EXPERIMENT MANUAL

Genetics & DNA Lab

WARNING. Not suitable for children under 10 years. For use under adult supervision. Read the instructions before use, follow them and keep them for reference. Do not allow chemicals to come into contact with any part of the body, particularly the mouth and eyes. Keep small children and animals away from experiments. Keep the experimental set out of reach of children under 10 years old.

WARNING — Science Education Set. This set contains chemicals and/or parts that may be harmful if misused. Read cautions on individual containers and in manual carefully. Not to be used by children except under adult supervision.

THAMES & KOSMOS

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

Information about Hazardous Substances

Please note the following risk and safety information for the chemicals contained in this chemistry kit. The following overview also shows the hazard symbol for the chemicals you will be using and identifies the hazards associated with it.

DANGER

Denatured alcohol (also known as methylated spirits; main ingredient ethanol, ethyl alcohol). Highly flammable liquid and vapors.
Keep away from heat/sparks/open flame/hot surfaces.
Request to parents: Keep denatured alcohol locked away. Fill the brown bottle yourself and decant only the amount that will be required for a few experiments.

Keep all chemicals locked away. Do not allow any of them to get into the hands of children. This applies above all to young children, but also to older children who — unlike the ones performing the experiments — have not been appropriately instructed by adults about proper safety measures.
IN CASE OF SWALLOWING: Immediately seek medical advice or help and have the packaging or label of the swallowed chemical available for reference.

Keep packaging and instructions as they contain important information.

We reserve the right to make technical changes.

WARNING. This kit contains functional sharp edges or points. Do not injure yourself!

Please note: You should read the important information about first aid in case of accidents on the outer back cover, handling hazardous substances on this page, and further information on pages 1-4.

Poison Control Centers (United States)

In case of emergency, your nearest poison control center can be reached everywhere in the United States by dialing the number:

1-800-222-1222

Local Hospital or Poison Centre (Europe)

Record the telephone number of your local hospital or poison centre here:

Write the number down now so you do not have to search for it in an emergency.
When in doubt, seek medical advice without delay. Bring the chemical and its container with you. In case of injury, always seek medical advice.

Dear Parents,

This experiment kit is for use only by children over 10 years who are interested in learning more about genetics in a fun way. Not only is this kit fun, it can also provide an introduction to the exciting world of the biological sciences.

It is normal to have questions about the safety of a kit that contains chemicals. The incorrect use of chemicals can cause injury and damage health.

The experimental equipment in this kit meets U.S. and European safety standards, which specify the safety requirements for chemistry experiment kits. These standards impose obligations on the manufacturer, such as forbidding the use of any particularly dangerous materials. The standards also stipulate that adults should assist their children with advice and assistance in their new hobby. We are addressing this information to you, so you can understand what this involves.

Take a look through this instruction manual and pay particular attention to the
→ **Basic rules for safe experimentation,**
→ **Information about hazardous materials**
(inside front cover), as well as
→ **First aid in case of accidents**
(outside back cover).

Many of the risks mentioned in these places cannot even occur with this experiment kit, but we have included all of the chemistry experiment kit safety guidelines for completeness.

Also take a look at the safety information accompanying the experiments. Carefully select the experiments that seem safe and appropriate for your child. Before starting the experiments, discuss the safety suggestions with your child.

Because children's abilities vary so much, even within age groups, supervising adults should exercise discretion as to which experiments are suitable and safe for them. The instructions should enable supervisors to assess any experiment to establish its suitability for a particular child.

The supervising adult should discuss the warnings and safety information with the child or children before commencing the experiments. Particular attention should be paid to the safe handling of acids, alkalies, and flammable liquids.

Read and follow these instructions, the safety rules, and the first aid information, and keep them for reference.

Only carry out those experiments which are listed in the instructions.

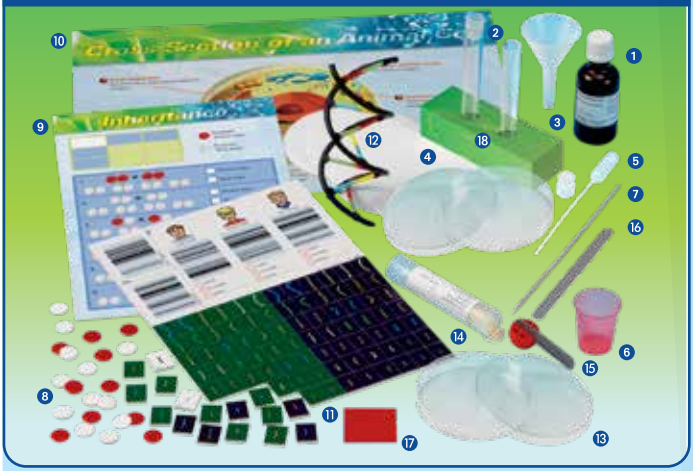
A special laboratory is not required for these simple experiments. The area surrounding the experiment should be kept clear of any obstructions and away from the storage of food. It should be well lit and ventilated and close to a water supply. A solid table with a heat resistant top should be provided.

When performing the experiments, your child should wear clothes that can take a little abuse (or an old smock). After completing the experiments, he or she should clean up the work area and thoroughly wash his or her hands.

Please be careful not to let the chemicals get into the hands of young children.

We wish you and your child a fun and interesting time with these experiments!

What's inside your experiment kit:



Additional things you will need:

Denatured alcohol (methylated spirits), table salt, dish washing liquid, teaspoon, 2 yogurt containers, ruler, felt-tip pens, knife, scissors, permanent marker, plastic wrap, hand blender, tomato, jelly jar, microwave

Checklist: Find – Inspect – Check off

✔	No.	Description	Qty.	Item No.
☐	1	Empty brown plastic bottle with lid	1	775740
☐	2	Test tube with stopper	2	772100
☐	3	Funnel	1	086228
☐	4	Filter paper sheet	10	772092
☐	5	Pipette	1	232134
☐	6	Measuring cup	1	065099
☐	7	Wooden skewer	1	713654
☐	8	White and red plastic chips	12	705818
☐	9	Inheritance worksheet	1	706847
☐	10	Cell poster	1	706848
☐	11	Chromosome puzzle and genetic fingerprinting cards	1	706846
☐	12	DNA model	1	705817
☐	13	Petri dish	2	723751
☐	14	LB agar	1	772529
☐	15	Lid opener	1	070177
☐	16	Plastic spatula	1	722970
☐	17	Red decoder film	1	161415
☐	18	Die-cut cardboard test tube stand	1	724180

Any materials not contained in the kit are marked in *italic script* in the "You will need" boxes.

→ Before doing anything else, please check all the parts against the list to make sure that nothing is missing.

→ If you are missing any parts, please contact Thames & Kosmos customer service.

CONTENTS

CHECK IT OUT

You will find supplemental information on pages 6, 11, 12, 19, 21, 22, 25, 30, 33, 37, 38, 40, 42, and 46.

Basic Rules for Safe Experimenting

All of the experiments described in this instruction manual can be carried out with no danger, as long as you conscientiously follow the advice and directions. Please read the following notices carefully.

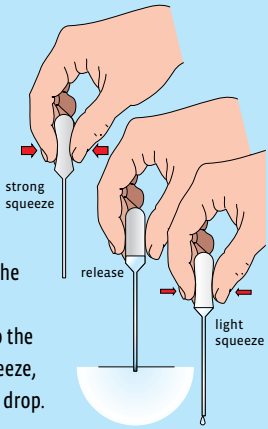
1. Read these instructions before use, follow them, and keep them for reference. Pay special attention to the quantity specifications and the sequence of the individual steps. Only perform experiments that are described in this instruction manual.
2. Keep young children and pets away from the experimental area.
3. When working, wear appropriate protective clothing, like an old smock and smooth gloves.
4. Store experimental sets out of reach of young children.
5. Clean all equipment after use.
6. Make sure that all containers are fully closed and properly stored after use. Carefully close the chemical vials and the denatured alcohol bottle after use and return them to their places in the kit.
7. Wash hands after carry out experiments. Chemicals that accidentally get onto your skin must be rinsed off immediately under running water.
8. Do not use any equipment which has not been supplied with the set, or that you are not specifically asked to obtain for a particular experiment.
9. Do not eat, drink, or smoke in the experiment area. Do not use any eating, drinking, or other kitchen utensils for your experiments. Any containers or equipment you use in your work should not be used in the kitchen afterwards.
10. Do not allow chemicals to come into contact with eyes or mouth.
11. If foodstuffs are prescribed in the instructions for use: Do not replace foodstuffs in original container. Dispose of immediately.
12. Also pay attention to the information on the chemical labels, the information about hazardous materials on the inside front cover, and the safety notes accompanying each experiment.
13. You must have an adult help you when working with the blender and the hot stove burner or microwave.

Opening the chemical vial:

When you open the vial, bits of material may stick to the lid and fall on your hand or work surface. You can prevent that by tapping the vial several times against the work surface before opening it.

Using the dropper pipette:

You will use the dropper pipette to add liquids drop by drop. Squeeze the upper part of the pipette with your thumb and index finger and dip the tip of the pipette into the liquid. As soon as you release pressure, the liquid will rise up the pipette. Then, with a light squeeze, you can add the liquid drop by drop.



This red magnifying glass pops up over and over again in this manual. It shows where you can check your answer to a question by laying the red decoder film over the answer box.

Isolating Genetic Material

This chapter begins with a crime! Read the story about the bank robbery on the next page. What evidence are the police left with? How can forensic scientists use the evidence to bring the perpetrators to justice? And what does all this have to do with DNA anyway?

"Hands Up!" yells Hank Schubert as his buddy Rudy Kramer holds the two bank tellers and the other employees at bay in the back of the room.

For months, both robbers worked on figuring out a plan for robbing the savings bank. The day has finally come. Tires squealing, they set off at 11:53 on the dot, pull on their masks, throw open the car doors, and race into the bank. "Just tell me what you want," says the branch manager Frank Milton calmly, as he leads the two robbers toward the safe. Less than two minutes later, the robbers have stuffed 310,483 dollars and 72 cents into a sack and are running toward the car, which their partner Martin Adler is keeping warmed up and ready to go with the engine running. The only problem is that in the heat of the moment Schubert runs into the glass door and cuts his hand. The main thing is to get away, he thinks. And soon the car speeds off and leaves the scene.

