# 1 Catapult – Workbook

## Page 1

What do I want to do with the model I am going to build?

What was the catapult used for in the past?

Try to make a sketch (rough drawing) of our model catapult.

Explain in your own words how the catapult works?

## Page 2

**Label the diagram of the model (use the terms in the word bank, below):**

pawl, wheel, secondary rubber band, axle, shooting arm, gear

## Page 3

A self-locking gear mechanism (ratchet) consists of a specially shaped gear and a pawl.

What is the function of the pawl?

Why is it better to use a self-locking gear mechanism (ratchet) in a catapult and not a regular gear?

Here is a drawing that demonstrates how a ratchet mechanism can help us pull a heavy bucket up out of a well.

Why do you think a ratchet is better than a regular gear?

## Page 4

Here is a self-locking gear mechanism (ratchet).

Draw an arrow to show in which direction each of the gears can turn.

There are three gears in the photo:

Gear no. 1 Gear no. 2 Gear no. 3

**Complete:** Of the three gears, the gear that is most suitable for a ratchet mechanism is gear number \_\_\_\_\_\_\_\_\_\_ (1, 2, 3).

## Page 5

We have learned that there are different types of energy.

For example: kinetic (movement), sound, potential (height), elastic, chemical, and more.

Fill in the type of energy that corresponds to each image.

A moving car has \_\_\_\_\_\_\_\_\_\_ energy.

A radio playing music has \_\_\_\_\_\_\_\_\_\_ energy.

A compressed balloon has \_\_\_\_\_\_\_\_\_\_ energy.

When we exercise, we are using \_\_\_\_\_\_\_\_\_\_ energy.

The girl on ladder has \_\_\_\_\_\_\_\_\_\_ energy.

Children singing have \_\_\_\_\_\_\_\_\_\_ energy.

## Page 6

**Fill in which types of energy corresponds to the following stages (use the terms in the word bank, below):**

\_\_\_\_\_\_\_\_\_ energy

**The rubber band is stretched.**

**The shooting arm is released and quickly travels upward.**

**The ball is in the air.**

Elastic, potential, kinetic

**Fill in the blanks so that the statements are correct:**

The \_\_\_\_\_\_\_\_\_\_ (thicker / thinner) the elastic, the more elastic energy is stored during stretching.

The more friction there is between the arm and the axis of rotation, the \_\_\_\_\_\_\_\_\_\_ (longer / shorter) the distance the ball will travel.

When the catapult moves along, we say that it has \_\_\_\_\_\_\_\_\_\_ (elastic / kinetic) energy.

An elastic with a smaller diameter will store \_\_\_\_\_\_\_\_\_\_ (more / less) elastic energy during the stretching process, and therefore the ball will travel a \_\_\_\_\_\_\_\_\_\_ (longer / shorter) distance.

## Page 7

Consider the purpose of the catapult in the past.

* Why did they prefer to build it out of wood?
* Why does it have wheels?

Danny replaced the rubber band attached to the shooting arm with a thicker one.

How did this affect the shooting distance?

**Indicate** onlythe sentences that are correct:

* A self-locking mechanism is also called a ratchet.
* When an elastic is stretched, it stores elastic energy.
* Instead of a rubber band, a rope or string can be used.
* The shooting arm is connected to the catapult using an axle.
* The ratchet mechanism allows the gear to rotate both ways.
* The amount of friction affects the distance the ball will travel.

## Page 8

**Advanced level – Questions about energy**

Without any connection to the model of the catapult, give an example where one type of energy is converted into a different type of energy:

Without any connection to the model of the catapult, give an example where energy is transferred from one object to another:

Danny kicked the ball.   
The ball rolled and finally stopped on a hilltop.

Fill in the type of energy that corresponds to the story at every stage:

\_\_\_\_\_\_\_\_\_\_energy

**Danny kicks the ball.**

**The ball rolls.**

**The ball is at the top of the hill.**

# 1 Catapult – Information Booklet

## Page 1

The catapult is an ancient weapon of war.

It was invented before the cannon. Soldiers used it to hurl heavy rocks long distances.

Because it was made of wood, it could be assembled right in the battlefield. Wheels were attached to make it easy to move.

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## Page 2

**What are the parts of a catapult?**

* **Axle** (for the shooting arm)
* **Wheel**
* **Gear**
* **Pawl** (a tab that fits into the slanted teeth of the gear)
* **Secondary elastic** (affixed to the pawl)
* **String** (connects the shooting arm and the gear axle)
* **Shooting arm**
* **Primary elastic** (attached to the shooting arm)

**How does the catapult work?**

**Loading stage:**

The gear is turned.

The rope pulls the shooting arm down and the elastic is stretched.

A paper ball is placed on the shooting arm.

**Shooting stage:**

The pawl is released from the gear.

The elastic yanks the shooting arm upward.

The paper ball flies into the air.

## Page 3

**Self-locking mechanism (ratchet)**

A gear attached to a rod (axle) can rotate in either direction.

**If we want the gear to turn in one direction only,** we need to **“lock”** it to prevent it from rotating in the opposite direction.

**How is this done?**

* Instead of using a standard gear, we use one with special, slanted teeth – a “ratchet gear.”
* We add a tab (pawl) with a projection that fits exactly into the spaces between the gear’s teeth.
* The pawl allows the gear to rotate only in one direction.

If the gear tries to turn in the opposite direction, the pawl becomes jammed between the teeth and prevents the gear from turning.

This mechanism that is made of

a ratchet gear + a pawl

is called a s**elf-locking mechanism,**

or in short – **ratchet**.

## Page 4

**The self-locking mechanism in the catapult**

**Loading stage:**

During loading, **the pawl is positioned within the gear**.

Therefore, it is possible to rotate the gear only in the direction of the red arrow.

As the gear is turned, the rope pulls the shooting arm down.

Even though the elastic is pulling it, the shooting arm remains down because the pawl prevents the gear from rotating back in the opposite direction.

**Shooting stage:**

When you are ready to shoot, **release the pawl**

to allow the gear to spin back the other way.

At this point, the elastic “successfully” yanks the shooting arm up to deploy the ball.

## Page 5

What is energy?

There is no exact definition of energy.

In general, we can say that anything that happens will have its own specific type of energy.

**Examples**

* **When an object is in motion** – it has **kinetic energy** (energy of motion).

A sailing boat

A rolling ball

* **When an object makes a sound –** it has **sound energy**.

A screaming baby

A ringing telephone

* **An object that is high up** has more energy than when it is down on the ground. This “**height energy”** is called “**potential energy”** (because it has the potential to release energy when it comes down).

A plane flying in the sky

A vase of flowers or a book on a shelf

* **If an object is stretched or compressed** (and it “wants” to return to its original state), it contains **elastic energy**.

In a spring (whether stretched or compressed)

In an elastic band (when stretched)

* **Animals (including humans)** use **chemical energy** in muscles to perform various actions.

## Page 6

**The energy diagram of the model**

Our model illustrates **three important features of energy:**

1. There are different types of energy.
2. Energy can change from one type into another (conversion of energy).
3. Energy can move from one object to another (transfer of energy).

Loading Stage / Shooting Stage

**Chemical energy** in the muscles of our hand (when turning the gear)

**Elastic energy** in the elastic band that is being stretched

**Kinetic energy** of the shooting arm (when the pawl is released and the arm quickly springs forward).

**Potential and kinetic energy** of the ball (when the ball soars upward)

**Transfer of energy:** Energy **is transferred** from the hand to the ball, through the

various partsof the model.

Conversion of energy:

Chemical energy **is converted** into elastic energy.

Elastic energy **is converted** into kinetic energy.

Some of the kinetic energy **is converted on**to potential energy.

One may say that the energy of the shooting arm is converted into the kinetic and potential energy of the ball.

# 2 The Jack – Hydraulic Scissor Lift Platform – Workbook

## Page 1

What do I want to do with the model I am going to build?

What is a jack/hydraulic lift used for?

Try to make a sketch (rough drawing) of our model jack/hydraulic lift.

Explain in your own words how a jack/hydraulic lift works?

## Page 2

**Label the diagram of the model (use the terms in the word bank, below):**

activating syringe, lifting platform, scissor-mechanism, base, tubing, operational syringe

## Page 3

In our model, the force passes through five stations.

For each station, write what (or who) applies the force and on what (or whom) the force acts:

|  |  |  |
| --- | --- | --- |
| Station | Who (what) applies the force? | On whom (what) does the force act? |
| 1 |  |  |
| 2 |  |  |
| 3 |  |  |
| 4 |  |  |
| 5 |  |  |

## Page 4

There are different types of hydraulic lifts.

In this picture, you see a hydraulic lift called a crane.

