will speed up faster than when you push it with less force.

EXPERIMENT 11

Mass and acceleration

You will need

- **Model C: Car**
- **Model D: Spring launcher**
- **Bottle weight**
- *Water*

Here's how

1. Place an empty bottle weight into the car.
2. Compress the spring launcher, and place the latch against the second pink pin.
3. Place the T-bar of the launcher against the car, then release the latch.
4. Fill the bottle weight with water, and replace it in the car.
5. Repeat steps 2–3. Which car traveled faster: the car with the full bottle weight or the car with the empty bottle weight?

WHAT'S HAPPENING?

Experiment 11 demonstrates another aspect of Newton's second law: how **mass** relates to **acceleration**. By using the spring launcher, you are keeping the force applied to the car constant. When you increase the mass of the car by adding water to the bottle weight, you see that the car does not accelerate (or speed up) as much. Whereas force is **directly proportional** to acceleration (when one goes up, the other goes up), mass is **inversely proportional** to acceleration (when mass goes up, acceleration goes down). See page 13.

Newton's 2nd Law of Motion

$$F_{net} = m\ a$$

Net force on an object (newtons)

mass (kilograms)

acceleration (meters/second²)

Engineers who design race cars attempt to minimize the mass of cars. For the same amount of engine power (force), a lighter car (less mass) will have greater acceleration, making them more competitive on the track. A lighter car also has less inertia — resistance to change in its motion — so it will respond quicker to steering.

EXPERIMENT 12

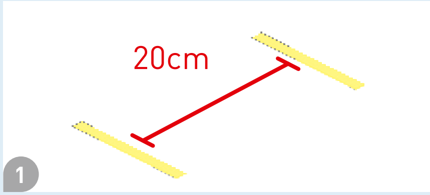
Momentum and velocity

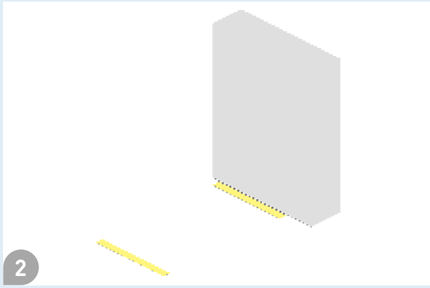
You will need

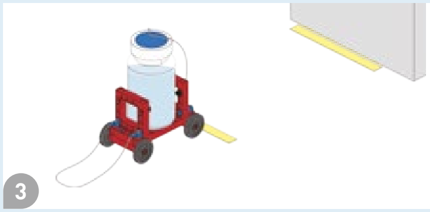
- **Model C: Car**
- **Model D: Spring launcher**
- **Bottle weight**
- **Tape measure**
- *Empty kit box*
- *Tape*

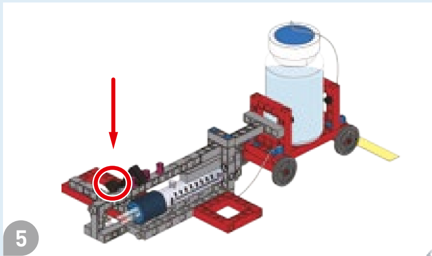
Here's how

1. Place two pieces of tape on a table top or floor, 20 cm away from each other. (Use the tape measure to measure. Keep these pieces of tape handy for experiment 13.)
2. Set up the empty kit box so it's standing straight up, touching the edge of one of the pieces of tape.
3. Place the car with a closed full bottle weight so that it is touching the edge of the other piece of tape.
4. Compress the spring launcher a little bit, and place the latch against the **first pink pin.**
5. Place the T-bar of the launcher against the car, then release the latch. The car should collide with the box. What happens to the box? Is it moved or knocked over?
6. Repeat steps 2–5, but this time compress the spring a little more, so that the latch rests on the **second pink pin.**
7. Repeat steps 2–5, but this time compress the spring even more, so that the latch rests on the **third pink pin.**









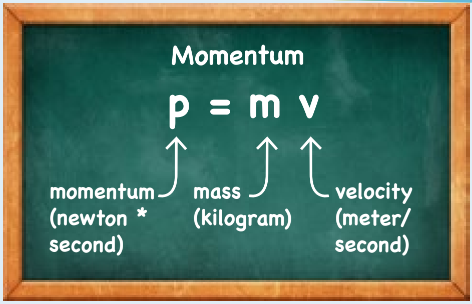
WHAT'S HAPPENING?

Science experiments are often set up to test cause and effect. Scientists change one thing at a time to see how changing that thing affects the outcome.

In experiment 12, you vary the force put on the car **(independent variable)** and you keep mass **constant.** In experiment 13, you vary the mass of the car **(independent variable)** and keep force **constant.** In both experiments you are investigating momentum **(dependent variable)** by noticing if the box is knocked over or moved.

EXPERIMENT 13

Momentum and mass

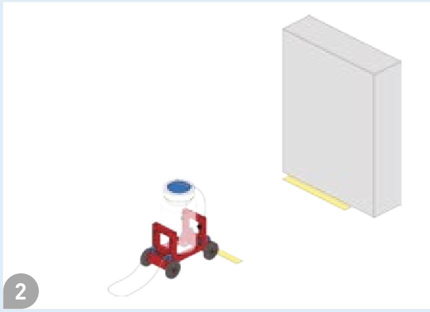


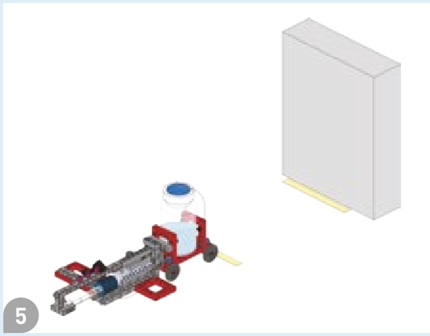
You will need

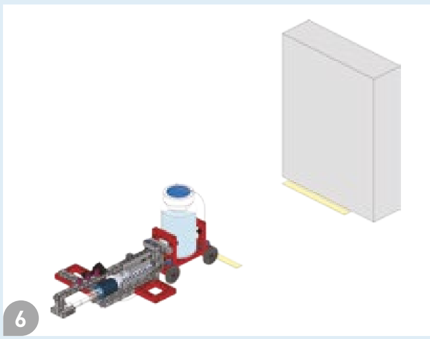
- **Model C: Car**
- **Model D: Spring launcher**
- **Bottle weight**
- *Empty kit box*
- *Water*
- *Tape*

Here's how

1. Set up the empty kit box so it's standing straight up, touching the edge of one of the pieces of tape.
2. Place the car with an **empty** bottle weight so that it is touching the edge of the other piece of tape.
3. Compress the spring launcher all the way, and place the latch against the **third pink pin.**
4. Place the T-bar of the launcher against the car, then release the latch. The car should collide with the box. What happens to the box? Is it moved or knocked over?
5. Repeat steps 2–4, but this time use a bottle weight that is **half full** with water.
6. Repeat steps 2–4, but this time use a bottle weight that is **full** of water.