"No trace of the perpetrators..." reads the headline in the paper the next morning. "Police are in the dark..."

Ten minutes after the holdup, Commissioner Walter Reddy is at the scene of the crime, interviewing witnesses — but he isn't getting much out of them.

"One of them was about 6 feet tall, the other was shorter," offers one of the bank tellers. "The taller one smelled of cigarettes and had a southern accent," adds the branch manager. "Pretty meager," sobs Reddy.

There are no fingerprints, of course, since the two were smart enough to wear gloves.

But Rob Green, the man from the forensics department, looks around a little more carefully.

He does at least manage to find a few drops of blood by the front doors and on the floor, which he carefully scrapes off and places in a test tube. And in front of the branch there are a couple cigarette butts on the ground. "The driver smoked," suggests one of the bank employees. "Not too bright," says Green.

His colleagues tell him to look for and gather tiny residues of hair or clothing in the vault. They might later be able to use them to supply a piece of evidence that is clear enough to get a confession from the perpetrators. Assuming, of course, that the police can nab them.

In this kit, you will be able to see how that works. You will isolate genetic material, the material that basically contains the "program" for a living organism. You will learn how researchers have decoded this program down to the smallest details. You will also investigate what you have in common genetically with your parents and grandparents (and what, on the other hand, makes you unique), and at the end you will be able to help bring the three bank robbers to justice. At the center of it all is the molecule that has done more than any other over the last hundred years to change our understanding of life: DNA.

Have you ever wondered why you get only tomatoes from tomato plants, and only potatoes from potato plants? Rabbits have rabbit babies and humans have human babies. Did you ever wonder why tomatoes don't have rabbit babies? It has to do with a gigantic programming code inside all living things. Science has been tracking this code down for over 150 years. Today it is finally clear where it is located. It is even possible to isolate the material that contains this program. Let's take a look.

EXPERIMENT 1

Isolating Genetic Material

Experiments 1 through 4 are meant to be done in sequence.

YOU WILL NEED

- → brown bottle with cap
- → plastic spatula
- → *denatured alcohol (methylated spirits)*
- → *table salt*
- → *dish soap*
- → *spoon*
- → *knife*
- → *tomato*
- → *freezer*
- → *blender or hand blender*
- → *two large empty yogurt containers (one yogurt container should be large enough for the hand blender to fit inside of it)*

HERE'S HOW

1. The night before your experiment, fill the brown bottle with denatured alcohol, and place it in the freezer to let it get nice and cold before the experiment.

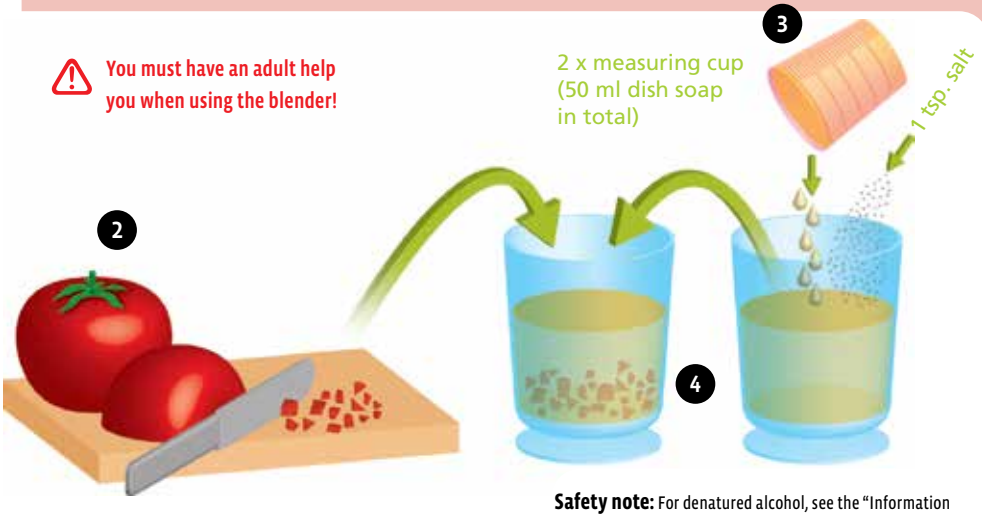
2. Now you'll freeze the genetic material from the cells. Cut half a tomato into very small pieces and place the pieces in the large yogurt container.

3. To the other yogurt container, add 50 milliliters of dish soap (twice the capacity of the measuring cup) and one teaspoon of salt.

4. Stir everything well with the spatula and pour it over the finely diced tomatoes.

5. Now puree everything carefully with the blender. Be careful not to spray it all over the place! A lot of foam will form because of the soap. The foam will get in your way, so it should be removed with the spoon.

You must have an adult help you when using the blender!



Safety note: For denatured alcohol, see the "Information about hazardous materials" on the inside front cover.

Further preparation for isolating DNA

YOU WILL NEED

- → tomato-soap mixture from Experiment 1
- → test tube
- → test tube stand (folded from die-cut cardboard sheet)
- → funnel
- → filter paper
- → *ruler*
- → *permanent marker*

Researchers often use a filter to get a clear solution from a cloudy one. For the next experiment, we will need a specific quantity of liquid.

HERE'S HOW

1. Use the ruler to measure three centimeters from the bottom of the test tube, and mark that distance by drawing a line with the permanent marker. Then, mark another line three centimeters above that. This will help us filter the right amount of liquid.

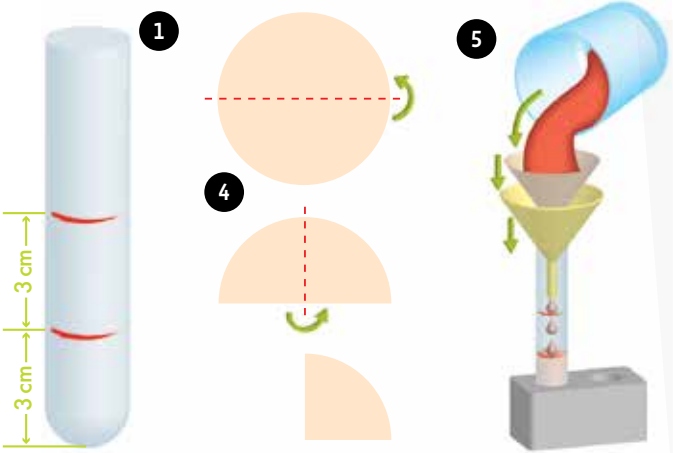
2. Next, you will need a stand for the test tube. Remove the test tube stand from its die-cut cardboard sheet and fold it into the stand.

3. Set the test tube in one of the holes and place the funnel in the test tube.

4. Fold the filter paper as shown in the illustration below and insert it in the funnel. If you run out of filter paper for later experiments, you can just cut a regular coffee filter so that it fits into the funnel.

5. Gradually pour the tomato-soap mush (from Experiment 1) in small portions onto the filter. It will take a while for clear liquid to fall, drop by drop, into the test tube.

6. Keep adding the mush until the liquid in the test tube reaches the first mark. It might take up to ten minutes. Be patient.



TIP

On the topic of patience: All scientists must be patient. Some larger experiments last for weeks or months, and sometimes they fail and have to be repeated all over again.

EXPERIMENT 3

The DNA becomes visible

YOU WILL NEED

- → cold denatured alcohol in brown bottle from Experiment 1
- → pipette
- → clear tomato-soap filtrate from Experiment 2
- → test tube stopper

This experiment is a cold bath for the filtrate, which is what researchers call the clear solution resulting from filtration.

HERE'S HOW

1. Get the denatured alcohol from the freezer, take a small amount into the pipette, and carefully let the cold alcohol run down the wall of the tilted test tube.

2. Repeat until the liquid level reaches the second marker. In a real laboratory report, it would say: Add an equal quantity of denatured alcohol to the filtrate.

3. You will see that the denatured alcohol has formed a layer above the filtered tomato liquid, because the alcohol is lighter than water. You may even be able to see a few clouds or flakes at the place where the two liquids meet. We want more of those.

4. Close the test tube with its stopper and turn it several times, slowly and gently, upside down and then right-side up again. Continue until the spirits and tomato liquid are mixed.
   Do you see something in the test tube?

→ WHAT'S HAPPENING?

If everything has gone according to plan, you should see some pale threads. If you can't see anything, put the test tube back in the freezer. After a few hours, you will see fine white threads and flakes in the test tube: They are none other than the fabled genetic material, or DNA for short. You have isolated the code that makes tomatoes come from tomatoes!

In the watery tomato solution, the genetic material is finely dissolved and thus evenly distributed and invisible to us. But when the material is surrounded by cold alcohol, it balls up and separates from the liquid. This is similar to the way that sour milk curdles when you pour it into hot coffee.

EXPERIMENT 4

Retrieving the genetic material

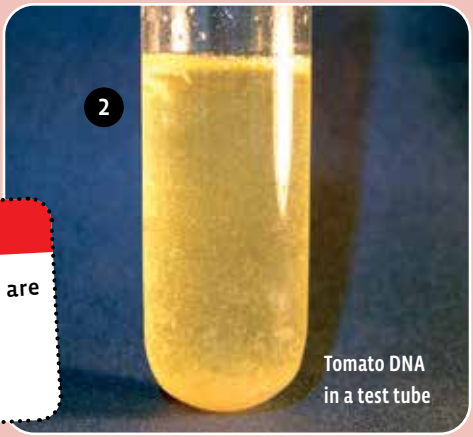
YOU WILL NEED

→ wooden skewer
→ test tube of isolated DNA from Experiment 3

HERE'S HOW

1. Use the wooden skewer to fish the DNA out of the solution. It is harmless. It comes from a harmless tomato, after all.

2. Take a closer look, but do not eat it — remember, there are still residues of dish soap and denatured alcohol on it.



Tomato DNA in a test tube

→ WHAT'S HAPPENING?

Every time you eat a tomato salad, you are also eating a small quantity of tomato DNA. One kilogram of food contains between 0.1 gram and 1 gram of DNA.