The lifting platform of the crane is raised by a long arm instead of a scissor mechanism.

To compare the scissor mechanism with the crane mechanism, complete the following table:

|  |  |  |
| --- | --- | --- |
| **Characteristic** | **Scissor mechanism** | **Crane arm** |
| **Height**  (Which reaches a greater height?) |  |  |
| **Stability against wind**  (Which is more stable?) |  |  |

**Johnny the gardener wants to trim a large, high tree.**

What type of hydraulic lift would you suggest he use?

Circle the correct answer: scissor mechanism / crane

Why?

## Page 5

Explain in your own words what a piston is:

Here are some pictures of tools that use pistons.

Try to identify where the pistons are hidden in the tools, and circle them.

## Page 6

**Indicate** onlythe sentences that are correct:

* A piston is a rod that can move back and forth inside a cylinder.
* Our model has two pistons.
* The longer the tubing is, the greater the force needed on the syringe to raise the platform.
* The word “hydraulic” is built from two words: water + pipe.
* Our model will work just as successfully whether the syringes are filled with water or with air.
* A hydraulic system uses gas to transfer power from one place to another.
* A pneumatic system uses gas to transfer power from one place to another.

Why do you think it is important not to tighten screws in the scissor mechanism “all the way” and leave them with a certain amount of “play”?

# 2 The Jack – Hydraulic Scissor Lift Platform – Information Booklet

## Page 1

A hydraulic scissor lift platform is a flat surface that can be raised or lowered. A smaller version, like our model, is also called a “jack.”

When constructing or renovating a building, one can use a hydraulic lift to raise and lower people and things (like an elevator that is outside of the building).

To maintain the stability of the platform during ascent and descent, **a scissor mechanism is used**.

The scissor mechanism ensures that the platform does not tilt and will always remain straight (parallel to the ground).

## Page 2

**What are the parts of a hydraulic lift?**

* **Lifting platform**
* **Scissor mechanism**
* **Activating syringe**
* **Tubing**
* **Operational syringe**
* **Base**

**How does the lifting platform operate?**

**Lifting Stage**

Press the activating syringe.

The operational syringe extends.

The scissor mechanism rises.

**Descending stage**

Pull the activating syringe.

The operational syringe withdraws.

The scissor mechanism descends

## Page 3

**What is a piston?**

A piston is a rod that can move back and forth inside a cylinder.

The cylinder makes sure that the piston will not veer to the sides but continually moves forward and backward in a straight line and in the same spot.

**Rod (piston)**

**Cylinder**

**Question:**

Is there a piston in the model we are building?

**Answer:**

Of course! Our model has two pistons.

**Each syringe consists of cylinder in which there is a piston (rod)**.

The piston (plunger, in this case) can move back and forth inside the cylinder.

**What is a hydraulic piston?**

**A hydraulic piston is a piston (i.e. a rod) that moves within a cylinder under the pressure of a fluid.**

If you fill the syringe with water, it becomes a hydraulic piston.

## Page 4

**When is a piston used?**

**We use a piston when we want to transfer power from one place to another.**

For example, in our model:

the power goes from our hands to the lifting platform through five stations!

* **The hand applies force** to the piston (rod) of the activating syringe.
* **The piston** **applies force** to the water.
* **The water applies force** to the piston (rod) of the operational syringe.
* **The piston applies force** to the scissor mechanism.
* **The scissor mechanism applies force** to the lifting platform.

**Question:**

If the tubing is longer, is more force required to lift the platform?

**Answer: No**.

The force needed to activate the piston does not depend on the length of the tubing.

## Page 5

**Hydraulic systems**

**Question:**

**What is the source of the word “hydraulics” and what is a hydraulic system?**

**Answer:**

The word “hydraulic” is formed from two Greek words:

Hydro = water

ulus = pipe

A hydraulic system is a system that is formed from pipes. The fluid that passes through them transmits power through the use of pressure.

In our model, the hydraulic system consists of:

**two pistons + tubing + water.**

In the next picture, we can see an excavator with a huge metal shovel:

Note that along the length of the shovel there are five hydraulic pistons.

The pistons are connected to different parts of the machine, making it possible to control the movement of the shovel.

## Page 6

A closer look at air pistons

In our model, we use hydraulic pistons.

This type of piston is called “hydraulic” because there is liquid (water in our model) inside it.

As we learned, when the piston moves, it pushes the liquid, which transfers the force elsewhere.

 It is important to know you do not have to use liquid. Gas can be used instead.

In this case, the piston applies force on the gas and this is what transmits the force.

**A piston that uses gas pressure to transfer force is called a pneumatic piston (air piston).**

**Question:**

Does our model have to use a hydraulic piston, that is to say, a piston that uses water?

**Answer:**

No. If you empty the water from the syringes, you will see that the model still works! Now, the piston presses on the air, and the air is what transmits the force.

**Question:**

When should you use the hydraulic piston (which uses fluid) and when should you use a pneumatic piston (which uses gas)?

**Answer:**

The main difference between the two pistons is that gas can be compressed and liquid cannot.

Therefore, when pressure is applied to the pneumatic piston, the transfer of force is more gradual.

If one wants to carry out a delicate operation (that is to say, with small movements), it is better to use a pneumatic piston.

When we want to use great force, we use a hydraulic piston.

# 3 Flashlight – Workbook

## Page 1

What do I want to do with the model I am going to build?

What did people use for light before the discovery of electricity and the invention of the light bulb?

Try to make a sketch (rough drawing) of our flashlight model.

Explain in your own words how the flashlight works?

(Hint. These words will help: electrical circuit, battery, LED bulb, closed switch, open switch, electric current, electrons.)

## Page 2

**Label the diagram of the model (use the terms in the word bank, below):**

Switch, LED light, battery, battery housing, wire conductor, cover.

## Page 3

Below is a table showing the differences between electric lighting and light created from fire.

Complete the table with the correct words.

|  |  |  |
| --- | --- | --- |
| **Characteristic** | **Electric lighting**  **(for example, a flashlight)** | **Light from fire**  **(for example, a torch)** |
| Method for turning on/off  (easy/difficult) |  |  |
| Is there a smell?  (yes/no) |  |  |
| How long does it last (long/short time) |  |  |
| Lighting intensity  (strong/weak) |  |  |
| Gives off heat  (a lot/a little) |  |  |
| Wind resistance  (yes/no) |  |  |
| Safe  (yes/no) |  |  |

## Page 4

Here are pairs of atomic particles. Determine if there is electrical attraction or repulsion in each situation.

electric attraction / electrical repulsion

Tory has four metal balls.

Two balls have a positive charge (they have an excess of protons),

and two balls have a negative charge (they have an excess of electrons).

Each time, Tory suspends two balls from the ceiling and photographs them.

Mark an “x” on the pictures that cannot be correct.

## Page 5

**Fill in the blanks so that the statements are correct:**

An electron and a proton \_\_\_\_\_\_\_\_\_\_ (attract / repel) each other.

An electron and another electron \_\_\_\_\_\_\_\_\_\_ (attract / repel) each other.

In an electric circuit, the electrons flow from the \_\_\_\_\_\_\_\_\_\_ end (negative / positive) of the battery to the \_\_\_\_\_\_\_\_\_\_ (negative / positive) end.

When a switch is \_\_\_\_\_\_\_\_\_\_ (closed / open), electric current can flow.

When a switch \_\_\_\_\_\_\_\_\_\_ (closed / open), the circuit is broken (disconnected).

In the electric circuit in the flashlight, \_\_\_\_\_\_\_\_\_\_ (electrical / light) energy is converted (changed) into \_\_\_\_\_\_\_\_\_\_ (electric / light) energy.

**“Conductive” material allows electrons to flow through it easily.**

Most metals conduct electricity very well.

Here is a list of materials. Circle the ones that are good conductors.

wood

iron

copper

glass

gold

silver

plastic

rubber

## Page 6

Here are some drawings of electric circuits.

In each circuit, mark the electrical device(s) that will work.

(Hint: Check if there is a continuous path for the electrons to flow from the negative end of the battery to the positive end.)

## Page 7

Here are a few sentences. Indicate only the sentences that are correct:

* The negative end of the battery is indicated by a small bump.
* A stream of electrons is called an electric current.
* A stream of protons is called an electric current.
* Conductive material allows electrons to flow through it easily and quickly.
* A device that runs on battery power is not an electrical appliance.
* A toy car that runs on a spring is an electrical appliance.
* When a radio works, electrical energy turns into sound energy.

An example of an electrical circuit is a battery connected to an electrical device with conductive wires.

Advanced level – Challenge question

Here is a diagram of an electrical circuit.