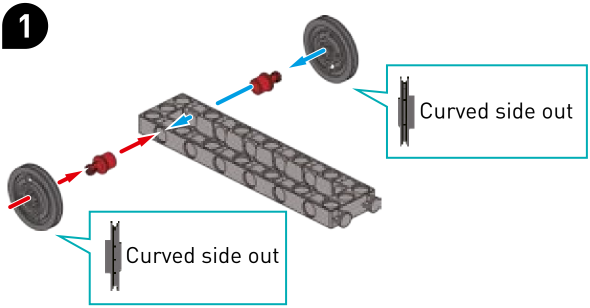


WHAT'S HAPPENING?

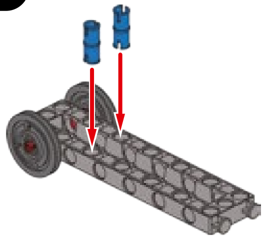
Momentum can be thought of as the measure of a moving object's "oomph" — its quality of motion. Mathematically, it is found by multiplying mass times velocity. An object will have more momentum if it's moving faster, or if it's heavier.

MODEL E: SPRING CAR

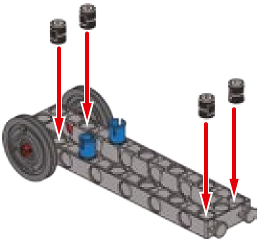
1



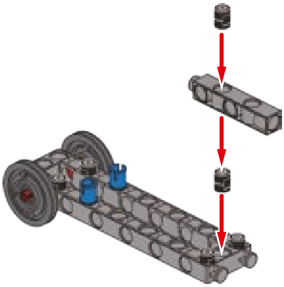
2



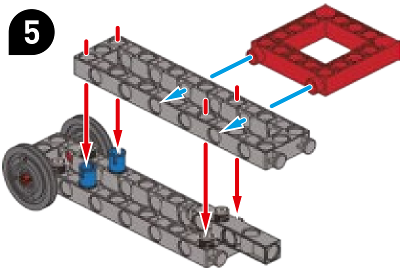
3



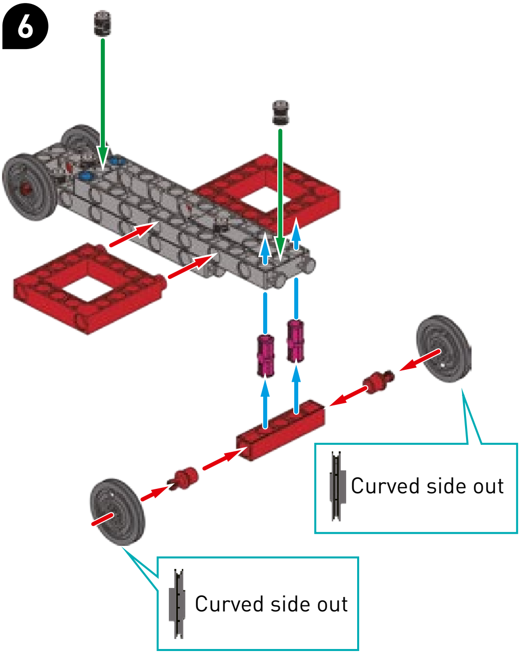
4



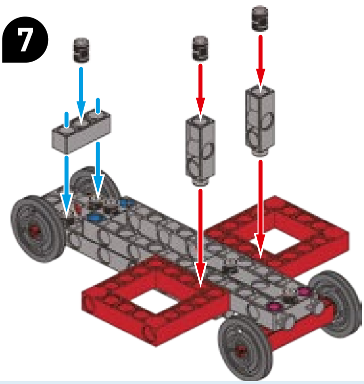
5



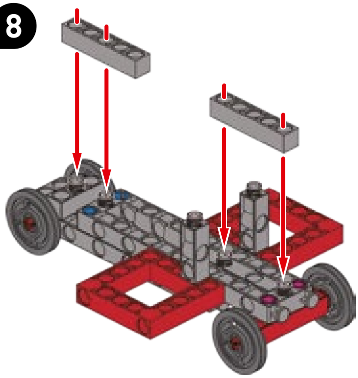
6



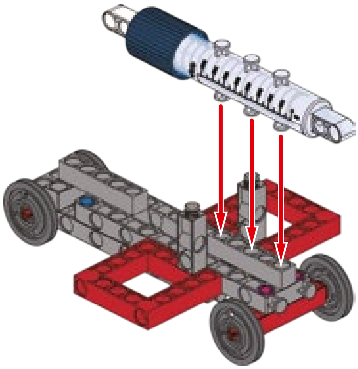
7



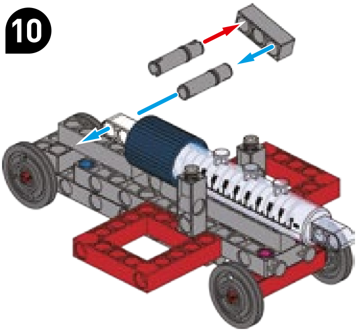
8



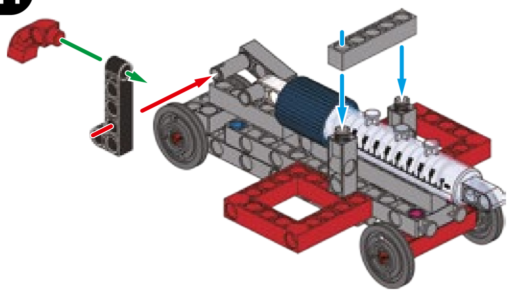
9



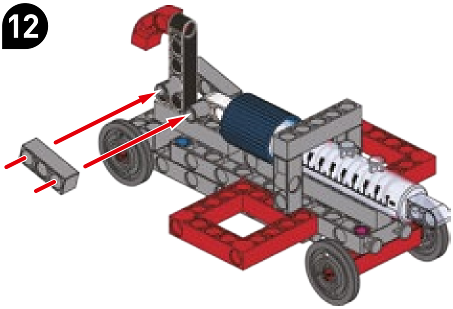
10



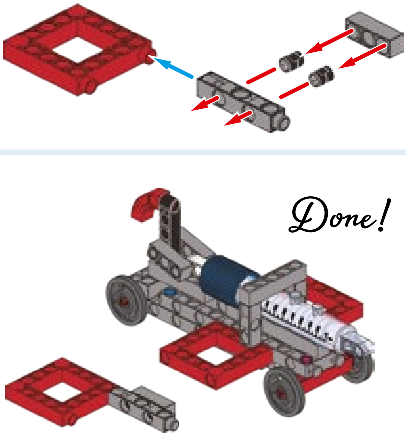
11



12



13



Done!