EXPERIMENT 5

Isolating more DNA

YOU WILL NEED

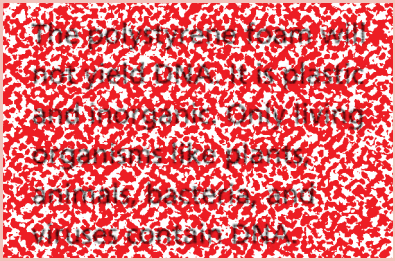
→ *half an onion*
→ *half a kiwi fruit*
→ *a piece of polystyrene foam (packing peanut or packaging material)*
→ *a piece of pickle*

HERE'S HOW

Can you find differences in the quantity of DNA in each of the samples listed to the left? One of the experiments should yield no genetic material at all. Why not?

→ → →

Use the red decoder film here to reveal the answer to the question posed in Experiment 5.



CHECK IT OUT

How much DNA is in various foods?

This table shows the quantity of DNA in five foods, in grams per kilogram by dry weight (meaning grams per kilogram of dried food).

Food	Grams of DNA
Calf's liver	17.3
Smoked trout	1.0
Broccoli	5.0
Potatoes	2.6
Wheat	0.7

WHO DISCOVERED DNA?

Today, we have it easy: We can simply use the freezer to cool down important experimental solutions, such as the denatured alcohol. The discoverer of genetic material, on the other hand, had to get up at five in the morning for his experiments, in order to be able to take advantage of the cool morning temperatures. The Swiss researcher **Johann Friedrich Miescher** (1844–1895) was the first person to isolate genetic material.

To do it, though, he used sources that were quite a bit less appetizing than tomatoes. Miescher took white blood cells obtained from pus in the used bandages of patients. From that, he was able to isolate a filamentous white substance, like the one that you isolated, in 1869. Miescher called it **nuclein** (from the same Latin source as the word nucleus — researchers liked to use words with Greek or Latin roots, since they were internationally easy to agree on).

Miescher wasn't sure, however, what it was that he had isolated. Only after he repeated the experiment with the sperm cells of salmon (which were common in the Rhine River at that time, and had particularly large cells, which made it easier to experiment with them) was he able, in 1871, to publish his findings. The most commonly used abbreviation today, DNA, stands for "deoxyribonucleic acid."

Heredity: Investigating Traits

How peas helped explain heredity

Gregor Mendel (1822–1884) is often called the father of genetics because of the breakthroughs he made in the study of heredity, or biological inheritance. From 1856 on, Mendel cultivated peas in the garden at the monastery where he lived and worked. He found it quite interesting that these plants could have such varied properties. He noticed that there are pea plants with white or red flowers, and ones with yellow or green peas. But Mendel didn't stop there, at the mere observation. He started to cross-breed the peas systematically. For example, he tried consistently combining the pollen of red-blooming plants with the ova (egg cells) of white-blooming plants.

Then, Mendel took on an enormous task: He investigated the features of well over 10,000 offspring plants — whether they had red, white, or maybe even blue blossoms. Gradually, Mendel was able to show that the instructions for features such as flower color are individually inherited from the egg and sperm cells (which, in a plant, are the pollen grains) of the mother and father plants. He showed that sometimes both the features from the mother and father plants showed up in the offspring plants. But sometimes, only one of the two features expressed itself.

He was ultimately able to summarize everything in three famous laws of inheritance. This was the beginning of modern genetics, even if words such as gene and genetics were totally unknown to him. He recognized that living organisms such as plants and animals carried many individual programs for characteristics such as flower color and passed them on to their offspring. He eventually figured out that each pea plant has two copies of the program for any one feature, such as flower color.

EXPERIMENT 6

Identifying relatedness

YOU WILL NEED

→ note pad below
→ *pen or pencil*

We know that the threads that you isolated in the last experiment are genetic material. But to discover that, a lot of researchers beginning well over 100 years ago had to painstakingly ponder and perform one experiment after another. It was just like a big puzzle to which one researcher contributed one piece and another added the next, over many decades.

At the core of all this research was the mystery concerning how heredity worked. It wasn't hard to determine that it existed. Has anyone ever said to you, "Wow, you're the spitting image of your father?" Or, "Your grandmother had your same eyes?"

HERE'S HOW

1. Think of ways in which you are similar to your siblings, parents, or grandparents.

2. Write them down below.

→ WHAT'S HAPPENING?

People noticed a long time ago that they resembled their ancestors. Obviously, every generation passes some sort of program on to the next, which makes people look like the generation before. A lot of researchers had some curious ideas about how this might work. People knew early on that new individuals arise through mating. The basic facts are like this: In order to produce a baby, one egg cell from the mother has to merge with one sperm cell from the father. But for a long time it wasn't at all clear how a new human being would arise from that. At the end of the 17th century, some researchers developed the idea that there were tiny copies of the father sitting in the sperm cells, which then grew into full-grown people. Proponents of this "sperm cell" theory were called animalculists. A quite different opinion was held by the ovists — who thought that the tiny offspring were actually sitting in the egg cell. Pure nonsense! But to explain things properly, a great researcher had to step up to the plate.

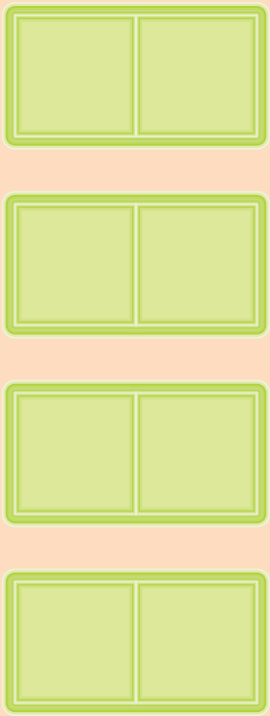
EXPERIMENT 7

Mendel and the Rules of Heredity

YOU WILL NEED

→ colored plastic chips

Gregor Mendel was an extremely multitalented person. He kept bees, worked as a gardener and teacher, occupied himself with research and philosophy, and, starting in 1868, headed the Augustinian monastery in Brünn (now Brno, in the Czech Republic). Now let's take a look at what Gregor Mendel discovered and how he discovered it.



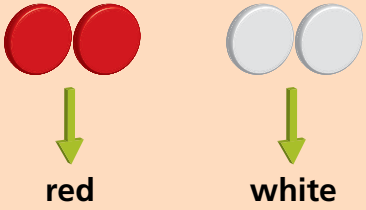
HERE'S HOW

1. A red chip represents the program for red flowers, and a white one represents the program for white flowers. In each plant, there will always be a combination of two programs, symbolized by two chips.

2. We have learned that each plant has two copies of each program. Place all possible combinations of the chip pairs in the four boxes above.
You will find the solution on page 47.

3. Think about which flower color the plants might have in each case. It will be obvious in the two cases where both chip programs represent the same color.

4. A particularly interesting case is when two different programs are combined in the parent plants. Mendel thought of two possible ways that the flowers of such offspring plants might look.



EXPERIMENT 7

→ WHAT'S HAPPENING?

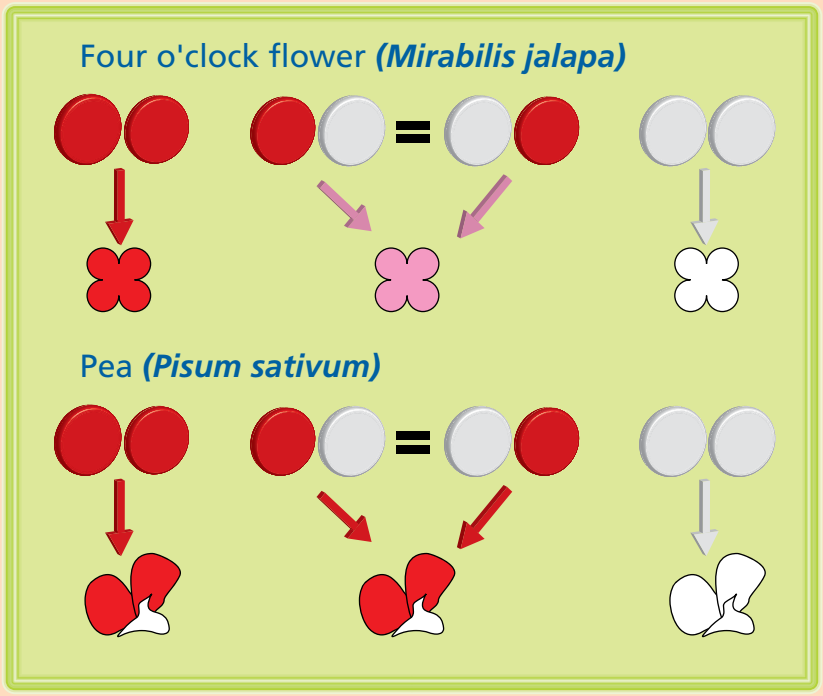
These are the possibilities:

a) If the programs complement each other equally, one program for red plus one for white would make pink flowers. This is what happens, for example, with the four o'clock flower, Mirabilis jalapa. One of these plants with a mixture of red and white programs does in fact have pink flowers.

b) But it is also possible for one program to dominate the other: for example, for the red program to prevail against the white program, so that the offspring plant has only red flowers even if both red and white programs are present. That is exactly how Mendel's peas behaved.


Pea


Four o'clock flower



How features are passed on

YOU WILL NEED

→ colored plastic chips

The way that features were distributed was still unclear to Mendel. But on this topic, he had a few more ideas. After all his experiments, it suddenly became clear as day to him that each partner only passes on one copy of each program to the offspring and not all the copies. That makes sense, because otherwise the number of programs would double with each generation.

Luckily, it is much more orderly than that: Only one of two possible programs passes from the parents to the children — so each of the offspring logically ends up with two copies again.

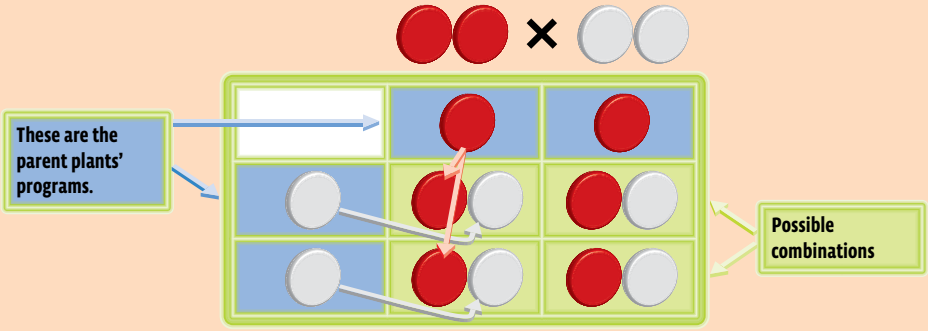
Now we can explain which four combinations of the programs can arise from two different pea plants when they are crossed.