Do you think the light will go on? (yes/no)

Explain your answer:

## Page 8

Conversion of energy:

**When using an electrical appliance, electric energy is converted (turns) into different types of energy.**

Use the terms in the word bank below to help you fill in the main types of energy that are involved in the operation of each device.

* In an electric iron, electrical energy is converted into \_\_\_\_\_\_\_\_\_\_ \_\_\_\_\_\_\_\_\_\_.
* In a food mixer, electrical energy is converted into\_\_\_\_\_\_\_\_\_\_ \_\_\_\_\_\_\_\_\_\_ and \_\_\_\_\_\_\_\_\_\_ \_\_\_\_\_\_\_\_\_\_.
* In a television, electrical energy is converted into\_\_\_\_\_\_\_\_\_\_ \_\_\_\_\_\_\_\_\_\_ and \_\_\_\_\_\_\_\_\_\_ \_\_\_\_\_\_\_\_\_\_.
* In an electric drill, electrical energy is converted into \_\_\_\_\_\_\_\_\_\_ \_\_\_\_\_\_\_\_\_\_ and \_\_\_\_\_\_\_\_\_\_ \_\_\_\_\_\_\_\_\_\_.
* In an electric kettle, electrical energy is converted into\_\_\_\_\_\_\_\_\_\_ \_\_\_\_\_\_\_\_\_\_.
* In an electric fan, electrical energy is converted into \_\_\_\_\_\_\_\_\_\_ \_\_\_\_\_\_\_\_\_\_.

Word bank:

light energy, kinetic energy, heat energy, sound energy.

# 3 Flashlight – Information Booklet

## Page 1

The flashlight we shall assemble is an electric flashlight.

It uses an LED light and runs on electricity supplied by a battery.

Before we see how it works, let’s learn its history.

In the past, before the discovery of electricity and the invention of the light bulb,

fire was used to illuminate the darkness.

For example, people used torches, campfires and candles.

When candles were used, they were put into ceramic or metal containers.

Later, they were put into containers with glass walls (lanterns).

**Why glass?**

The transparent glass allowed the light from the burning candle to shine through,

and additionally prevented the wind from extinguishing the candle.

## Page 2

Even after the invention of the electric lightbulb, people continued to use candles!

**Why?**

The electric lights were not portable. This is because they were attached to the wall and couldn’t be moved.

In contrast, candles could be taken anywhere that required light.

Congratulations!!

In 1896, the first portable electric light was invented!

Thus, for the first time, electric lighting became mobile (it could be moved from place to place). Because the batteries that were used at that time could only be operated for a very short time, the light had to go on and off quickly – a “flash” – and that is why it became known as a “flashlight.”

**Question:**

What are the advantages of electric lighting (for example, light from an electric flashlight)

over light from fire (for example, light from a candle)?

**Answer:**

* Easy to turn the light on and off;
* There is no burning smell and no smoke;
* The light generally lasts longer;
* The light is stronger;
* There is hardly any emitted heat;
* It is more durable (fire can be extinguished by the wind);
* It is safer (less danger of a fire/burn).

## Page 3

**What is an electron and what is a proton?**

Electrons and protons are extremely small particles (microscopic) found in the atoms of everything around us.

There is a very strong attraction between an electron and a proton. This is called electrical attraction.

Because of the attraction if you put one near the other, they will move toward each other and it will be difficult to separate them.

To distinguish between electrons and protons, we say that

an electron has a negative charge, which we indicate with a minus sign (-),

and the proton has a positive charge, which we indicate with a plus sign (+).

Electrical attraction.

**Proton Electron**

When an electron and a proton meet, their total charge equals zero (the opposite charges cancel each other out).

Unlike the electron and proton, which attract each other, particles of the same type reject each other.

**Electric repulsion**

## Page 4

**How is a battery built?**

The battery consists of three adjacent cells:

**Cell with positive charge**

**Separator cell**

**Cell with negative charge**

**Question:** What is the role of the separator cell?

**Answer:**

The separator cell prevents the negative charge from getting close

to the positive charge, despite the strong attraction between them.

We saw that each battery has a positive end (+) and negative end (-).

To differentiate between the ends, it is customary to put a small bump on the positive end while the negative end is left flat.

**The positive end has a bump.**

## Page 5

What is an electrical current?

Question: What will happen if you connect the negative end of the battery to the positive end with a copper wire?

**Answer:**

As we learned, the electrons on the negative end of the battery are attracted to the positive end.

A copper wire gives the electrons an easy way to get to the positive end of the battery.

Therefore, as soon as you connect the copper wire to each end of the battery, the electrons will begin to flow through the wire from the negative to the positive end.

**We call a flow of electrons in a wire an “electric current.”**

**Question:** When will the electrons stop flowing along the copper wire?

**Answer:**

Whenever an electron goes from the negative to the positive end, two things happen:

the negative end becomes less negative (because electrons leave);

the positive end becomes less positive (because electrons enter).

The electrons will continue to flow toward the positive end, making it less and less positive until it eventually stops attracting electrons.

In this case, we say that the battery is exhausted (dead battery).

## Page 6

**What is “electrically conductive” material?**

**Question:**

Instead of the copper wire, can we use a wire made from some other material? For example, could we use a wire made of gold or a wire made of plastic?

**Answer:**

It is important that the wire is made from a material through which electrons can flow. Such material is said to be **“conductive.”**

Usually, metal wires are used because metals are excellent electrical conductors.

Electrons can flow through conductive material very quickly.

Plastic is an example of a non-conductive material.

**What is a switch?**

**Question:**

What would happen if you cut the copper wire?

**Answer:**

When you cut the copper wire, it makes a break in the circuit. This means that the electrons are no longer able to travel to the positive end of the battery. Therefore, the electric current stops.

**Instead of cutting the wire, we can use a switch.**

A switch allows us to connect or disconnect the wire with the push of a button.

When the wire is connected – the electric current can flow (flow of electrons).

When the wire is disconnected – the electric current is broken (electrons won’t flow).

## Page 7

**What is an electrical appliance?**

An electrical appliance is a device that runs when an electric current (flow of electrons) passes through it.

**Question:**

What electrical appliances do you know?

**Answer:**

Any device that runs on batteries or by connecting it to an electrical outlet in the house is an electrical appliance.

For example: television, computer, air conditioner, fridge, radio, cell phone, vacuum cleaner, washing machine, light, and more.

## Page 8

**The electric circuit**

To activate an electrical appliance, we must ensure that the electric current running along the conductor wire passes through the appliance.

Therefore, connect the appliance to the electrical conductor as follows:

**Electrical appliance**

Note: To get to the positive end of the battery, the electrons must pass through the appliance.

While passing, the electrons “give” the device some electrical energy to make the appliance work.

Passing through the electrical device is not as easy for the electrons as passing along the conducting wire. Therefore, when, connected to the electrical appliance, the electrons slow down.

**Components of an electric circuit:**

**battery + conductor + electrical appliance**

## Page 9

**How does our model flashlight work?**

The flashlight that we are building has an electrical circuit built from four components:

1. batteries
2. conductive wire
3. LED bulb
4. switch.

**When the switch is closed** – electrons can flow from the negative end of the battery to its positive end. (In other words, there is an electric current.)

The electric current passes through the LED bulb, causing it to light.

**When the switch is open** – there is a break in the circuit, so the electrons have no way to reach the positive end of the battery. (In other words, there is an electric current.)

Because no electric current is passing through the LED bulb – it remains off.

## Page 10

**What are the exterior parts of the model flashlight?**

**cover**

**LED bulb**

**What are the interior parts of the model flashlight?**

**battery compartment**

**battery**

**switch**

# 4 Car Gearbox – Workbook

## Page 1

What do I want to do with the model I am going to build?

What is the difference between a gear (cogwheel) and a regular wheel?

Try to make a sketch (rough drawing) of our car gearbox model.

Explain in your own words how the model works?

(Hint: Try to explain the process by stages – from the moment you start the motor until the color wheel spins.)

## Page 2

**Label the diagram of the model (use the terms in the word bank, below):**

color wheel, primary driving gear, conductive wires, movable axle,

battery housing, motor, fixed axle, handle to move the movable axle.

## Page 3

Here are some diagrams of meshed gears.

The driving gears are green.

Indicate the direction of rotation of each of the other gears with arrows:

## Page 4

Here is a diagram of two meshed gears.

**The green gear is the driving gear.**

Driving gear

Driven gear

**Fill in the blanks, so that statements are correct:**

The direction of the driven gear is \_\_\_\_\_\_\_\_\_\_ (the same as / opposite to) the direction as the driving gear.

The number of teeth of the driven gear is \_\_\_\_\_\_\_\_\_\_ (twice / half) the number of teeth of the driving gear.