Support piece

EXPERIMENT 14

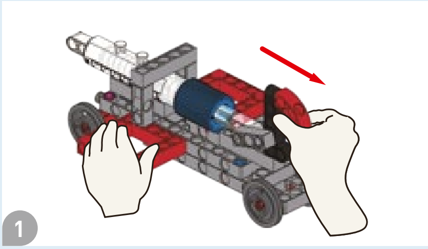
Action/reaction car

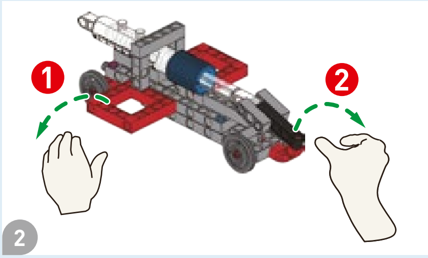
You will need

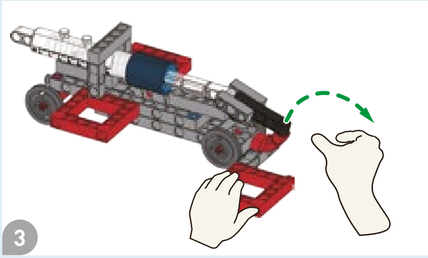
– **Model E: Spring car**

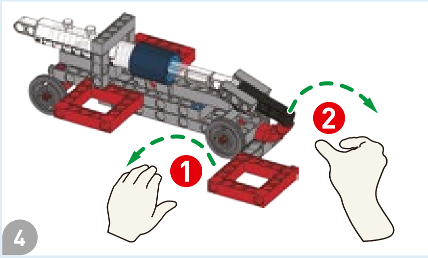
Here's how

1. Hold the spring car steady with one hand while you pull back the spring hook with your other hand. Place the hook against the back of the car.
2. Let go of the car with your right hand, then release the spring hook with your other hand.
3. Repeat step 1. **Place the support piece** behind the wheels of the spring car. Hold the support steady while you release the spring.
4. Repeat step 1. Place the support behind the wheels. **Let go of the support piece.** Now release the spring.





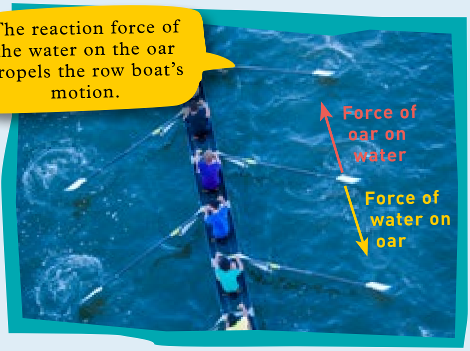




WHAT'S HAPPENING?

See Newton's third law on page 13. **Step 2:** The plunger of the spring puts a forward force on the car (action 1), and the car puts a force on the plunger in the opposite direction (reaction 1). **Step 3:** The reaction 1 force puts a backward force on the support (action 2), and the support puts a forward force on the car (reaction 2). There is little friction between the wheels and the surface, so the car moves forward. The fixed support acts like a massive wall, so it doesn't move. **Step 4:** The car now puts a force on an unfixed support. There is the force pair as in step 3, but the motion is now shared. Mass matters; the lighter support accelerates more than the heavier car.

The reaction force of the water on the oar propels the row boat's motion.



EXPERIMENT 15

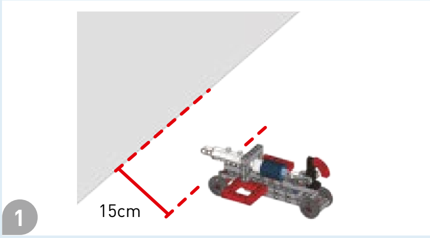
Hitting a wall

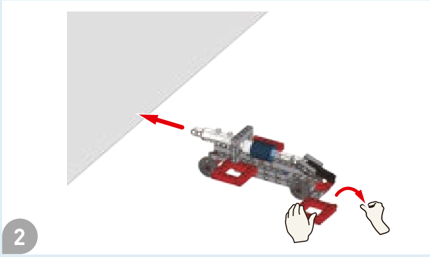
You will need

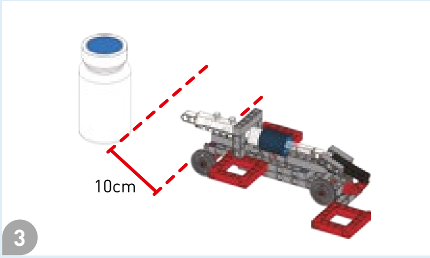
– **Model E: Spring car**

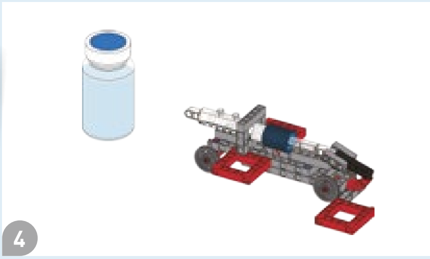
Here's how

1. Set up the spring car approximately 15 cm from a wall.
2. Add the support behind the wheels of the spring car, pull back the spring and launch the spring car into the wall.
3. Now set up the spring car approximately 10 cm from an empty bottle weight. Launch the spring car into the bottle weight.
4. Repeat step 3 with a full bottle weight. What do you observe?





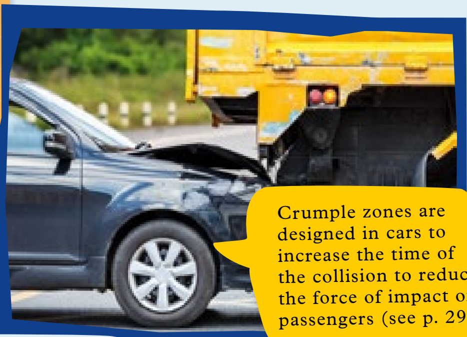




WHAT'S HAPPENING?

We know from Newton's third law of motion (see page 13) that when they collide, the spring car exerts as much force on the bottle as the bottle exerts on the spring car. But mass matters! The forces on the two are the same, but the object with the lower mass will accelerate more.

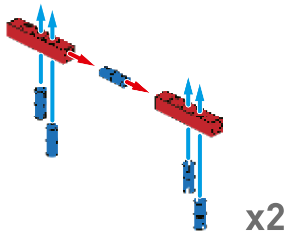
In a collision between a small car and a truck, the forces on the two vehicles are the same for both, but since the mass of the car is lower than that of the truck, the car will accelerate (negative acceleration as it comes to a stop), which is more dangerous for the occupants. The truck also has more momentum and kinetic energy because of its mass. Since this energy is transferred to the car, the car will often crumple as it absorbs the impact.