HERE'S HOW

1. For the first pea plant breeding exercise, one pea should have two programs for red, and the other should have two for white. By placing the colored chips in the grid drawing below, you can easily figure out all possible combinations.

2. In each case, one program from one parent is crossed with one program from the other.

   Because we are dealing with peas here, all the offspring are red, since the program for red color always dominates. Not a trace of white to be seen — at least, not from the outside, by looking at the flower color.

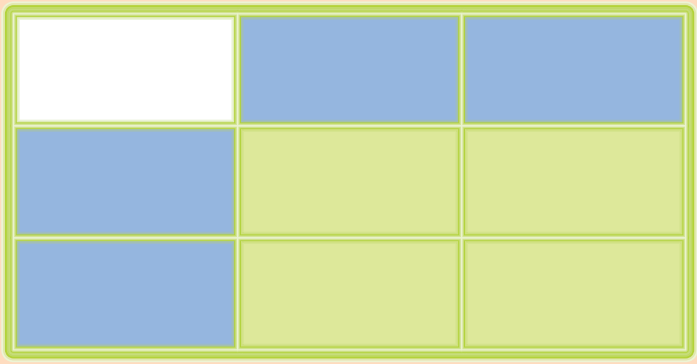


The X indicates that pea plant 1 (red-red) is crossed with pea plant 2 (white-white). From that crossing, we get four possible pea plant offspring, all with red flowers.

EXPERIMENT 8

3. What combinations arise in the offspring from these red plants? Place the plastic chips in the grid to the right.

You will find the solution on page 47.



→ WHAT'S HAPPENING?

Mendel's breakthrough:

As if by magic, all of a sudden, plants with red flowers would produce offspring with white flowers. Mendel used this kind of experiment to reveal the fact that there were hidden programs with a secret life of their own, operating behind the scenes to control the features of living things. You might be saying, "Pea plants are boring! I couldn't care less about the colors of their flowers!"

Okay, but it can also work like this: What would you think if all of a sudden a kid with red hair cropped up in a family in which the parents and grandparents only had brown hair? This new discovery would explain it: Features that would otherwise remain hidden, that have been suppressed by the dominant program copies, suddenly have the chance to express themselves when a pair of them are present together in the same organism.

In science as in art, recognition often comes late

Mendel's ground-breaking insight was hardly noticed by his contemporaries, and passed into oblivion for more than 30 years. Not until 1900 did other researchers unearth his work and say: Wow, this guy figured out the basis of heredity! If you want to read more about Mendel and his work, go to the web site: www.mendel-museum.com

BRAIN TEASER:

Suppose each of your grandparents has two programs to pass on. Each of them passes both programs on to your parents, and each of them in turn to you. If it worked this way, how many programs would you have?

ANSWER:

You would have 8 programs. Your children would have 16, and so on.

EXPERIMENT 9

Browned-eyed parent, blue-eyed child

YOU WILL NEED

→ colored plastic chips
→ inheritance worksheet
→ *red felt-tip pen*

It isn't quite this simple, but let's assume that human eye color is controlled by a single program and that each of us has two copies of the program. How could there be blue-eyed children in a family that otherwise only has brown-eyed members?

HERE'S HOW

The white chips represent the program for blue eyes, and the red ones for brown eyes. The program for brown eyes dominates the program for blue eyes in humans. If even one brown eyes program is present, the result will be brown eyes.

1. Assemble all the possible eye color program combinations that can occur with all possible parents. Think about the combinations that may occur.

2. On the inheritance worksheet, you will find all possible combinations indicated in the six large blue boxes. Place one chip combination after the other in the grid located at the top of the sheet. You know how to do this from Experiment 8.

3. Following each combination, enter the result into the appropriate blue box. To do that, simply color in the white disks with the red felt-tip pen. You already know that the program for brown eyes dominates the program for blue eyes. Now enter the number of children that would have blue eyes and the number that would have brown eyes into the little boxes on the right side of the sheet.

You will find the solution on page 47.

→ WHAT'S HAPPENING?

Only if both parents carry at least one hidden copy for blue eyes can the feature appear in the offspring. As soon as just one parent has two copies of the brown eyes program, a spouse with blue eyes can do nothing to pass that feature on to the children. (Maybe the grandchildren though.) The actual inheritance of eye color in humans only roughly follows this pattern. In reality, there are extra programs involved.

A single program is not enough to develop and control a living being. Instead, thousands are required. Researchers do not yet know the exact number. For humans, one of the most recent estimates is 20,000 to 25,000 individual programs. Each of us has two copies of each, resulting in double that number for the whole set. Half of the programs come from the mother, the other half from the father.

Many programs are passed on independently to the offspring. This means that "blue eyes" can be combined with "big feet," or "blue eyes" with "small feet," or "blue eyes" and "big feet" with "big ears." There is a vast number of possible combinations. →

Cells and Chromosomes

Where are these thousands of programs that control our bodies and make us who we are located? To answer that question, let's take a brief trip into our own insides. Your body is made of about 100 trillion cells — that's 100,000,000,000,000 of them. That's rather inconceivable. If you laid them all out in a straight line, they would stretch out for four million kilometers, and wrap 100 times around the world. How did we come to know all this? Well, why else do we have around 30 billion brain cells? A fly doesn't have to worry about this kind of thing, because it only has around 100,000 cells upstairs.

Like all animals and plants, humans come from a single starting cell formed by the fusion of an egg and a sperm cell. The egg cell is actually the largest human cell, and at one tenth of a millimeter in size it is just barely visible to the naked eye. If it is fertilized by a sperm cell, it divides in two cells, and then the two cells divide again and then all those cells divide — the embryo grows in the mother's womb, the baby grows, you grow... until you are about 18 years old. And even after that point, many cells in the body keep dividing, because some are always dying off and have to be replaced.

A skin cell on your ear lobe lives for one month, one on your belly a little over two weeks, yet other cells, such as the ones on your bottom, just live four days. Every second, about 50 million cells die inside us and on us, and if they are outside on our skin, they simply fall off, and we leave behind as a kind of cellular trace showing where we have gone and been. And when you scrape your knee, you might lose several million cells in one fell swoop in a few drops of blood. They, too, will be immediately replaced: By other blood cells, which divide and divide and divide...

BRAIN TEASER:

In Experiment 9, which offspring would surprise the parents?

ANSWER:

In Family 2, there is an unexpected blue-eyed child. In Family 4, there are no blue-eyed children.

Inside a cell

YOU WILL NEED

→ cell poster

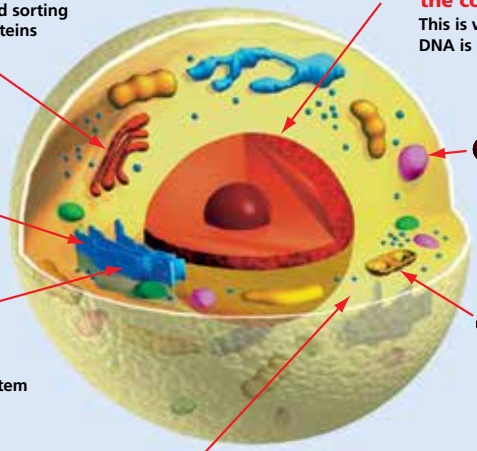
HERE'S HOW

1. Look at the cell poster included in your kit. You see the inside of a cell.

→ WHAT'S HAPPENING?

This is an animal cell. Human cells look basically like this one too. All cells are similarly constructed, although there are about 220 different cell and tissue types inside us.

When a cell divides, it pinches together in the center and distributes most of its individual components equally between its two daughter cells. (Obviously, cells have no gender, but the cells resulting from the splitting of a cell are called daughter cells). Later it may do this again and again.



7. Golgi Apparatus
Conversion and sorting station for proteins

1. Cell Nucleus: the control center
This is where the DNA is located.

6. Ribosomes: protein factories
They build proteins from amino acids.

2. Lysosomes: garbage dumps
This is where unneeded materials are disposed of.

5. Endoplasmic Reticulum (ER)
Rapid transport system for proteins

3. Mitochondria: power plants
This is where the energy that the cell needs is produced.

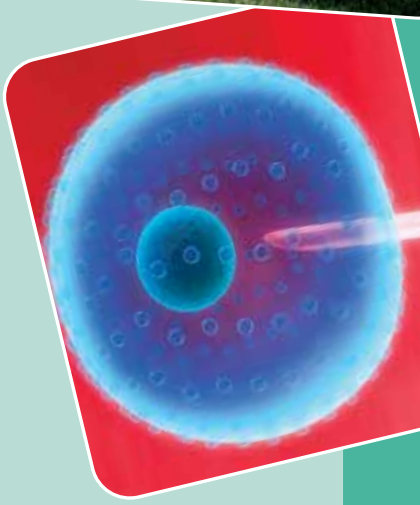
4. Cytoplasm
This liquid makes up most of the cell's volume. It consists mainly of water. It also contains proteins, fats, and sugars.

Diagram of an animal cell

CHECK IT OUT

DOLLY

How humans tricked the rules of heredity



Dolly was a Scottish sheep born on July 5, 1996. Just under a year later, as the world learned about her, she caused a worldwide commotion. With this famous sheep, researchers were able for the first time to clone, or copy, a mammal. In nature, that isn't too unusual. Plant cuttings, for example, are clones, and the plants are genetically identical. People have long been able to clone frogs. But with mammals, clones are a rare event: identical twins are genetically identical, and they really do look so similar that it's hard to tell them apart. They come about when the egg cell divides into two independent embryos following fertilization.