Each time the driving gear advances by one tooth, the driven gear advances by \_\_\_\_\_\_\_\_\_\_ (one tooth / two teeth).

The driven gear is \_\_\_\_\_\_\_\_\_\_ (faster / slower) than the driving gear.

For each complete revolution that the driving gear makes, the driven gear completes \_\_\_\_\_\_\_\_\_\_ (one half of a revolution / two revolutions).

The diagram shows how the speed of the driving gear can be \_\_\_\_\_\_\_\_\_\_ (increased / decreased).

## Page 5

**The following drawings illustrate some possible positions of the gears in our model.**

**Circle the appropriate word to complete the sentence next to each drawing.**

The driven gear (brown) rotates at a speed that is \_\_\_\_\_\_\_\_\_\_ (greater / equal / less) than that of the driving gear (green).

The driven gear (brown) rotates at a speed that is \_\_\_\_\_\_\_\_\_\_ (greater / equal / less) than that of the driving gear (green).

The driven gear (brown) rotates at a speed that is \_\_\_\_\_\_\_\_\_\_ (greater / equal / less) than that of the driving gear (green).

## Page 6

Next to the green gear, draw a gear that will turn at **the same** speed.

Complete: The gear we drew has \_\_\_\_\_\_\_\_\_\_ teeth.

Next to the grey gear, draw a gear that will turn at **twice** the speed.

Complete: The gear we drew has \_\_\_\_\_\_\_\_\_\_ teeth.

Next to the blue gear, draw a gear that will turn at **half** the speed.

Complete: The gear we drew has \_\_\_\_\_\_\_\_\_\_ teeth.

# 4 Car Gearbox – Information Booklet

## Page 1

The model we are going to build demonstrates how the wheels of a car are connected to its engine.

Then, we will explain how you can change the speed of rotation of the car’s wheels without changing the speed of the engine.

**Gear**

**A gear (or “cogwheel”) is a wheel with teeth (or cogs) along its circumference.**

All the teeth are of equal size and equal distance from each other.

[[REMOVED EXTRANEOUS TEXT]]

Inside a car, there are many gears that are set up similar to the model we are going to build. We call an entire assembly of gears and rods a “gearbox.”

## Page 2

**Integrated gears**

Integrated gears are gears placed next to each other – such that the teeth from one gear fit into (mesh into) the spaces of the second gear.

When two gears are meshed and one of the gears is turned in a particular direction, its teeth cause the other gear to rotate in the opposite direction.

Driving gear – the first gear to turn. Its teeth push the gear that is meshed with it.

Driven gear – the second one to turn.

With each “push,” the driving gear advances by one tooth (in the direction of the green arrow) and the driven gear simultaneously advances by one tooth (in the direction of the orange arrow).

## Page 3

**Gears in different sizes**

**Question:** Is it possible to mesh a large gear with a small gear?

**Answer:** Yes!

Meshed gears need not be the same size (diameter). However, the size and spacing of their teeth must be the same.

Note that the larger gear has more teeth than the smaller gear – but all the teeth are the same size.

Because the size and spacing of the teeth are identical, whenever the driving gear moves one tooth forward, the driven gear also moves one tooth forward.

**Question:** Do different sized gears rotate at the same speed?

**Answer:** No!

When meshed gears are of different sizes, the smaller gear (obviously) has fewer teeth. Therefore, the small gear will complete one rotation before the large gear finishes one complete rotation of its own.

In other words: **The smaller gear will rotate faster than the big gear**.

## Page 4

**Transmission ratio – in depth**

The transmission ratio is the ratio between the number of revolutions made by the driving gear and the number of revolutions made by the driven gear.

The transmission ratio reveals which gear is faster and by how much.

**Example 1 – Gears are the same size (identical speeds)**

**Driving gear has 10 teeth**

**Driven gear has 10 teeth**

Each time the driving gear advances by one tooth, the driven gear also advances by one tooth.

Because each gear has 10 teeth, they will both finish one full rotation at the same time –

after 10 advances of the teeth.

In this case, we can say that for every one rotation of the driving gear, the driven gear also rotates one rotation.

In other words: **The transmission ratio is one to one (1:1).**

If a transmission ratio of one to one (1:1), it means that the speed of the driven gear is equal to that of the driving gear.

## Page 5

**Transmission ratio – in depth**

**Example 2 – Gears are of different sizes (different speeds)**

**The driving gear has 20 teeth**

**The driven gear has 10 teeth**

Each time the driving gear advances by one tooth, the driven gear also advances by one tooth.

The driving gear completes a full rotation after 20 increments, but the driven gear completes one full rotation after **only** 10 increments.

In this case, we can say that for every one rotation of the driving gear, the driven gear makes two rotations.

In other words: **The transmission ratio is one to two (1:2).**

If a transmission ratio of one to two (1:2), it means that the speed of the driven gear is twice as fast that of the driving gear.

## Page 6

**What are the parts of our gearbox model?**

* **Movable axle (the driven gears rotate on this rod)**
* **Handle to move the movable axle.**
* **Battery housing, including batteries and a switch.**
* **Conductive wires**
* **Motor**
* **Main driving gear**
* **Fixed axle (the driving gears rotate on this rod)**
* **Color wheel (to represent the wheel of a car)**

**How does our model work?**

**Stage 1**

The batteries provide power to the motor.

The motor rotates the main driving gear.

The main driving gear rotates the fixed axle.

The driving gears rotate.

**Stage 2**

The movable axle is moved back and forth using the handle.

A gear on the movable axle meshes with the teeth of a gear on the fixed axle.

The color wheel spins. (Its speed depends on the size ratio – transmission ratio – of the gears that meshed.)

# 5 Windmill – Workbook

## Page 1

What do I want to do with the model I am going to build?

Try to make a sketch (rough drawing) of our windmill model.

What were windmills used for in the past?

How do windmills work?

(Hint. These words will help: wind, blades, millstone stones, grains of wheat, flour)

## Page 2

**Label the diagram of the model (use the terms in the word bank, below):**

Belt drive, driving gear, conductive wires, blades,

driven gear, drive shaft, motor, battery housing including switch

## Page 3

The following diagram helps to explain how the model of the windmill operates through 6 stages.

Alongside each stage, write what is happening.

A bonus for those who learned about energy:

At each step, write how the energy is being converted.

## Page 4

**Here is a diagram of a belt drive transmission system.**

**The green gear is the driving gear.**

**Driven gear**

**Driving gear**

**Fill in the blanks, so that statements are correct:**

* The driven gear moves in the \_\_\_\_\_\_\_\_\_\_ (same / opposite) direction as the driving gear.
* The circumference of the driven gear is \_\_\_\_\_\_\_\_\_\_ (twice / half) the size of the driving gear.
* For each complete revolution of the driving gear, the driven gear completes \_\_\_\_\_\_\_\_\_\_ (one-half of a revolution / one complete revolution / two revolutions).
* The driven gear is \_\_\_\_\_\_\_\_\_\_ (faster / slower) than the driving gear.
* The diagram shows how to \_\_\_\_\_\_\_\_\_\_ (increase / decrease) the speed of the driving gear.

## Page 5

**Here is a diagram of a belt drive transmission system.**

**The driving gear is colored green. Use arrows to indicate the direction of movement of the belt drive and the driven gear:**

Draw a belt drive transmission system so that the additional gear will have **the same speed** as the green gear.

Draw a belt drive transmission system, so that the additional gear will be **faster** than the grey gear.

Draw a belt drive transmission system, so that the additional gear will be **slower** than the blue gear.

## Page 6

The model of the windmill has two modes of operation.

Circle the appropriate option for each sketch.

The blades rotate at a speed that is \_\_\_\_\_\_\_\_\_\_ (faster than / equal to / slower than) than the motor’s speed.

The blades rotate at a speed that is \_\_\_\_\_\_\_\_\_\_ (faster than / equal to / slower than) than the motor’s speed.

# 5 Windmill – Information Booklet

## Page 1

The model that we build works like an electric fan – it uses an electric motor and a belt (rubber band) to rotate the blades at different speeds.

However, the model *looks* a windmill and therefore that is what it is called.

In the past (before the use of electric machines), people used windmills to grind wheat into flour.

It is therefore also called a flourmill or gristmill.

In the picture on the left, you can see a photo of a real windmill!

The wind turns the blades of the mill, and the turning blades activate a set of gears that rotate the grinding stones (millstones).