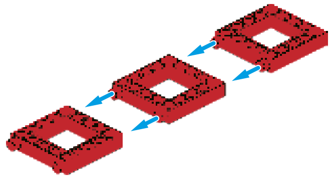
Crumple zones are designed in cars to increase the time of the collision to reduce the force of impact on passengers (see p. 29).

MODEL F: IMPACT PLATFORM

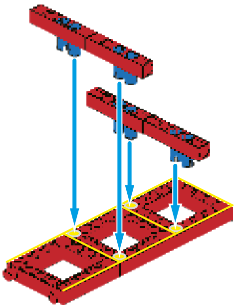
1



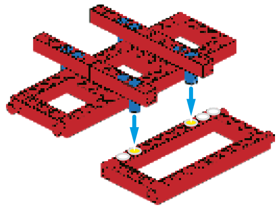
2



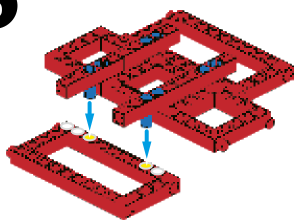
3



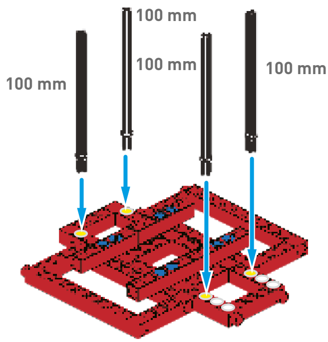
4



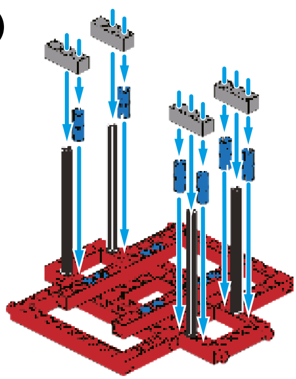
5



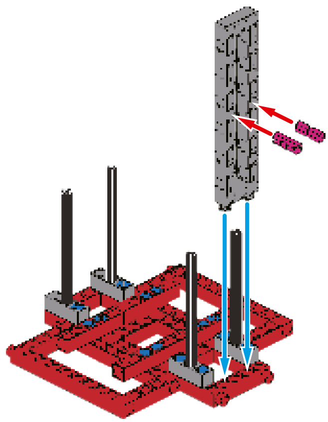
6



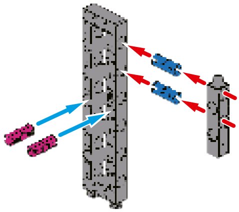
7



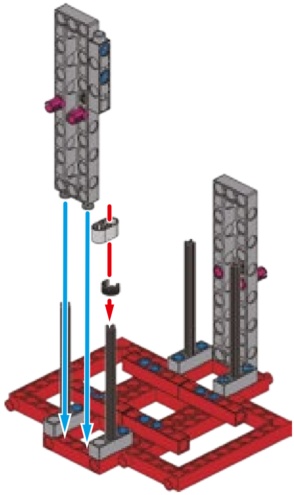
8



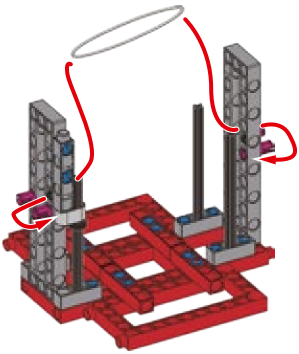
9



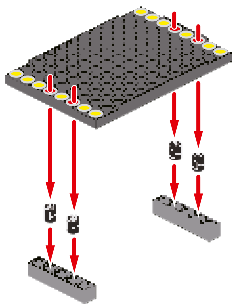
10



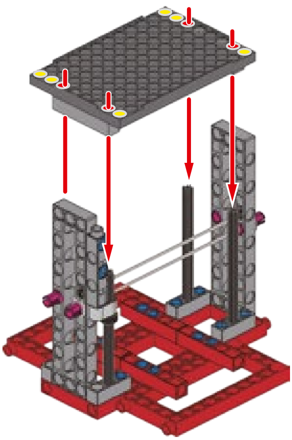
11

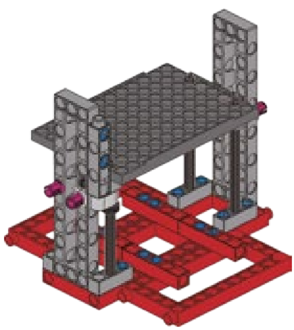


12



13





Done!

EXPERIMENT 16

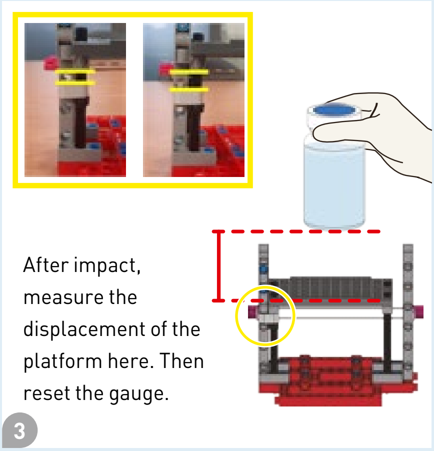
High drop

You will need

- **Model F: Impact platform**
- **Bottle weight**
- **Tape measure**
- *Tape*

Here's how

1. Set up the impact platform on the ground near a wall or table leg.
2. Use the tape measure or measure approximately 10 cm above the platform, and mark the height with a piece of tape.
3. Hold a full bottle weight at the marked height, then drop the bottle onto the platform. Use the tape measure to measure the displacement of the rubber bands.
4. Now change the initial height to 20 cm above the platform and repeat step 3.
5. Now change the initial height to 30 cm above the platform and repeat step 3.



After impact, measure the displacement of the platform here. Then reset the gauge.

3

EXPERIMENT 17

Heavy drop

You will need

- **Model F: Impact platform**
- **Bottle weight**
- **Tape measure**
- *Tape*

Here's how

1. Set up the impact platform on the ground near a wall or table leg.
2. Use the tape measure or measure approximately 30 cm above the platform, and mark the height with a piece of tape.
3. Hold an empty bottle weight at the marked height, then drop the bottle onto the platform. Use the tape measure to measure the displacement of the rubber bands.
4. Fill the bottle weight with water and repeat step 3. What do you observe?

WHAT'S HAPPENING?

Just like in experiments 12 and 13, in the experiments on this page, you are isolating two independent variables — height (in experiment 16) and mass (in experiment 17) — to see how they affect a free fall. Potential energy is directly proportional to both mass and height, therefore when you increase mass and when you increase height, the bottle has more potential energy. Potential energy is converted into kinetic energy as the object falls. Objects with more kinetic energy have more momentum too, so they hit the platform with more force.