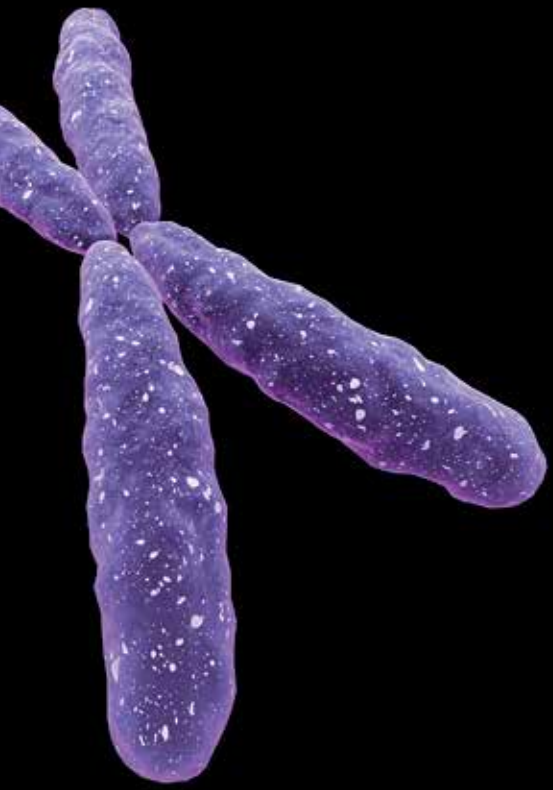
But the idea of creating a genetic copy of a mammal — such as a cow, dog, sheep, goat, cat, or even a human — remained in the realm of science fiction until Dolly came along. This is the trick the researchers used: They removed the cell nucleus from a normal somatic (body) cell of the animal. At the same time, they take the cell nucleus from the egg cell of another animal and inject the first nucleus into it. Then, they trick the egg cell into thinking that it has been fertilized, and it starts to divide. The researchers then transfer the artificial embryo into the womb of another animal, which in the ideal case will end up bringing an intact animal into the world.

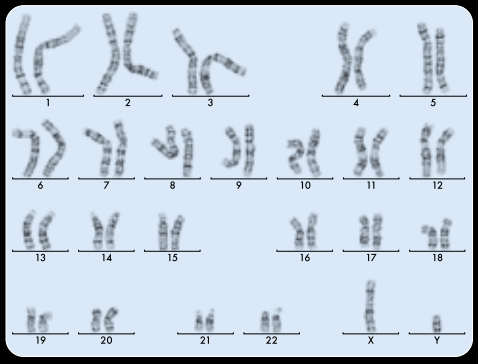
Cloning has since been performed on dogs, cats, mice, horses, and rats. But the success rate is very low. Only a few embryos survive, and quite a few that do are born with defects — a high price to pay for the realization of an idea.

Nobody has ever succeeded in cloning a human, and there are many moral and ethical issues involved in such a pursuit.

CHECK IT OUT

Chromosomes





Karyogram — graphic representation of the set of chromosomes of a male

Mendel certainly accomplished a lot, but even after his discoveries, it wasn't clear where in the body the inherited programs for our features might be located.

After about 1850, researchers working with microscopes began to notice strange spiral shapes in a special region of the cell that they called the cell nucleus. Around 1880, a few of them began to suspect that these shapes might have some special importance. The anatomist **Wilhelm Roux** (1850–1924) even claimed in 1883 to have observed that the strange strings were always present in pairs, and that they were evenly and accurately distributed between the daughter cells with each cell division. He observed correctly. Today we call the "sausage-like" shapes in the cell nucleus **chromosomes**. They are long threads of hereditary material, which are rolled up with lots of twists and packaged by the cell. There is a very simple reason for this: If it were stretched out, the hereditary material (like what you isolated from tomatoes in the first chapter) would be much too long to be housed in a single cell. Human DNA would be a full two meters long if stretched out — much too long for a cell with an average length of forty thousandths of a millimeter, or just 0.000040 meters!

So the long thread is folded and wound up until it fits. The chromosomes that you see here in the photos are just about four thousandths of a millimeter long. Thus, they easily fit inside the cell.

We also just saw how we always have two programs for any feature. In addition to that, there is another astounding case of symmetry: Each cell in the body always has exactly the same number of chromosomes. We will now determine that number.

EXPERIMENT 11

Examining Chromosomes

YOU WILL NEED

→ **chromosome sheet (set A)**
→ ***plastic bag***
→ ***scissors***

HERE'S HOW

1. Cut out the individual chromosomes from chromosome set A. Now you have an enlarged set of the chromosomes from a single human cell, a large model of that which researchers routinely examine from small blood samples under the microscope.

2. Now turn all the individual chromosomes over so that you have them laid out in black and white in front of you. How many chromosomes are there?

Human cells have 46 chromosomes.

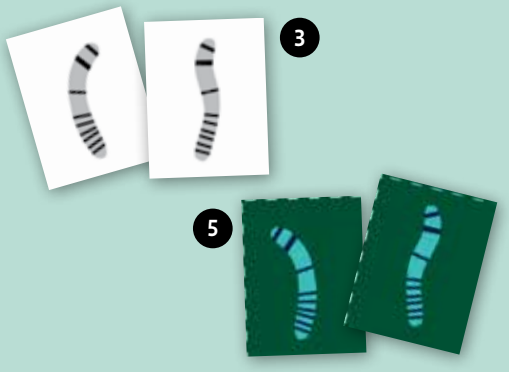
3. Think about how you would organize the chromosomes. According to the rules of Gregor Mendel, all the programs for features are doubled in each cell. Can you see whether certain chromosomes fit together?

4. Organize the chromosomes in matched pairs according to their sizes.

5. To check whether you found the right pairs, simply turn the cards over. You can tell by their colors and numbers whether you matched them up correctly.

6. Something doesn't add up: There are 22 chromosome pairs, but there are two individual chromosomes left over. Due to their characteristic shape, they are called X and Y chromosomes. They determine whether the person is a boy or a girl. Boys have one X and one Y chromosome, while girls have two X chromosomes. So now you can also tell whether your chromosome puzzle is for a boy or a girl.

7. You can save the chromosome pieces in the small plastic bag that is included with the kit. Let your friends try the puzzle too!



BRAIN TEASER:

Does a boy's Y chromosome come from his mother or his father?

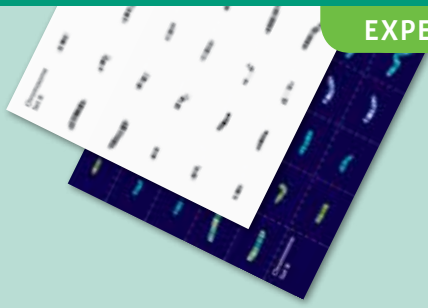
ANSWER:

Each mother and father has 23 chromosomes. A boy's Y chromosome comes from his father.

One additional chromosome

YOU WILL NEED

→ chromosome sheet (set B)
→ *plastic bag*
→ *scissors*

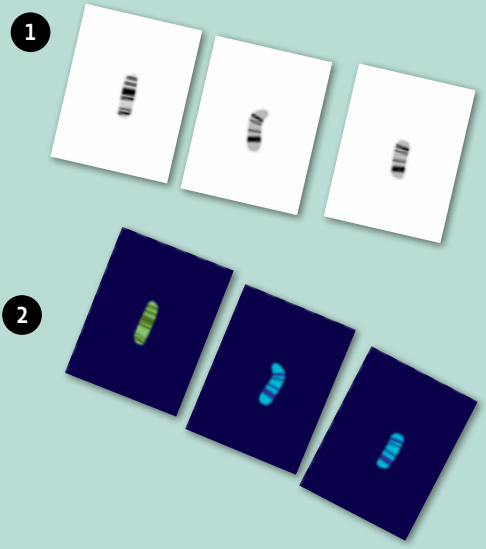


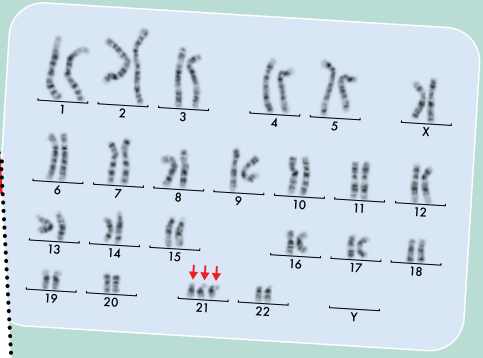
HERE'S HOW

Now we'll take a look at another set of chromosomes.

1. Cut out the chromosome set B and sort them again so that they match.
   Is it a boy or a girl?

2. Here, again, you can check whether you sorted the chromosomes correctly by turning the cards over.





With Trisomy 21, the 21st chromosome appears three times.

→ WHAT'S HAPPENING?

This set of chromosomes has not two, but three copies of the 21st chromosome. That is a sign of a hereditary disease with the name Trisomy 21. About one out of every 700 children naturally comes into the world with this condition, also known as Down Syndrome.

CHECK IT OUT

The History of Down Syndrome

There are about 350,000 people in the United States with Down Syndrome. It is one of the most common chromosomal abnormalities, and it affects people of all backgrounds, races, ages, and genders.

Although the condition was recognized in people much earlier, Down Syndrome was first identified as a unique syndrome in the 19th century by an English doctor named John Langdon Down, for whom the condition is named. In the middle of the 20th century, a French physician named Jerome Lejeune discovered that patients with the syndrome all had 47 chromosomes instead of the normal 46. Later, it was discovered that it was specifically the presence of a third 21st chromosome that resulted in Down Syndrome.

Today, people living with the condition are active, contributing members of our communities. Every year, more and more people with Down Syndrome are graduating from high school and college, finding jobs, and living on their own.

The DNA model:

A lot of people worked on it, but only three won the Nobel Prize

By the year 1953, it was already clear that the DNA in the chromosomes had to be the hereditary material, and that it therefore contained the program that shaped the construction of our bodies down to the tiniest cells, and that defined the color of our hair or even to some extent the tendency to become a sports star or a studious bookworm.

But scholars were still stumped by the task of figuring out the component parts of the threads and, most of all, by the puzzle of how the program for life was stored in them. DNA is an abbreviation of the rather complicated word **deoxyribonucleic acid**. Chemists call this kind of structure a **molecule**. Molecules are much smaller than cells — they are the chemical building blocks of cells, but also of things like sugar, salt, rubber boots, and the plastic in the test tube included in this kit.

Decoding the Structure of DNA

The year was 1953. Two rather brash researchers presented the correct interpretation of the structure of genetic material: the American James Watson (born 1928) and the Englishman Francis Crick (1916-2004). Let's see if we can't figure it out along with them.