**Windmill**

**Millstones**

**Wheat**

## Page 2

**What are the parts of our windmill model?**

**Roof**

**Blades**

**Drive shaft (to rotate blades)**

**Motor**

**Conductive wires**

**Battery housing including batteries and a switch**

**Drive shaft (to rotate blades)**

**Driven gear**

**Belt drive (rubber band)**

**Driving gear**

## Page 3

**How does the model windmill work?**

* **The batteries provide power to the motor.**
* **The motor turns the driving gear.**
* **The driving gear activates the belt drive (rubber band).**
* **The belt drive (rubber band) makes the driven gear rotate.**
* **The driven gear turns the drive shaft.**
* **The drive shaft turns the blades.**

## Page 4

**Energy diagram of the model**

Our model illustrates **three important features of energy:**

1. There are different types of energy.
2. Energy can change from one type into another (conversion of energy).
3. Energy can move from one object to another (transfer of energy).

Electrical energy from batteries

Kinetic energy of the motor

Kinetic energy of the driving gear

Kinetic energy of the belt drive

Kinetic energy of the driven gear

Kinetic energy of the drive shaft

Kinetic energy of the blades

Transfer of energy:

**Energy is transferred** between various parts of the model: From the batteries to the blades.

Conversion of energy:

Electrical energy **is converted** into kinetic energy.

## Page 5

**Belt drive (transmission)**

A belt drive transmission consists of two gears connected by a continuous strap (belt).

**Driving gear**

**Drive belt**

**Driven gear**

The gear that begins the movement is called the driving gear.

The driving gear’s job is to make the belt move.

When the belt moves, the second gear rotates.

This gear is called the driven gear.

Our model has a set of transmission drive belts (rubber bands) that passes (transmits) the movement from the motor (at the bottom of the model) to the blades (which are at the top of the model).

Drive belts are very common and can be seen in many devices:

In bikes – the belt (chain) transfers the movement of the pedals to the wheel of the bicycle.

## Page 6

**Transmission ratio – in depth**

The transmission ratio is the ratio between the number of revolutions made by the driving gear and the number of revolutions made by the driven gear.

The transmission ratio tells us which gear is faster and by how much.

**Example 1 – gears of the same size (identical speeds)**

**Driven gear**

**Driving gear**

Each time the driving gear has made one complete revolution, the driven gear has also made one complete revolution.

In other words, they will both complete one full revolution at the same time.

In this case, we can say that:

For every one revolution of the driving gear,

the driven gear also rotates one revolution.

This means that **the transmission ratio is one to one (1:1).**

The significance of a transmission ratio of one to one (1:1) is that the speed of the driving gear is equal to the speed of the driven gear.

## Page 7

**Transmission ratio - in depth**

**Example 2 – Different sized gears (different speeds)**

**Driven gear – large**

**Driving gear – small**

Notice that the larger the gear, the longer it will take for it to complete one revolution.

In the example illustrated, the driving gear is small and the driven gear is large.

This means that when the driving gear (small) has finished one full revolution, the driven gear (large) has not yet finished one revolution.

If, for example, the circumference of the driving gear is 10 cm and circumference of the driven gear is 20 cm, when the driving gear has completed one full revolution, the driven gear has only finished one-half a revolution.

In this case, we can say: two revolutions of the driving gear are required for the driven gear to complete just a single revolution.

In other words: **the transmission ratio is two to one (2:1)**.

The meaning of a transmission ratio that is two to one (2:1) is that the speed of the driving gear is twice as fast as the speed of the driven gear.

## Page 8

**Transmission ratio in our model - in depth**

In our model, the blades can turn at either a low speed or high speed.

**First mode of operation – low speed**

In this case, the drive belt (rubber band) connects the driving gear to the driven gear.

Since the driven gear is larger, it is slower than the driving gear.

**Therefore, the blades will rotate more slowly than the rotation of the motor.**

**Second mode of operation – high speed**

In this case, the drive belt (rubber band) connects the driving gear to the drive shaft.

Since the diameter of the drive shaft is small (relative to the driving gear), it rotates faster than the driving gear.

**Therefore, the blades will rotate faster than the rotation of the motor.**

# 6 Archimedes’ Screw – Workbook to here

## Page 1

What do I want to do with the model I am going to build?

Try to make a sketch (rough drawing) of our model of an Archimedes’ screw.

What is the main use of an Archimedes’ screw?

## Page 2

**Label the diagram of the model (use the terms in the word bank, below):**

storage for marbles, motor, Archimedes’ screw, driven gear,

slide, slanted surface, driving gear, supporting wall

## Page 3

The following diagram helps to explain how the model of the Archimedes’ screw operates in 5 stages.

Alongside each stage, write what is happening.

A bonus for those who learned about energy:

At each step, write how the energy is being converted.

## Page 4

**Fill in the blanks from the word bank at the bottom of the page.**

An Archimedes screw consists of a rod around which is wrapped a coil (similar to the shape of a spring).

When the rod is rotated, the surface pushes forward whatever is on it.

The Archimedes’ screw was invented by the scientist Archimedes more than 2,000 years ago, to move water from a low place to a high one.

Because its main purpose is usually to transfer water, it is also sometimes called a screw pump.

So the water doesn't spill, the entire screw mechanism can be inserted into a cylinder, or the spiral surface can be formed with walls.

A conveyor based on Archimedes’ screw is called a screw conveyor.

An example of its use is in chicken coops to distribute seeds.

**seeds, walls, high, screw conveyor, screw pump, cylinder, water, transfer, pushes, coil, low, wrapped,**

# 6 Archimedes’ Screw– Information Booklet

## Page 1

The **Archimedes’ screw** is a machine that was invented by the scientist Archimedes to move water from a low point to a higher point.

In our model, we use the principle of Archimedes’ screw to move marbles from the bottom end of a rod to the top.

Archimedes is considered one of the greatest inventors of all time.

He was born in Greece and worked part of his life in Egypt.

His discoveries and inventions are in the fields of mathematics, physics, astronomy and more.

The Archimedes’ screw is one of his best-known inventions, mainly because people use it

to this very day.

**Archimedes**

**(287-212 BC)**

## Page 2

**What are the parts of our model of the Archimedes’ screw?**

**Supporting wall**

**Slide**

**Storage area for marbles**

**Driving gear**

**Driven gear**

**Two legs**

**Slanted surface**

**Archimedes’ screw (rod + coil)**

**Marble**

**Battery housing including batteries and a switch**

**Conductive wires**

**Motor**

## Page 3

**How does our model work?**

* **The batteries provide power to the motor.**
* **The motor turns the driving gear.**
* **The driving gear turns the driven gear.**
* **The driven gear turns the Archimedes’ screw.**
* **The Archimedes’ screw pushes the marble upward.**

In our model, the Archimedes’ screw is constructed of a rod around which is wrapped a coil.

The marble represents the water that is being moved from “low ground” to “high ground.”

When the rod rotates, the slanting circular movement of the coil pushes the marble upward.

When the marble reaches the top, it enters the slide and rolls back to the bottom of the model.

## Page 4

**Energy diagram of the model**

* Electrical energy from batteries
* Kinetic energy of the motor
* Kinetic energy of the driving gear
* Kinetic energy of the driven gear and the rod
* Kinetic energy and potential energy of the marble

Transfer of energy:

The energy **moves** between the different parts of the model:

from the batteries to the marble.

Conversion of energy:

Electric energy is **converted** into kinetic energy.

Conversion of energy:

Kinetic energy is **converted** intopotential energy.

## Page 5

The **Archimedes’ screw as a water pump**

An Archimedes’ screw is mainly used to transfer water from a low place to a higher one – and is therefore also called a **screw pump**.

In this diagram, you can see that when the handle is turned, the Archimedes’ screw rotates. Here, water that is scooped up by the apparatus at the bottom becomes trapped in the coil and moves up until it reaches the top where it drains into the upper reservoir.

**Rotation handle**

**Rod** **(rotation axle)**

**Archimedes screw**

A rod along which is wrapped a spiral surface (in the form of coil)

**Upper reservoir**

**Lower reservoir**

To make sure that the water doesn't spill on its way up, the screw can be inserted into

a large cylinder, or the coiled surface can have sides.

## Page 6

**Other uses of the Archimedes’ screw**

In addition to pumping water, the Archimedes’ screw has other uses.

It is often used asconveyor – namely to move (to convey) items from one place to another.

In these cases, we call it a screw **conveyor.** For example:

In a chicken coop, a screw conveyor is used to lift seeds for the chickens to the upper cages.

In this snack machine, you can see that the snacks are also arranged inside a screw conveyor built from a coil of metal.

When we choose a snack, the appropriate coil rotates and the snack is pushed forward according to the principle of the Archimedes’ screw.

The principle of Archimedes’ screw is also used when drilling in sand and for some agricultural machines.

# 7 Crankshaft – Excenter Mechanism – Workbook

## Page 1

What do I want to do with the model I am going to build?

Try to make a sketch (rough drawing) of our model of “eccentric” stairs.

Here is a picture of a standard gear and an eccentric gear.