EXPERIMENT 18

Shape and impact

You will need

- Model F: Impact platform
- Full bottle weight
- Tape measure

Here's how

1. Repeat steps 1–2 from experiment 17.
2. Drop the full bottle weight vertically onto the platform.
3. Now drop the full bottle weight horizontally onto the platform.
4. Experiment by dropping different objects onto the platform.

WHAT'S HAPPENING?

The shape of an object in a collision affects the pressure that the object exerts. In experiment 18, you drop the same object (the full bottle weight) onto the impact platform. The vertical bottle weight has a smaller area at the point of collision, so there is more pressure.

The force of impact is directly proportional to the change of momentum and indirectly proportional to the length of time of a collision. This is why stunt people fall onto crash pads and why air bags are built into cars. These increase the time of impact, thus greatly reducing the force.

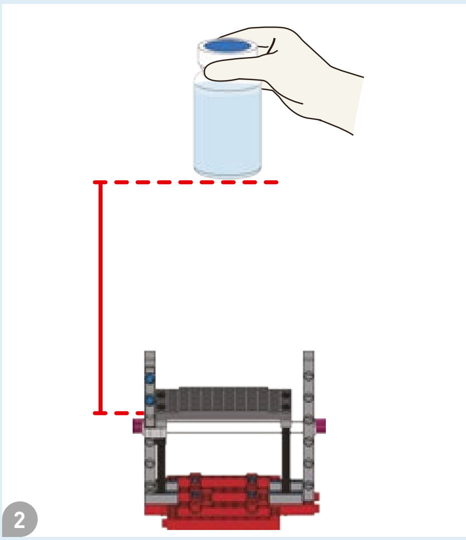
Force of Impact

$$F_{impact} = \frac{\Delta P}{\Delta t}$$

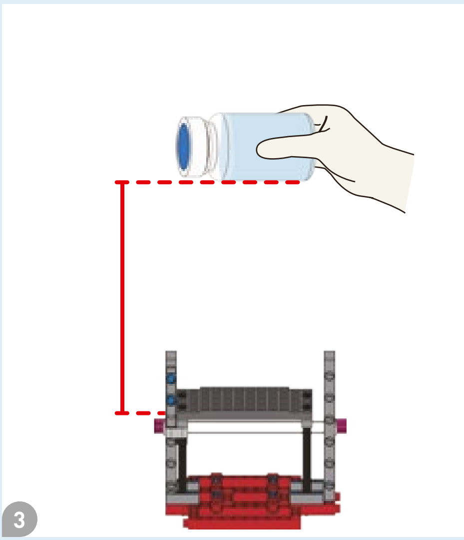
force of impact (newtons)