EXPERIMENT 13

Building the backbone of DNA

YOU WILL NEED

→ DNA model pieces

HERE'S HOW

1. Lay all the pieces on a table.

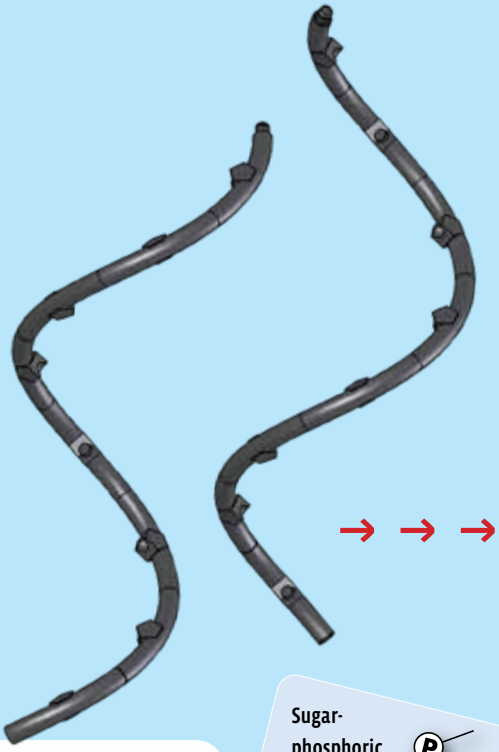
2. Your starting position is more or less the same as that of many researchers at the beginning of the 1950's. They, too, experimented with models like this in order to figure out how the parts fit together to form the structure of DNA.

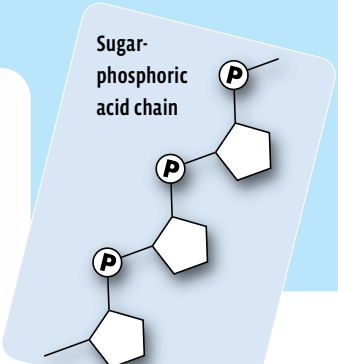
Models are helpful tools for showing an enormously enlarged schematic version of reality. The model that you have here represents a dramatically enlarged DNA molecule, because an actual DNA thread is just two millionths of a millimeter wide.

Before the structure of DNA was discovered, researchers already knew what the individual building blocks of DNA were. The black building blocks with the pentagons had to form the framework for the long, uniform thread, that much was clear. The five-cornered pieces represent chemicals that researchers call sugars. They are related to the sugar you have in your kitchen: confusing but true! Tiny sugars are the building blocks for the white sugar crystals that we use when we bake things. In this case, it is a very specific sugar building block. The long, curved black pieces represent something called phosphoric acid.

These two individual components form a sort of basic framework in which phosphoric acid and sugar alternate. Now it's your turn.

3. Assemble the black components to create two equally long strands. In the model's five-cornered pieces, you will see a hole. This provides a place to attach more building blocks, as you will soon see.





Completing the DNA model

YOU WILL NEED

→ DNA model pieces

In 1953, it was also obvious that there were four more building blocks — the colored pieces in our model — arranged in such a way that two of them were always present in precisely equal quantities, and the other two were also always present in equal quantities. In your kit, the green and the red pieces go together, as do the yellow and blue ones. Chemically, they are known as bases.

People also already knew that the strand wasn't straight, but that it turned around its own axis — something like when you hold a string at one end and twist the other end around and around. That gives rise to a helix structure — just like a spiral staircase.

Watson and Crick had figured this out with pictures that other scientists, including Maurice Wilkins (1916–2000) and Rosalind Franklin (1920–1958), had taken of DNA with the help of x-rays. The rest, however, was yet unsolved. How in the world could all that fit together into a molecule?

HERE'S HOW

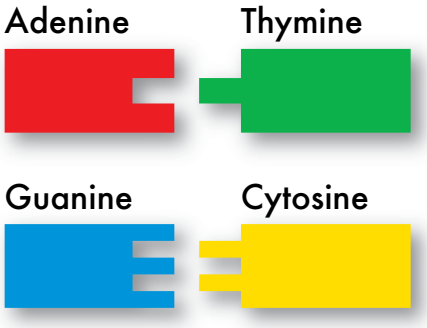
1. Can you figure out how to assemble the colored elements onto the black backbone strands so that the matching ones are always exactly opposite each other?

2. Attach the colored base pieces onto the two black sugar-phosphoric acid strands in such a way that each colored base fits precisely with the one across from it. This means that the red base must match up with the green base, and the blue base must match up with the yellow base.

3. Now connect all the colored elements together. The result will look like a spiral staircase.

It was a model something like this that James Watson built by hand out of cardboard and glue on February 21, 1953. He hit upon a way that the adenine bases (A, which is red here) and thymine (T, green) as well as guanine (G, blue) and cytosine (C, yellow) might be connected in the middle by so-called hydrogen bridges. Namely, A and T are connected by two hydrogen bridges and G and C with three hydrogen bridges. The pairings A with G or C with T would not work. You can see that in your model too.

The final trick was to recognize that these base pairs could only be shaped in the optimal way if the entire structure was designed not in the form of a simple ladder, but rather turned on its own axis like a screw. This is called a double helix. You can see in the model that the bases only fit together if the sugar-phosphorus framework is twisted like a telephone cord.



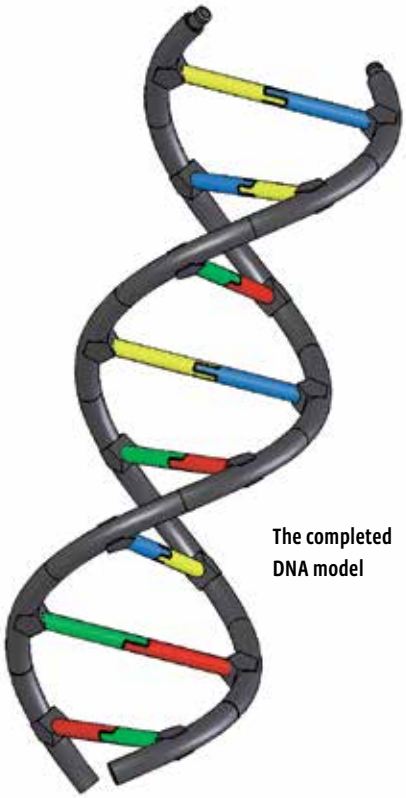
The four DNA bases — the pairing is always the same.

EXPERIMENT 14

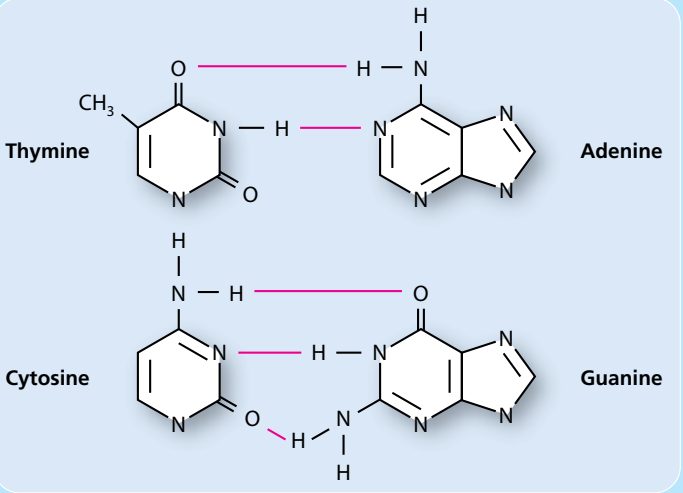
This model is, without a doubt, the most famous model of the 20th century. Watson and Crick published it in the British scientific journal "Nature" on April 24, 1953. In their article, they also added one really tricky sentence: "It has not escaped our notice that the specific pairing we have postulated immediately suggests a possible copying mechanism for the genetic material."

Huh? You didn't understand that? You wouldn't be expected to right off the bat. This is what they were trying to say: This molecule can pass on information!

With their discovery of the structure of the genetic material, they had found a way that a single molecule could actually encode information and thereby contain genetic programs.



The completed DNA model



The base pairs and their bonds: The red lines are the hydrogen bridges.

CHECK IT OUT

The Nobel Prize is not always fair

The greatest honor for a researcher remains the **Nobel Prize**, which is awarded every year in Stockholm for achievements in disciplines such as physics, chemistry, and medicine. In 1962, it was won by James Watson and Francis Crick, along with the New Zealander Maurice Wilkins, for their discovery of the structure of DNA. In that discovery, Rosalind Franklin also performed important groundwork by, for example, explaining to Watson and Crick that the bases lay inside the molecule and not on the outside, as they had incorrectly depicted it in a preliminary model. Later, many colleagues accused the two of them of failing to acknowledge her important contributions adequately. But Franklin didn't win the Nobel Prize, since she had already died and the prize isn't awarded posthumously. Mendel didn't receive it either since the prize has only existed since 1901.

WATSON GETS HIS DNA

On May 31, 2007, James Watson took delivery of his personal DNA: a DVD disk containing the entire sequence of bases in his genes. Scientists use the fancy term "individual DNA sequence." On the one hand, the basic DNA structure is the same for all humans. But the estimate is that there are differences at about every 1,000th place in the long sequence of bases. Every individual is different — each of us has our own unique DNA. In the autumn of 1990, the **Human Genome Project** was founded, with the goal of completely deciphering the human genome, to identify the sequence of base pairs in human DNA down to their individual chromosomes. This will lay the groundwork for investigating and better understanding hereditary diseases. Many doctors and pharmaceutical firms believe that it will one day be possible to first decode patients' DNA and then treat their illness much more effectively on the basis of a precise understanding of their genetic characteristics. This also poses interesting moral and ethical questions.

EXPERIMENT 15

Relaying the DNA code

YOU WILL NEED

→ DNA model from Experiment 14

Today, the exact sequence of bases in our DNA can be decoded in the lab. If all the bases are written down in order, it results in a gigantically long chain: A, T, C, or G repeated about three billion times one after the other. If you take each chromosome just once and write the sequence of all the bases, a tiny slice of it might look like this:

...ATTTCCGTTAAGGGCTATTATGGGGTTT...

At first glance, that looks like gibberish — as if someone were writing nonsense at a computer keyboard using just four letters.

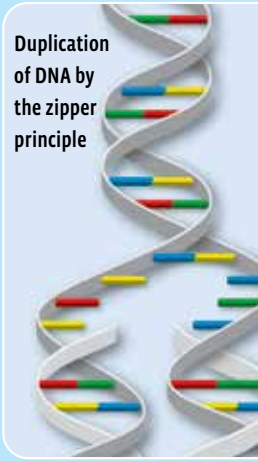
Watson and Crick's discovery in 1953 explained how this supposedly nonsensical string of bases can be passed on to the offspring one by one. And that happens completely automatically, as long as nature uses just one trick and keeps a big enough supply of bases on hand.