Write the name of each gear above it it and explain the difference between the two.

(Hint. These words will help: axis of rotation, center)

## Page 2

**Label the diagram of the model (use the terms in the word bank, below):**

rectangular drive shaft, lower structural rod, acrylic slide, stair, eccentric gear, stair bracket, upper structural rod, handle

## Page 3

The following diagram helps to explain how the model of the eccentric stairs operates in 4 stages.

Alongside each stage, write what is happening.

A bonus for those who learned about energy:

At each step, write how the energy is being converted.

## Page 4

**Here is a short explanation about how the eccentric gear works.**

**Fill in the blanks from the word bank at the bottom of the page.**

The axis of rotation of the wheels of bicycles, the wheelbarrow and the car is exactly at their centers.

The word eccentric consists of two words: The word ex (meaning outside) and the word centric (center)

When we say that a gear is eccentric, we mean that it does **not** turn around its central axis.

Unlike a regular gear, the eccentric gear changes its position while rotating and it rises and falls.

In our model, we use the eccentric gear to convert (change) the rotational movement of the handle to a linear movement (up and down) of the stairs.

The car engine also uses eccentric gears – here they are used to change the linear motion of the pistons into the rotational motion of the vehicle’s wheels.

**centric, engine, rises, rotational, centers, pistons,**

**eccentric, ex, linear, convert, axis, position**

# 7 Crankshaft – Excenter Mechanism – Information Booklet

## Page 1

The model we shall build shows how rotational movement (the movement of the gears) can be converted to a continuous, repetitive linear movement (the movement of the stairs).

In other words, how turning the gears will cause the stairs to go up and down.

The mechanical principle by which the model operates is called “eccentric” (which means “off-center”). We shall explain the principle in detail later in this booklet.

Many machines are based on the eccentric principle.

For example, in the next picture, we can see the part of the car engine called the “crankshaft.” The crankshaft operates using this principle.

As you can see, the crankshaft found in the car engine very much resembles our model.

## Page 2

**What are the parts of our crankshaft model?**

**4 stairs**

**4 eccentric gears**

**4 stair brackets**

**Rectangular drive shaft**

**Upper structural rod**

**Rear wall (acrylic)**

**Acrylic slide**

**Right side**

**Handle (for turning)**

**Rectangular rotation rod**

**2 lower structural rods**

**Acrylic front wall**

**Left side**

## Page 3

**What is an axis of rotation?**

In the following picture, you can see the wheel of a wheelbarrow:

The wheel of the wheelbarrow is connected to a rod (the axle) that is exactly **in the center** of the wheel.

Since the wheel rotates around the rod, the rod is called the “**axis of rotation”** of the wheel.

Like the wheelbarrow, the wheels of the other vehicles we are familiar with rotate around rods (axles) that are exactly in the center of the wheel.

That is, **the wheel’s axis of rotation** is in its center.

**Off-centered axis of rotation**

**Question:** How will the wheel rotate if its axis of rotation (the axle) is not in the center?

**Answer:**

To check this, we shall compare gears with different axes (plural of “axis,” pronounced *aks’-eez*) of rotation:

These axes of rotation *are not* centered.

These axes of rotation are centered.

When you rotate the handle from the bottom to the top (half a rotation), the gears will end up looking like this:

**Conclusions:**

When the axis of rotation is in the center – the gear doesn't change its position when it turns.

When the axis of rotation is *not* in the center – the gear oscillates (goes up and down) as it turns.

## Page 5

**The eccentric principle**

The word eccentric is made up of two parts:

**Ex = outside or off**

**centric = relating to the center**

We call a gear (or other object) eccentric when it rotates around a point that isn't in its center.

This type of gear changes its position during the rotation.

The **eccentric principle in our model**

In our model, each gear is eccentric (i.e., the axis of rotation of each gear is not at its center).

Therefore, when the drive shaft rotates, the gears seem to go up and down.

In our model, the eccentric gears convert the circular motion of the handle to the cyclic (repeating) linear (up and down) movement of the stairs.

## Page 6

**How does our crankshaft model work?**

* The handle is turned.
* The rectangular drive shaft rotates.
* The four eccentric gears revolve, during which they go up and down.
* Each stair rises or falls, depending on the position of the gear beneath it.

**The cyclic path of the marble**

If we place a marble on one of the stairs and turn the knob – the marble begins to roll and complete a cycle (an action that repeats itself).

The top of each stair is slanted. Because of the slant, the marble will roll in the desired direction.

When the marble reaches the fourth stair, it rolls to the slide, and from there it rolls back to stair 1.

## Page 7

**Energy diagram of the model**

* Chemical energy of the hand (turning the handle)
* Kinetic energy of the rotating handle
* Kinetic energy of the rod
* Kinetic energy of the eccentric gears
* Potential and kinetic energy of the stairs

**Transfer of energy:**

The energy **is transferred** from the hand through the various parts of themodel to the stairs.

**Conversion of energy:**

Chemical energy **is converted** to kinetic energy.

**Conversion of energy:**

Kinetic energy **is converted** to potential energy.

## Page 8

**The eccentric principle in the car – in depth**

The part of a car engine called the crankshaft uses the eccentric principle.

This is how the crankshaft works:

**The pistons are attached eccentrically to the gears on the crankshaft.**

**When the pistons are in their upper position, an explosion of the gas mixture creates pressure, which drives the piston downward. (Remember, the pistons are enclosed in a cylinder.)**

**The momentum of the rapidly descending piston sends it back up.**

**This up-and-down motion of the pistons eccentrically connected to the gears, causes the drive shaft to turn.**

**Eventually, this rotational motion reaches the wheels of the car.**

**Piston**

**Eccentric gear**

Both in our model and the engine of a car: **eccentric gears are used as an intermediary between circular motion and linear motion, but in opposite directions**.

In our model**:**

Rotational motion (rotation of the drive shaft)

conversion by the eccentric gears

Linear (up and down) motion of the stairs.

In a car engine:

Linear (up and down) motion of the pistons

conversion by the eccentric gears

Rotational motion (rotation of the drive shaft and car wheels).

# 8 Combination Lock – Workbook

## Page 1

What do I want to do with the model I am going to build?

Try to make a sketch (rough drawing) of our model of a combination lock.

Explain in your own words how a combination lock works.

(Hint. These words will help: key, rotating (numbered) cams, slot, combination code)

## Page 2

**Label the diagram of the model (use the terms in the word bank, below):**

Rotating (numbered) cams, cover, 5 support rods, stationary discs (separating discs),

cylinder-shaped storage space, serrated key, locking rod

## Page 3

**Here are various combination locks.**

**Below each lock, write the correct combination code.**

(Hint: The numbers corresponding to the slots form the code for lock.)

Complete: The combination code for this lock is: \_\_\_\_\_\_\_\_\_\_

## Page 4

Here are 3 cams of a combination lock.

Write numbers on the cams so that combination code will be: **2 2 2 .**

Here are 2 cams of a combination lock.

Write numbers on the cams so that combination code would be: 5 4.

Here are 3 cams of a combination lock.

Draw shapes of the cams so that combination code will be:

## Page 5

Here are some combination locks. For each lock, calculate how many combination codes can be created for it.

Complete: This lock has \_\_\_\_\_\_\_\_\_\_ possible combination codes.

## Page 6

**Here is a short explanation about how the combination lock works. Fill in the blanks from the word bank at the bottom of the page.**

A combination lock is a lock for which one needs to know the correct combination code to be able to open and lock it.

The lock consists of numbered cams that can rotate.

Each cam has one slot. When all the slots are aligned in the same direction, the key can go in and out.

The number of rotating cams indicate the length of the combination code. For example, if there are five rotating cams on the lock, the combination code will be a sequence of 5 numbers, letters or symbols.

You can use a lock as a small safe. Inside the lock there is a space in the shape of a cylinder in which it is possible to hide jewelry or a note.

To calculate how many possible combination codes that lock could have, you have to make a mathematical calculation. The field of mathematics where such calculations are made is called combinatorics.

cylinder, calculation, sequence, length, combinatorics, symbols, key,

safe, slot, combination code, cams, jewelry

# 8 Combination Lock – Information Booklet

## Page 1

A combination lock is one that can be opened only if one knows

the combination code (a secret sequence of numbers, letters or symbols).

~~A combination lock has several names:~~

Here are some pictures of various combination locks and their uses:

* combination lock attached to a cable (e.g. to lock up a bike)
* combination lock with a metal U-shaped shackle (e.g. to lock a gate)
* combination lock with a clasp (e.g. on a briefcase or suitcase)

## Page 2

**What are the parts of our combination lock model?**

* **3 rotating cams (discs).** You will write the numbers of your desired combination code on these cams.
* **Locking rod**
* **5 support rods**
* **4 stationary discs (fixed in place – cannot turn)**
* **Cover**
* **Serrated (toothed) key**
* **Cylinder-shaped storage space**

## Page 3

**How does our model combination lock work?**

Every rotating cam has eight protrusions on which we can write numbers, letters or symbols.