change in momentum

change in time



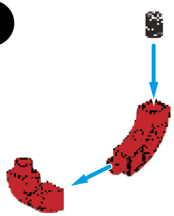
2



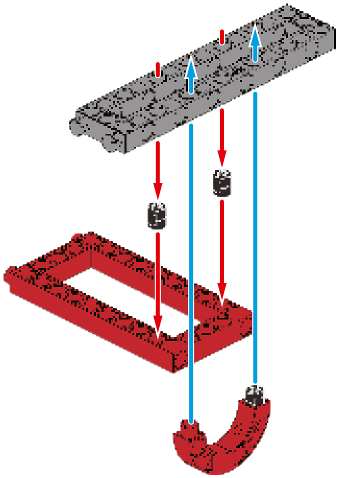
3

MODEL G: DROPPING DEVICE

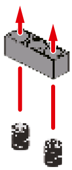
1



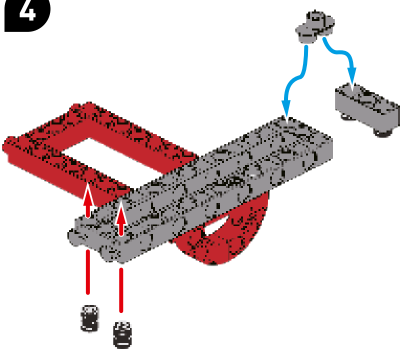
2



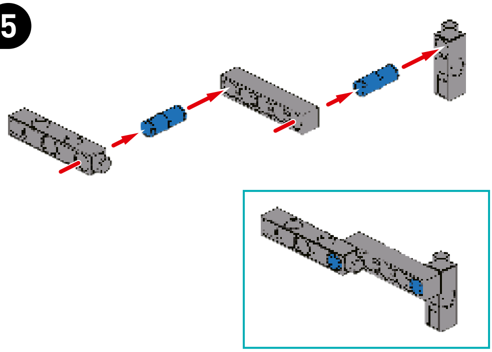
3



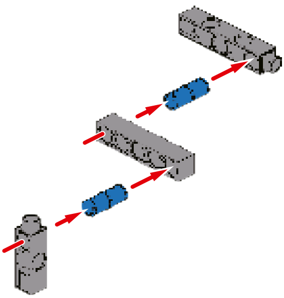
4



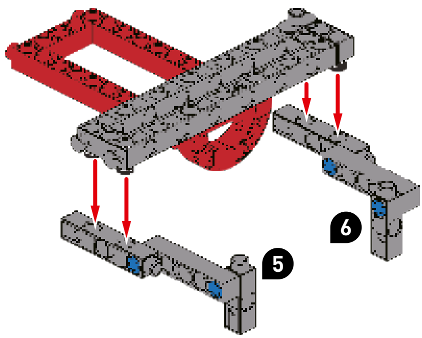
5

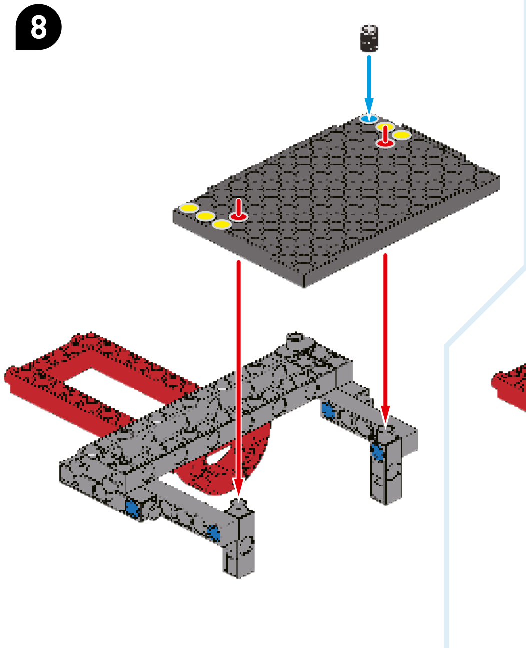


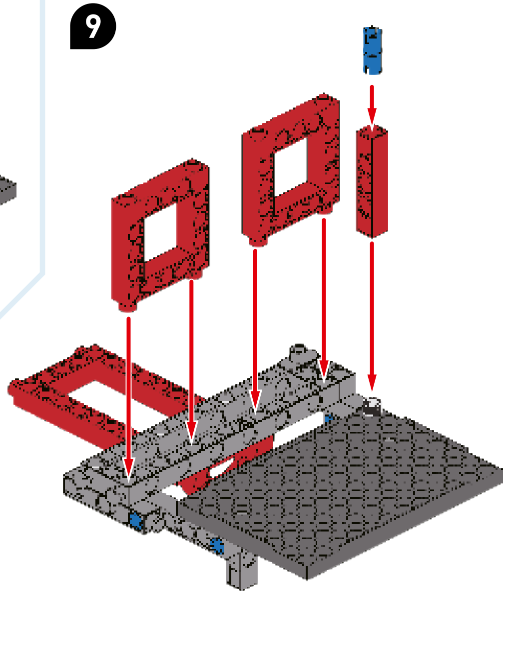
6

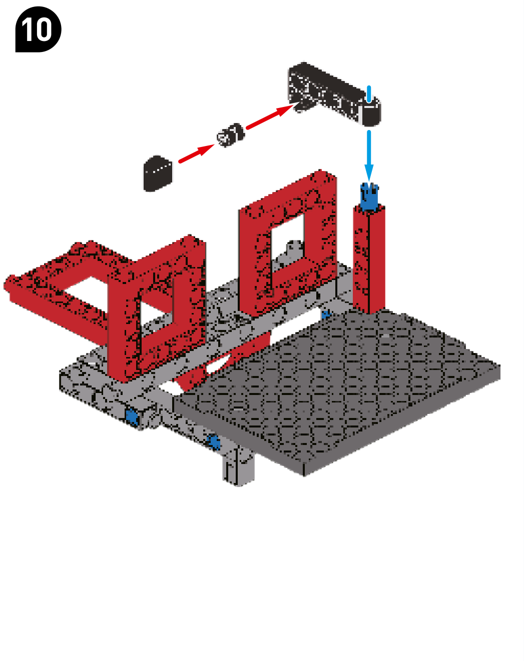


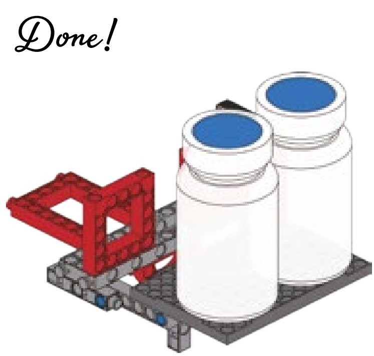
7




8


9


10


Done!

EXPERIMENT 19

Which will hit first?

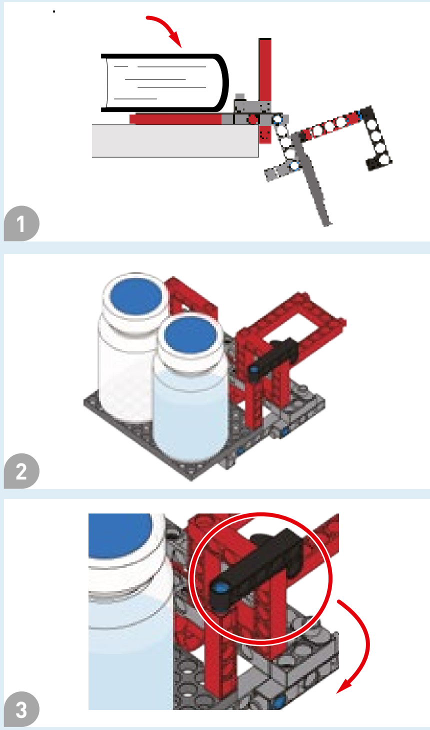
You will need

- **Model G: Dropping device**
- **2 bottle weights**
- **Table**
- *Heavy books*

Here's how

1. Set up the dropping device on the edge of a table, and use heavy books to weigh it down.
2. Place one empty bottle weight and one full bottle weight next to each other on the dropping device platform.
3. Release the latch of the dropping device. Which bottle hits the ground first, or do they hit at the same time?

Tip: You might want to film the experiment in slow motion with a smartphone.



EXPERIMENT 20

Air resistance

You will need

- **Model G: Dropping device**
- *2 pieces of paper*

Here's how

1. Set up the dropping device on the edge of a table, and use heavy books to weigh it down.
2. Crumple one piece of paper. Fold the other piece of paper so it is approximately 4 x 5 inches.
3. Place the pieces of paper next to each other on the dropping device and release the latch. Which hits the ground first?

WHAT'S HAPPENING?

Even though the two pieces of paper have the same mass, and therefore the same force of gravity pulling them down, the crumpled paper hits the ground first. Because of its shape, the air resistance on the flat paper is greater than the air resistance on the crumpled paper. Therefore, the flat paper reaches terminal velocity quickly, and falls at that slower speed until it reaches the ground.

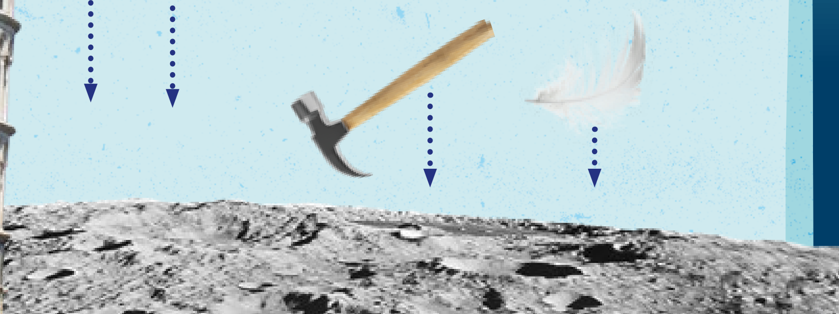
CHECK IT OUT

The motion of FALLING BODIES

The Great Debate: Aristotle vs. Galileo
For nearly 2,000 years, the world followed the teachings of Aristotle, who claimed that heavier objects fall faster than lighter ones. It wasn't until the late 16th century that a young Italian scientist named Galileo Galilei challenged this long-held belief. According to legend, Galileo conducted a dramatic experiment at the Leaning Tower of Pisa. He dropped two iron balls of the same size but different weights simultaneously from the top of the tower. To the shock of those watching, the balls hit the ground simultaneously, proving that Earth exerts the **same gravitational pull** on all objects regardless of their mass. This discovery highlighted a major flaw in ancient scientific thought: Aristotle likely never tested his theory. Had he simply experimented with two objects of different weights, as Galileo did, this fundamental law of physics might have been discovered 2,000 years earlier.