HERE'S HOW

1. Think about how nature can make sure that each daughter cell gets the exact same genetic material when a cell divides. Can you think of a way that the genetic code could be copied?

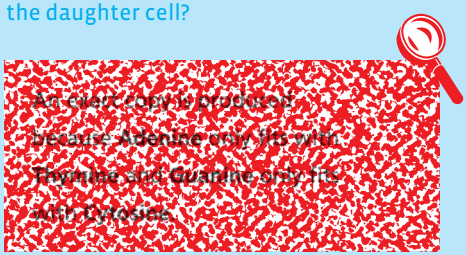
Here's one idea: Nature has to open up the DNA molecule much like a zipper opens, exposing the bases in the middle. Then, the matching base building blocks can attach to the exposed bases.

2. Let's try it. First, we will separate the bases in the DNA model. Leave one strand intact and divide the other into building blocks called **nucleotides**. These are individual building blocks composed of three molecules, phosphoric acid, sugar, and a base. These nucleotides are available to the cell in great quantities.



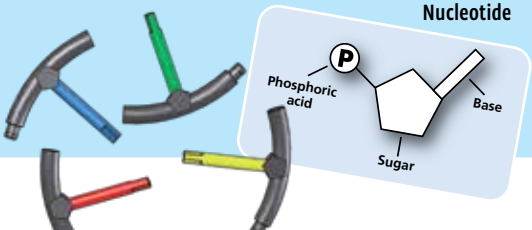
Duplication of DNA by the zipper principle

3. Now think about how to guarantee that an exact copy of the original double strand is produced. Complete the DNA.
So, how is DNA copied and passed down to the daughter cell?



The cell uses this trick to construct one copy of its set of chromosomes prior to every cell division. Then, the identically copied sets are divided between the daughter cells. The DNA can indeed pass something on.

The cell uses this trick to construct one copy of its set of chromosomes prior to every cell division. Then, the identically copied sets are divided between the daughter cells. The DNA can indeed pass something on.



Dividing chromosomes properly

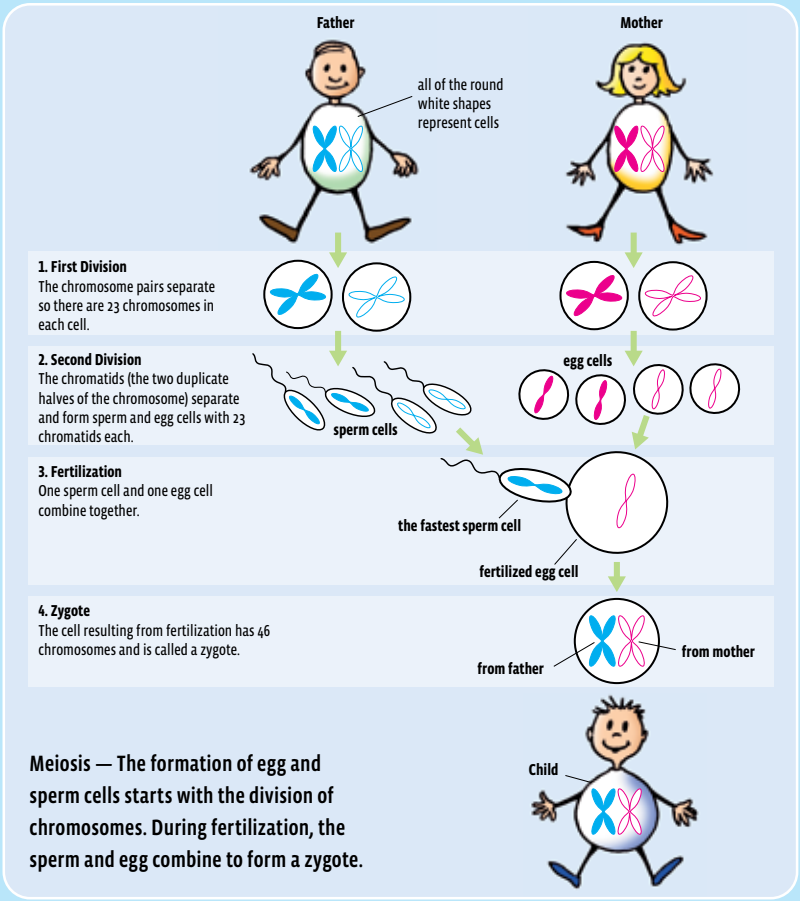
YOU WILL NEED

→ the diagram below

HERE'S HOW

There's still a teensy-weensy problem: What happens to the number of chromosomes when the egg and sperm cells fuse? In theory, the next generation would get a double set of chromosomes. That would mean that the daughter of the following generation would have a quadruple set of chromosomes, and her child would get eight times the original number. Of course, that won't work. Nature has invented a logical trick to deal with this. The diagram below shows how it works.

1. Follow the diagram carefully, step by step, to see how chromosomes divide.



Meiosis — The formation of egg and sperm cells starts with the division of chromosomes. During fertilization, the sperm and egg combine to form a zygote.

CHECK IT OUT

Cracking the Genetic Code

The programs that control living organisms, and the programs that those organisms pass on to their offspring, are composed of a very specific sequence of bases on the DNA. In the technical language of researchers, these programs, or sequences of bases, are called genes.

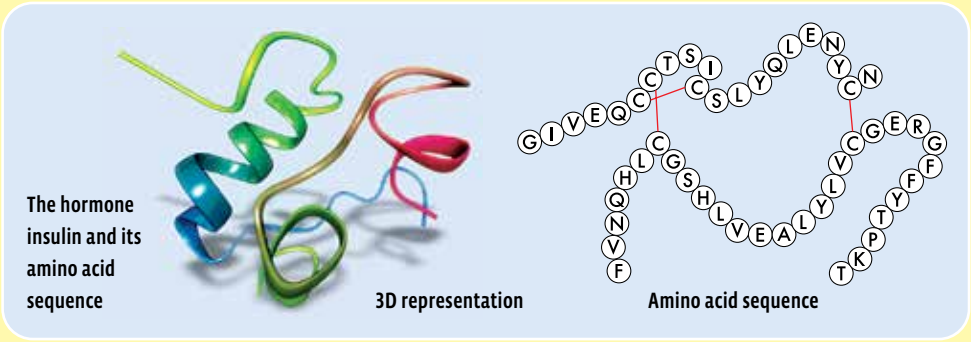
Today, the way in which a gene controls things is mostly understood. An extravagant machine in the cells translates the genetic code into the sequence of individual protein building blocks. Along with DNA, fat, and sugar, proteins form an important group of materials in the body. Many proteins act as accelerators — they ensure, for example, that the things that you eat every day are quickly broken down and digested. Only in that way can the energy that you need to get out of bed early in the morning, ride your bike to school, or play soccer afterwards, be efficiently released. Without digestive proteins, a piece of bread would sit in your gut all day without much happening to it. And a lot of people wouldn't get out of bed in the morning at all.

Proteins consist of individual building blocks, so-called amino acids. Nature offers a total selection of 20 amino acids for making proteins. One well-known protein, for example, is insulin. It is an indispensable hormone that every healthy human produces in the pancreas. We need insulin to be able to digest the sugar in foods. People with diabetes have to inject themselves with the hormone in advanced stages of the illness. Here's a question: If DNA tells the body how to produce insulin, how would that be encoded? How might the program for insulin look? What is the blueprint, the instruction manual, for assembling the protein?

The answer has been known since 1961: Three bases in a gene sequence always form a coding unit, and each coding unit makes a specific amino acid.

The following table shows you how the various amino acids are abbreviated. An "A" stands for the amino acid alanine, for example.

... ATT TTT CCG GTT AAG ...



The hormone insulin and its amino acid sequence

3D representation

Amino acid sequence

How many "words" can DNA make?

YOU WILL NEED

- *paper*
- *colored pencils (red, green, blue, yellow)*

The genetic material forms coding units called codons. These are something like individual words in a language. As a sort of analogy, let's take the most important code of all: our language.

As you know, the English language has an alphabet consisting of...

a b c d e f g h i j k l m n o p q r s t u v w x y z

...26 letters. In order to understand something, or say something that makes sense, we form words. Simple examples are "What?" or "Great!" or "Man!" They are not always perfectly precise, but they are enough for basic communication. It gets clearer when we pack several words together into sentences. A simple example: "Don't get it!" or more elegantly: "I did not quite understand that." The selection of sentences is immeasurable. In total, the English language has somewhere over 500,000 words. Your average person can get through life perfectly well with only about 75,000 words.

Now back to DNA. Bases are like letters, codons are like words, and genes are like sentences. The question now is: How many different DNA "words," or codons, can be created with the four letters? The letters are the four bases abbreviated A, T, G, and C. In 1961, it was determined that each "word" in DNA consists of exactly three "letters" — no more, no less. That is, each codon consists of precisely three bases in sequence.

Amino Acid	Abbr.	Letter symbol
Alanine	Ala	A
Arginine	Arg	R
Asparagine	Asn	N
Aspartic acid	Asp	D
Cysteine	Cys	C
Glutamine	Gln	Q
Glutamic acid	Glu	E
Glycine	Gly	G
Histidine	His	H
Isoleucine	Ile	I
Leucine	Leu	L
Lysine	Lys	K
Methionine	Met	M
Phenylalanine	Phe	F
Proline	Pro	P
Serine	Ser	S
Threonine	Thr	T
Tryptophane	Trp	W
Tyrosine	Tyr	Y
Valine	Val	V

Let's also assume that we can create as many words as there are different possible combinations of the four letters. In addition, all of the letters can repeat several times. So two words might be:

AAA and TTT

Two more might be:

ATG and CGA

And now it's your turn...

HERE'S HOW

1. Write down all possible combinations of the 4 bases.

EXPERIMENT 17

2. Try to think of a strategy for mixing the letters up as little as possible and for ensuring that you don't forget any letter combinations. It works best if you use a different color for each base (in other words, for each letter). You will find the solution on page 47.