**Note that there is a slot under only one of the protrusions!**

The slot is the only place through which the toothed key can pass.

The toothed key can freely pass in and out of the lock only when all three slots are lined up at the top!

The slots of the three cams must be aligned at the top.

**Example 1 – the key can pass through**

The cams are aligned with all the slots at the top –

the key can enter and leave freely.

**Example 2 – the key cannot pass through**

Not all the slots are aligned at the top –

the key cannot pass all the way through.

This slot is not at the top –

the key cannot pass.

## Page 4

**Locking and unlocking the lock**

To understand how to lock and unlock the lock, we shall look at an example.

When Danny put together the model, he wrote numbers on the cams as follows:

If the cams are aligned as in this picture,

the topmost protrusions show this sequence of digits: 1 1 1 .

Because some of the slots are not at the top, Danny cannot insert the key.

**Locking stage**

To be able to get the key in, Danny has to rotate the cams so that the upper parts will show this sequence of digits (combination code): 1 6 7 .

In this situation, the slots of all the cams are at the top and the key can pass.

After Danny inserts the key,

he has to turn the cams in any direction so that random numbers align at the top.

At this point, the three slots will no longer be aligned at the top, the key will be “locked in place,” and the cover on the lock cannot be removed.

**Unlocking stage**

To open the lock, the key has to be able to exit the lock.

Danny must rotate the cams back to the combination code: 1 6 7.

At this point, the three slots are again aligned at the top

and the key can be easily removed.

## Page 5

**What you can do with the model?**

The model can be used both as a standard-type lock and also as a safe!

**Standard lock**

**Safe**

You can use the cylindrical space inside the lock to hide a secret note or precious jewel.

Only someone who knows the correct combination code will be able to open the lock and take out what is hidden inside.

**Interesting facts:**

In the book *The Da Vinci Code*, by Dan Brown, a similar combination lock is attributed to inventor Leonardo da Vinci.

As the story goes, the lock was built in the shape of a cylinder to be able to pass along secret messages!

A message was written on a paper scroll inserted into the cylindrical structure of the lock. Only someone who knew the combination could get the message out and read it.

Brown made up the word “cryptex” for this “portable vault” by combining the words kryptós (Greek for “hidden, secret”) and codex (Latin for “scroll”).

**Leonardo da Vinci**

**(1452 – 1519)**

## Page 6

**How many combinations codes can there be?**

A combination lock is opened by a combination code (a sequence of digits).

**How many combination codes can there be?**

**Example 1 – a two-digit combination code**

Let us examine a lock built with two different cams:

* The left cam has three numbers.
* The right cam has four numbers.

We can write down all the possible combination codes:

**If we keep the left cam with the number 1,** and rotate the right cam.

**If we keep the left cam with the number 2,** and rotate the right cam.

**If we keep the left cam with the number 3,** and rotate the right cam.

These are all the “permutations” of the two cams.

In summary: If the left cam has three different modes and the right cam four, then for each of the three possibilities on the left cam, the right cam can be adjusted four different ways.

Therefore, there are 12 different possible combination codes in total (3 multiplied by 4).

## Page 7

**How many combination codes can there be?**

A combination lock is opened by a combination code (a sequence of digits).

**How many combination codes can there be?**

**Example 2 – Our combination lock model**

Our model lock has three cams.

Each cam has room for eight numbers:

Left cam

Middle cam

Right cam

We can calculate the number of possible combination codes just like we did in the previous example:

8 possibilities for the left cam

8 possibilities for the middle cam

8 possibilities for the right cam

512 possible combination codes!

**You should know:**

The science of mathematics has many different areas of study.

One of them is called **combinatorics**.

In combinatorics, we learn how to calculate the number of combinations possible with a series of numbers.

## Page 8

**The serrated key - in depth**

In our model, the key has three teeth.

3 teeth

**Question:** What is the role of the teeth?

**Answer:** When the rotating cams are not lined up according to the correct combination code, the slots are not lined up at the top.

This keeps the key from passing freely in and out of the lock.

.

In other words, the role of the teeth is to make sure that the key will go in or out of the lock only when the cams are lined up according to the combination code.

The slot is not facing up.

**Question: Why must the key have 3 teeth?**

**Answer:** Because the model has 3 rotating cams, the key has 3 teeth.

When the key is locked into place, each of the three teeth are positioned behind

a rotating cam that is blocking it and keeping it from moving freely.

Even if two cams are set to the correct code, the third disc will block the tooth behind it

**and the model will remain locked.**

That is, to open the lock, all the teeth have to pass, one behind the other,

through a clear path.

That is, all the numbers must match the combination code.

The rotating discs block the teeth behind them.

Only one of the discs blocks the tooth behind it.

# 9 Drawing Machine – Workbook

## Page 1

What do I want to do with the model I am going to build?

Try to make a sketch (rough drawing) of our model of our drawing machine.

The drawing of our model is the result of two actions that occur at the same time.

What are the two actions?

**Action 1:**

**Action 2:**

(Hint. These words will help: marker, closed shape, paper)

## Page 2

**Label the diagram of the model (use the terms in the word bank, below):**

holes for supports, driven gear, acrylic arm, support for the arm,

marker, driving gear, hole for marker, wooden base

## Page 3

**In this model, rotating the driving gear, causes the four other gears to rotate.**

Circle the drawing that correctly illustrates the directions of rotation of all the gears.

**Driving gear**

## Page 4

**Here is a short explanation about how our drawing machine works. Fill in the blanks from the word bank at the bottom of the page.**

The drawings you can make using the model we built are based on

geometric shapes.

A closed geometric shape is one that has no beginning and no end. Therefore, even if you go over it a number of times, the result is always one shape.

The drawing the model produces is the result of two actions that occur simultaneously:

1. The marker draws a closed geometric shape.
2. The board rotates the paper.

If you change the shape that the marker draws, the entire drawing changes.

In mathematics, there is a special name for the type of drawing our model makes. They are called hypocycloids. This shape is the path of a point that is on a small circle rolling on the inner edge of a large circle.

path, closed, rotates, two, marker, large, circle,

geometric, end, hypocycloids, one, simultaneously, drawing

# 9 Drawing Machine – Information Booklet

## Page 1

Is mathematics related to art?

This model will prove to you that it is!

Using this geometric drawing machine, you can quickly and easily draw a range of remarkable, unique pictures that are all based on geometric shapes.

Here are just some of the pictures you can draw to amaze your family and friends:

## Page 2

**What are the parts of our drawing machine?**

* **Acrylic arm**
* **Marker**
* **Support for the arm**
* **Table leg**
* **Driving gear**
* **Wooden base**
* **Driven gear**
* **Drawing paper**
* **Holes for supports**
* **Hole for marker**

## Page 3

**Drawing a shape on a paper in motion**

**Assignment:** Take a long, rectangular piece of paper, draw a circle on it, and go over the circle several times. What will your drawing look like?

**Answer:**

A circle is a closed shape — that is, it has no beginning and no end.

Therefore, if we repeat the circle several times, each circle will be drawn one on top of the other, and the result will be a drawing of one circle.

**Question:** What will your drawing look like if you ask a friend to slowly pull the paper (while drawing the circles)?

**Answer:**

Although the circle is a closed shape,

because the page moves, the pencil will be drawing the circle each time on another place

on the page. So it seems that the circle is “advancing” along the paper.

**Question:** What will your drawing look like if you ask a friend to pull the paper really quickly?

**Answer:**

## Page 4

**How do we make a drawing using our model?**

In our model, the drawing is the result of two actions that occur simultaneously (at the same time).

**Action 1:**

The marker that is attached to the arms repeatedly draws a closed shape.

**Action 2:**

The base of the drawing board turns the paper on which the marker is drawing.

This causes the marker to be constantly drawing on a different part of the paper.

.

The marker draws a closed shape (for example, a circle).

The paper rotates.

## Page 5

**How can we change the drawing that we make with our model?**

You can change the shape of your drawing in one of several ways:

1. You can change which of the three holes of an arm is positioned on the arm support.

Place a different hole on the support.

b. You can attach the arm to another support.

Change the location of the arm.

Each of these methods will change the shape that the marker makes.

The marker draws a different shape because of the relative change between the arms.

Thus, the shape of the entire drawing changes.

## Page 6

**The connection to mathematics – in depth**

The connection between our model and mathematics relates to two geometrical shapes – the **cycloid** and the **hypocycloid**.