Air Resistance: The Hammer and the Feather
If gravity pulls all objects equally, why does a feather fall slower than a hammer if you drop them at the same time? The answer lies in **air resistance** — a type of friction exerted by the air that acts in the opposite direction of motion. The strength of this force depends on the object's mass, its surface area, and its speed; because a feather is light and has a large surface area relative to its weight, the air catches it more effectively than the heavy, compact hammer. However, in a **vacuum** where there is **no air** to provide resistance, Galileo's theory holds perfectly true. This was famously demonstrated in 1971 by Apollo 15 astronaut David Scott, who dropped a hammer and a feather on the Moon. Because the Moon has no atmosphere, there was no air resistance to interfere, and both objects fell at the exact same rate, hitting the lunar surface at the same time.

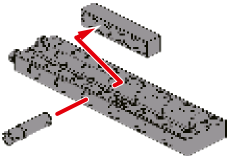
Terminal Velocity: Finding the Balance
When an object begins to fall, gravity is the strongest force acting on it, causing it to speed up. However, as the object goes faster, the upward push of air resistance increases. Eventually, these two **forces balance** each other, so the object **stops accelerating** and continues to fall at a steady, constant speed known as **terminal velocity**. A skydiver provides a perfect example of this: in a belly-to-Earth position, they reach a terminal velocity sooner, since there is more air resistance on this shape. By staying upright and pulling in their arms and legs, they reduce their surface area and thus air resistance, allowing them to accelerate for longer before reaching an even higher terminal velocity.



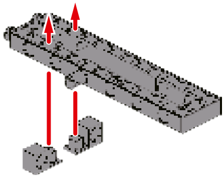
MODEL H: ELASTIC LAUNCHERS

1

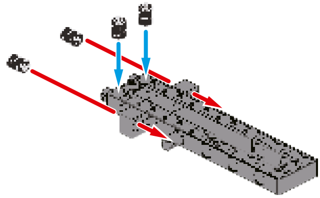
Do all of these assembly steps two times. You will build two elastic launchers.



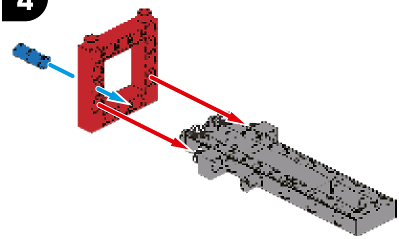
2



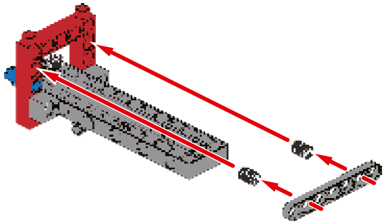
3



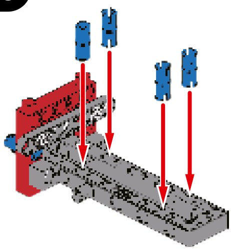
4



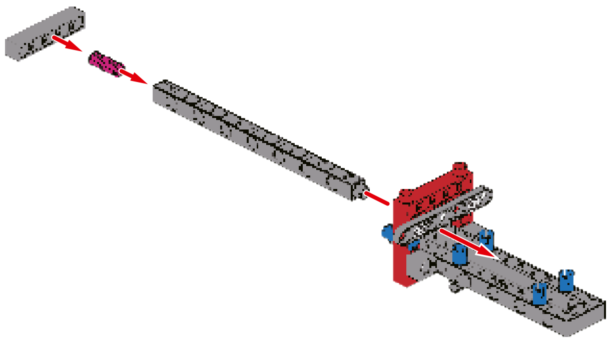
5



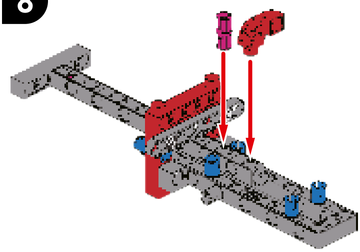
6



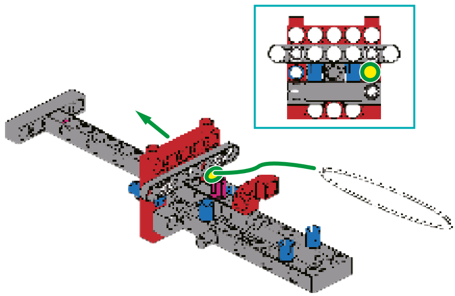
7



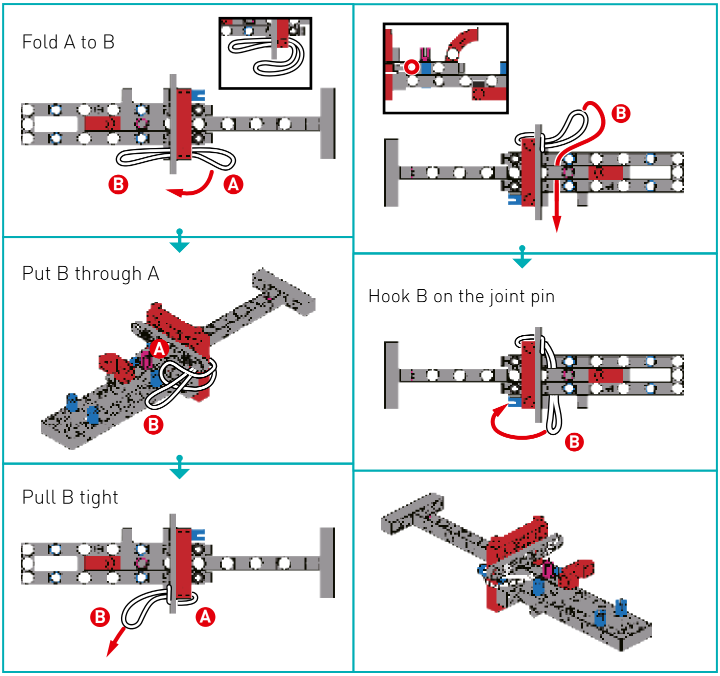
8



9

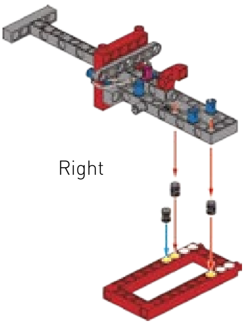


10

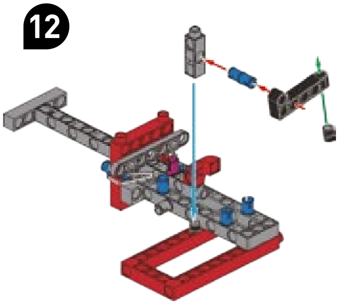


2x

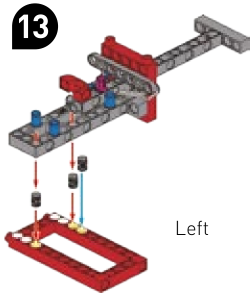
11



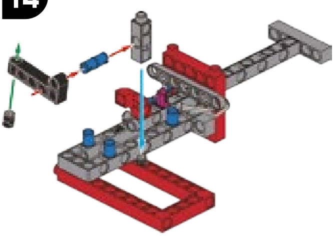
12

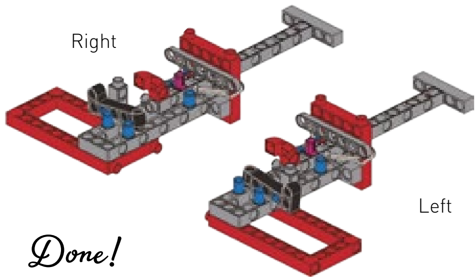


13



14





Done!