**Cycloid**

Here is a circle that is rolling along a straight line:

Let’s focus on one particular point on the circumference of the circle, for example, the black dot.

The path that the black dot makes is called a cycloid.

**Hypocycloid**.

Now, let us take the same small circle, but this time, we roll

it inside the circumference of a larger circle.

Again, we select one specific point and observe the shape of its path.

This type of path is called a **hypocycloid**.

**You should know:**

The beautiful drawings made by our model are based on hypocycloid shapes.

# 10 Mathematical Balancing Device – Workbook

## Page 1

What do I want to do with the model I am going to build?

Try to make a sketch (rough drawing) of our model of a mathematical balancing device.

The children in the picture both weigh the exact same.

Why isn’t the seesaw balanced?

Hint. These words will help: weight, balance point, distance, effect (or power or torque)

## Page 2

**Label the diagram of the model (use the terms in the word bank, below):**

acrylic panel, place to store marbles, axis of rotation (fulcrum),

base, arm, calibration weights, places to position marbles, bearing

## Page 3

**Here are some examples of our mathematical balancing device. Based on the positions of the marbles, will the arms be balanced?**

Advanced level exercise:

In the examples above where arms are not balanced, where can you add marbles to make them balance?

## Page 4

**Draw marbles in the appropriate places to balance the arms.**

Advanced level exercise:

Danny has 3 red marbles.

In each case (above), try to balance the arms using all three marbles.

## Page 5

**Here are a few sentences. Indicate** onlythe sentences that are correct:

* In this picture, there is no fulcrum.
* If we want to increase the effect of our weight (force), we must move it away from the fulcrum.
* According to this picture, the weights of the two children on the seesaw are about equal.
* If the person fails to lift the stone, he should use a shorter rod.

Below are four drawings. Circle the ones that shows the best way to balance the large bucket (contains 10 liters of water) with the small bucket (contains 5 liters of water).

## Page 6

**Here is a short explanation about the law of the lever. Fill in the blanks from the word bank at the bottom of the page.**

The law of the lever explains how you can transform a small force to one that has great effect.

Archimedes formulated the law of the lever more than 2,000 years ago.

Archimedes discovered that the effect of a force depends on its distance from the fulcrum.

As the distance from the fulcrum increases, the effect of the force increases.

To illustrate this law, Archimedes said the sentence “Give me a place to stand, and I shall move the Earth with it.”

Using the law of the lever one can understand why to cut thick wires, it is easier to use cutters with long handles

The effect (intensity) of the force is also called torque.

long, Earth, increases, law of the lever, Archimedes,

fulcrum (balance point), small, distance, torque, effect, thick

# 10 Mathematical Balancing Device – Information Booklet

## Page 1

Thismodel **mathematical balancing device** is based on Archimedes’ **law of the lever**.

With this model, we can understand how to use the law of the lever to balance weights.

In addition, we can use the model to solve mathematical puzzles.

Archimedes is considered one of the greatest inventors of all time.

He was born in Greece and worked part of his life in Egypt.

His discoveries and inventions are in the fields of mathematics, physics, astronomy and more.

The law of the lever is considered to be one of Archimedes’ best-known principles, mainly because today it has many uses.

**Archimedes.**

**(287-212 BC)**

## Page 2

**What are the parts of our mathematical balancing device?**

* Arm
* Acrylic panel
* Place to store marbles
* Base
* Places to position marbles
* Calibration weights
* Axis of rotation (fulcrum)

**Bearing**

A (ball) bearing consists of two rings in between which are small balls.

The bearing allows the balance to rotate freely (almost without friction) around the axis of rotation.

## Page 3

**Same force – different effects**

Do we need super strong muscles if we want to move a very large rock or to break a thick tree branch?

To answer this question, let’s take a look at the tree that is here in Danny’s backyard.

Danny wants to climb the tree and sit on this long branch.

**Question:**

Where do you think it is safer for him to sit? Closer to the trunk or farther along it?

**Answer:**

The farther from the trunk Danny sits, the more effect his weight will have on the branch, and the greater the chance will be that the branch will break.

In other words, even though Danny is placing the same force (weight) on the branch in both cases, when Danny is farther from the trunk, his weight has more power and effect (in the language of physics – greater torque).

The great Greek scientist, Archimedes, studied this subject and formulated the law called the “law of the lever.”

The word “lever” (when used as a verb) can mean “to raise.” As a tool, a lever can apply “leverage” to increase the **power** of the **force** we are applying. Danny’s weight (the **force** he is putting on the branch) will have enough **power** to break the branch – if he sits **far enough** away from the trunk.

## Page 4

**Law of the lever – Seesaw, example 1**

We can demonstrate the law of the lever with a seesaw.

The seesaw in the illustration consists of a beam of wood resting on a triangular-shaped base.

The base is exactly at the center of the wooden beam.

The point of the base on which the beam is resting is called **the balance point**, because the beam balances on it.

**Beam**

**Balance point**

**Base**

When children with equal weights sit at each end of the beam,

the beam will be perfectly horizontal, that is to say, it is balanced:

**Question:** What happens when one of the children moves from the end toward the balance point (fulcrum)?

**Answer:**

The beam will not remain balanced.

As the child approaches the fulcrum, his weight will have less effect (power),

and the beam will descend on the other side.

Conclusion: **The closer a body is to the fulcrum, the less effect (power) its weight will have.**

This also leads to the following conclusion: **The further a body is from the fulcrum, the more effect (power) its weight will have.**

## Page 5

**Law of the lever – Seesaw, example 2**

Let us again observe a seesaw where two children of equal weight are sitting on each end. As we saw above, the beam will be perfectly balanced (horizontal).

**Question:** What will happen if one of the children is heavier?

**Answer:**

The beam will not remain balanced. The side of the beam holding the heavier child will descend.

For the beam to become balanced once more, the heavier child must move

toward the fulcrum.

Now, even though the children do not weigh the same, the beam will be in a state of balance.

As we saw in example 1, **the closer a body is to the fulcrum, the less effect (power) its weight will have.**

Page 6

**The law of the lever in our model**

Our model resembles a seesaw for marbles.

All the marbles are identical – they all weigh exactly the same.

There are seven places on each side of the beam where marbles can be positioned.

Let us examine three different cases:



Here, there is one marble resting on each side of the beam in position number 5.

Since both marbles are of equal weight and are equally distanced from the center (fulcrum), the beam will be in a state of balance.



Position 7 is the position that is furthest from the fulcrum.

Position 1 is the position that is closest to the fulcrum.

The weight of the marble in position 7 will have seven times more effect than the weight of the marble in position 1. In this case, the rod will not be balanced.



The weight of the marble in position 7 has seven times the effect of the marble in position 1. To balance the beam, we add a marble in position 6 on the left side (its weight has six times the effect of the marble in position 1).

## Page 7

**Archimedes’ law of the lever.**

Archimedes discovered that when we apply a force onto a balanced beam, the effect (power) of the force does not only depend on the size (mass) of the force, but also its distance from the fulcrum.

The effect (power) of the force is also called **torque**.

**Archimedes expressed this discovery in mathematical terms:**

**The magnitude of the force**

times

**its distance from the fulcrum**

**torque**

(effect/power of the force)

In other words, the further away from the fulcrum we are when we apply the force, the greater its effect (power) will be.

Therefore, one marble in position 7 exerts torque (power) on the beam that is 7 times greater than that of a marble in position 1.

To illustrate the law of the lever, Archimedes is known to have said:

**“Give me a place to stand, and I shall move the Earth with it.”**

**A** **finger applies a very small force,**

but because of its comparatively great distance from the fulcrum, it has an enormous effect!

**A very great distance!**

**Fulcrum**

Simply put: If you give me a very, very long pole and a fulcrum that is far enough away, I can move the world with only one finger.

## Page 8

**Uses of the law of the lever**

We will look at two machines that are based on the law of the lever:

**A crane**

The crane has a very long arm so it can raise objects that are situated at a great distance from the crane.

However, even when the load the crane is lifting is relatively light, it will still apply a lot of force on the arm of the crane (because it is so far from the fulcrum).

To balance the long arm (as it is raising even a relatively light object), there is a shorter arm on the other side that has heavy stones hanging from it.

Large weight hanging close to the fulcrum

Small weight hanging far from the fulcrum

**Steel cable cutter**

To cut metal wires we use a device that works like a pair of scissors.

This is called a cable cutter.

To cut thin wires, the force from the muscles in our hand is sufficient to bring the handles together.

However, when we want to cut especially thick wires (cables, for example), we use a cutter with long handles.

This way, the force we are applying with our hand is very far from the fulcrum, and therefore the power will be great.

The size of the blades is identical.

The only difference is the length of the handles.