EXPERIMENT 21

Bumper cars

You will need

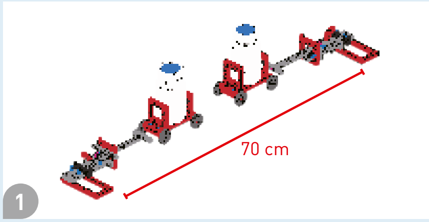
- 2x Model H: Elastic launchers
- 2x Model C: Cars
- 2x Bottle weights

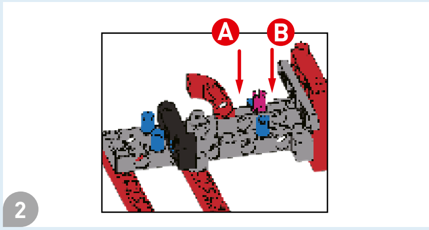
Here's how

1. Set up the elastic launchers so that their bases are approximately 70 cm apart.
2. Pull both elastic launchers back and place the black latch into position B. (The launcher has two power levels; you can hook the latch at point A for less power and at B for more power.)
3. Place the cars in front of the launchers, so they are touching the T-bars.
4. Release the latches of the elastic launchers at the same time. What happens during the collision?

WHAT'S HAPPENING?

The law of **conservation of momentum** states that the total momentum of two objects before a collision will equal the total momentum of the objects after the collision in an isolated system (with no friction). Momentum (see p. 21) depends on mass and velocity. With velocity, both speed and direction are important, so when two objects are traveling toward each other, the total momentum of the system is zero. After the collision, total momentum will be zero.





EXPERIMENT 22

Conservation of momentum

Here's how

1. Place a full bottle weight into one of the cars and repeat experiment 21.
2. Repeat experiment 21, except pull one of the launchers back to position A.
3. Instead of creating a head-on collision, try launching the cars at different angles to see what happens.
4. Place one of the cars in the center, and launch the other car into it, so the first car is stationary at the beginning of the collision.
5. Repeat step 4, but change the weights in the cars.

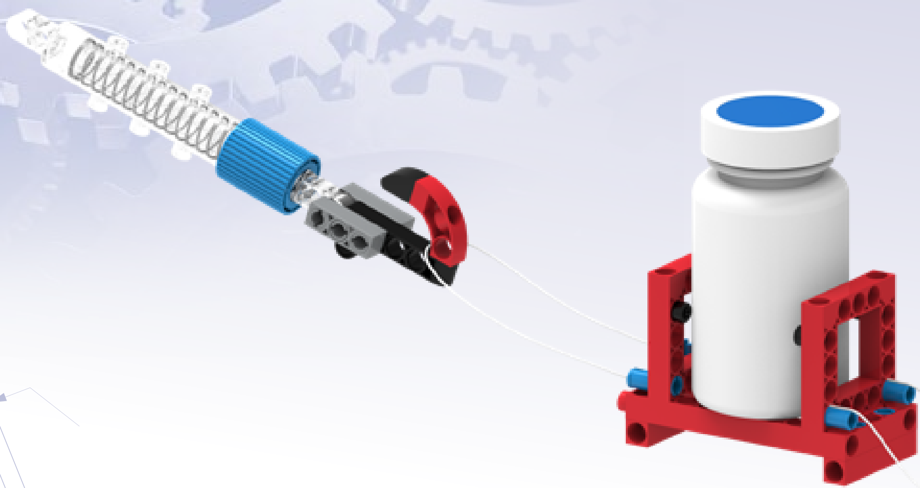
When the bowling ball hits the pins it transfers some of its momentum and kinetic energy to the pins. The ball slows down a little as the pins speed up. The total momentum in the ball/pin system is conserved.

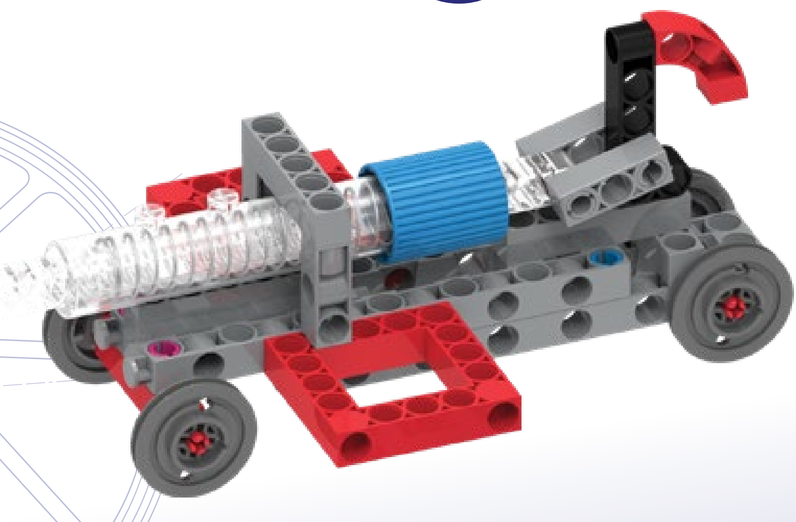
Box design: Dan Freitas and Alexandra Derderian-Clavette
Additional graphics and layout: Dan Freitas
Text and editing: Hannah Mintz, Prapti Verma, Lili DeSisto, and Ted McGuire
Technical product development: Genius Toys Taiwan Co., Ltd.
Manual design concept: Atelier Bea Klenk, Berlin
Manual layout: Hannah Mintz
Manual illustrations: Genius Toys Taiwan Co., Ltd.
Manual photos: Adobe Stock

Distributed in North America by Thames & Kosmos, LLC. Providence, RI 02903
Phone: 800-587-2872; Web: www.thamesandkosmos.com

Distributed in United Kingdom by Thames & Kosmos UK LP. Cranbrook, Kent TN17 3HE
Phone: 01580 713000; Web: www.thamesandkosmos.co.uk

Printed in Taiwan/Imprimé en Taiwan





550076-03-090226

Do you have any questions?
Our technical support team
would be glad to help you!

Thames & Kosmos US
Email: support@thamesandkosmos.com
Phone: 1-800-587-2872

Thames & Kosmos UK
Web: thamesandkosmos.co.uk
Phone: 01580 713000