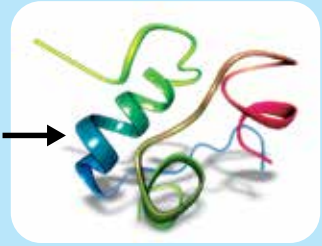
BRAIN TEASER:

How many codons can be formed by the genetic code?

Hint: This is a multiplication task. How many letters can be in the first position (at the beginning) of a word, and with how many letters can each one be combined with? And again in the third position?

ANSWER:

The number of possible combinations is 4 x 4 x 4 = 64. There are 64 codons that can be made. That's not very many compared to the number of words in our language. Amazingly enough, nature would really only need 20 codons, as there are only 20 amino acids. Some codons define the same amino acid. A list of all possible combinations can be found on page 46.

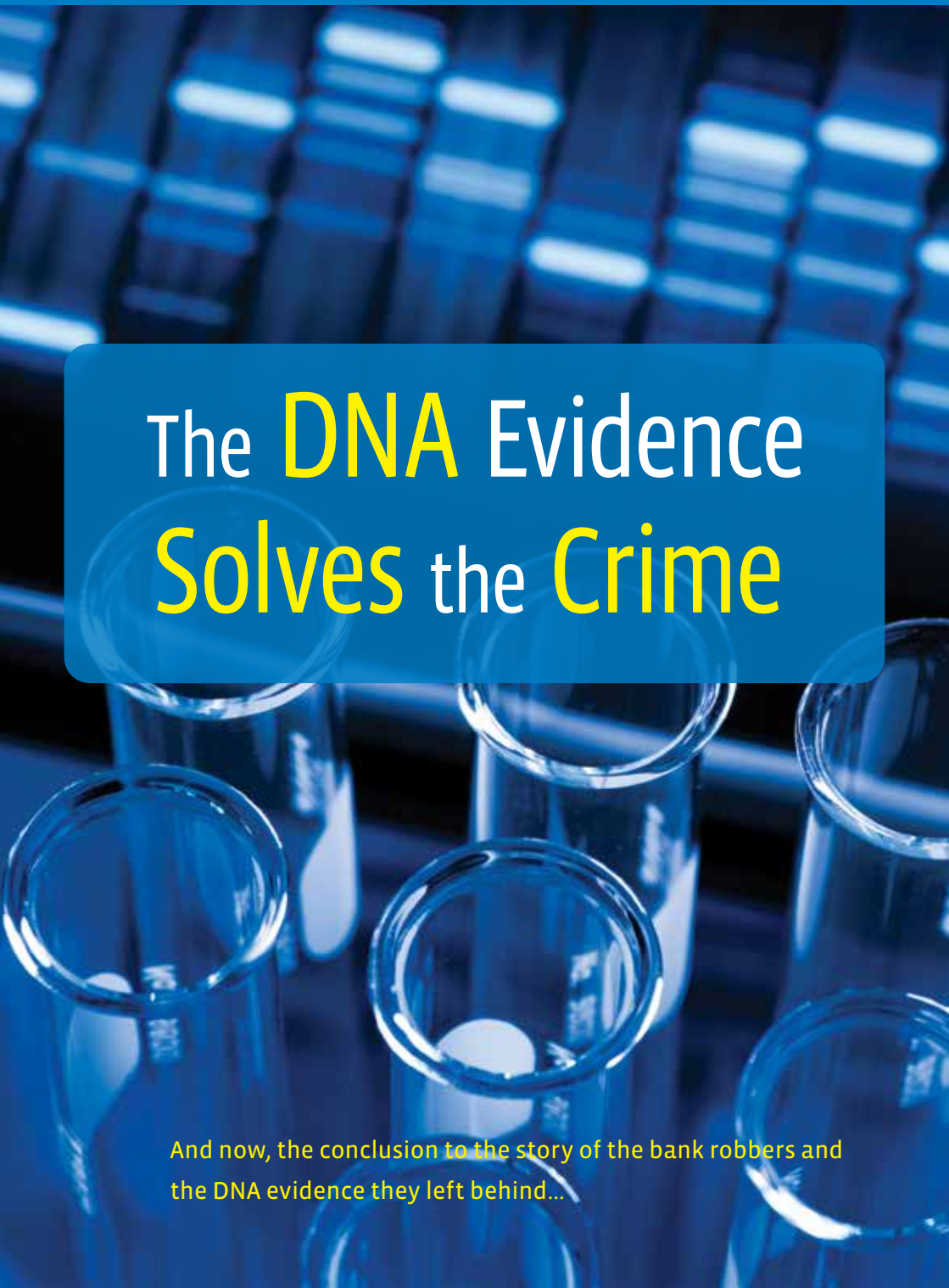


Each codon specifies a single amino acid.

→ WHAT'S HAPPENING?

Nature is thrifty. A series of simple three-base codes is enough to program all of life. Human DNA has perhaps 20,000 to 25,000 genes. To stick with the language analogy: The book of DNA has less than 25,000 sentences. The DNA sentences, like those of language, are of various lengths, depending on the length of the encoded proteins. But the story in the book of DNA is ultimately surprisingly short.

But as in poetry and literature, sometimes it is not the quantity of words, but the meaning behind them, that matters. With DNA, this meaning is the code for life itself.



The DNA Evidence Solves the Crime

And now, the conclusion to the story of the bank robbers and the DNA evidence they left behind...

CHECK IT OUT

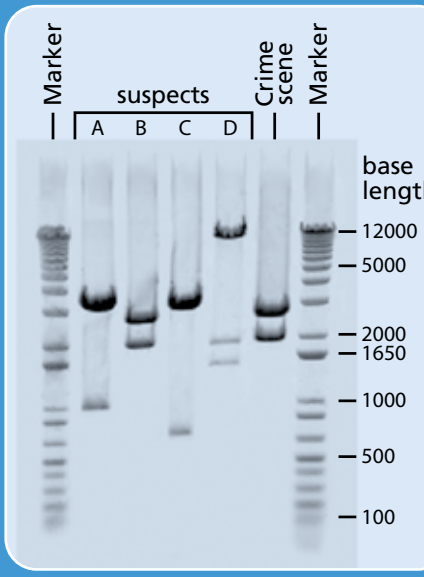
The bank robbers got away safely, changed their getaway cars twice, and are hiding out at Aunt Molly's. Molly runs a small bed-and-breakfast in the country, where the three of them are renting a room. That doesn't suit Molly, and she suspects that something is going on. "What are you doing staying here so long?" she asks them almost every day. But Schubert just grunts: "What difference does it make to you? We'll pay for the room, you know."

After two weeks, the three of them agree to divide up the money and fly the coop. Schubert wants to take a vacation in Brazil, while Kramer and Adler want to go to New York. Of course, they take off without paying. Molly is very mad. She can put two and two together. Where did they get their money? And wasn't there something in the paper two weeks ago about a bank robbery? Molly snitches on them to the police. "One of them wants to go to Brazil," she says, "and the others to Berlin."

Schubert gets caught two days later while checking in at the airport, and the others are nabbed a little later at a cheap hotel in New York. But the police have just one tiny problem. "Hey, what's going on?" is the indignant comment from all three as they are arrested. "We're just innocent citizens." And in fact, how are the police supposed to prove that the three are the actual culprits? By their faces? Impossible — the witnesses can't identify them, on account of the masks. By the sound of their voices, as one of the witnesses suggested at the lineup? Not enough. Fingerprints at the scene of the crime? There aren't any. Within 24 hours, the police have to release all three from detention, if they have no evidence.

This is the moment for someone who otherwise spends most of his time working quietly in the investigation lab. Robert Green brought his samples — the drops of blood, the cigarette butts, as well as a few bits of lint and hair — from the scene of the crime to the police lab, where he isolated DNA from them and stored it in the freezer. He found tiny quantities of DNA, around 10 billionths of a gram in each case.

Now his hour has arrived. Green doesn't just need patience, he also needs some saliva.



This picture shows an actual banding pattern from a forensics lab — a genetic fingerprint.

From each of the suspects, he takes a swab of a few cells from the inside of their left cheeks. He had obtained a court order to do it beforehand.

"Now let's take a look at the fingerprint," he says, and the three of them laugh themselves silly. What kind of fingerprint? Is he nuts? "Take it easy. I mean the genetic fingerprint," says Green.

Then he isolates DNA from the cells in the three samples, runs them through several more lab procedures, and after a few hours has large images in front of him — each with a remarkable pattern of black stripes.

"Here is the exact profile of two of you gentlemen," announces Green triumphantly. "Take a look for yourselves: those are two as yet unaccounted-for patterns from the samples collected at the scene of the crime. And here are the patterns for each of the bank employees who were in the room at the time of the robbery..." Then Green shows them some more pictures. "But these ones here," as he shoots the three of them a glance, "These are two of the patterns from today, fresh from the samples that I just took from you. By the way: these patterns might be found in at most one person in 200,000. If that is not enough for you, then I can give you patterns that will identify each of you as one of the culprits with a 99.999999 percent probability."

DNA analysis in a forensic science lab

EXPERIMENT 18

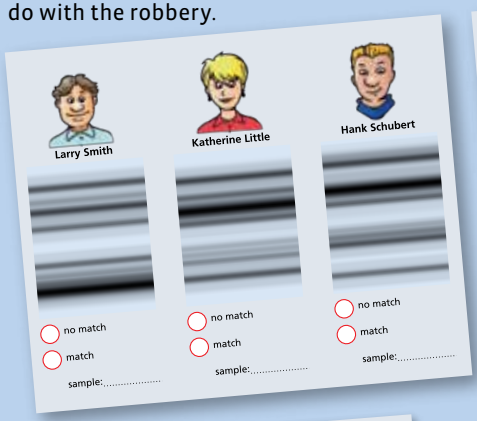
The criminal profile

YOU WILL NEED

→ genetic fingerprinting sheet

HERE'S HOW

Dr. Green printed out his results here. You can see a set of genetic fingerprints. Figure out which two people match the genetic fingerprints taken from the cigarette and the traces of blood, and which people apparently had nothing to do with the robbery.



Schubert's sample from this morning precisely matches the pattern from the blood sample. Adler's matches the sample from the cigarette butt. "But Rudy was there too!" is Hank Schubert's furious remark. "Thanks, gentlemen," interjects Commissioner Reddy, "You can give me that exact statement for the official record in the room next door."

The genetic fingerprint from the blood matches Hank Schubert's. While the cigarette's fingerprint matches that of Martin Adler.

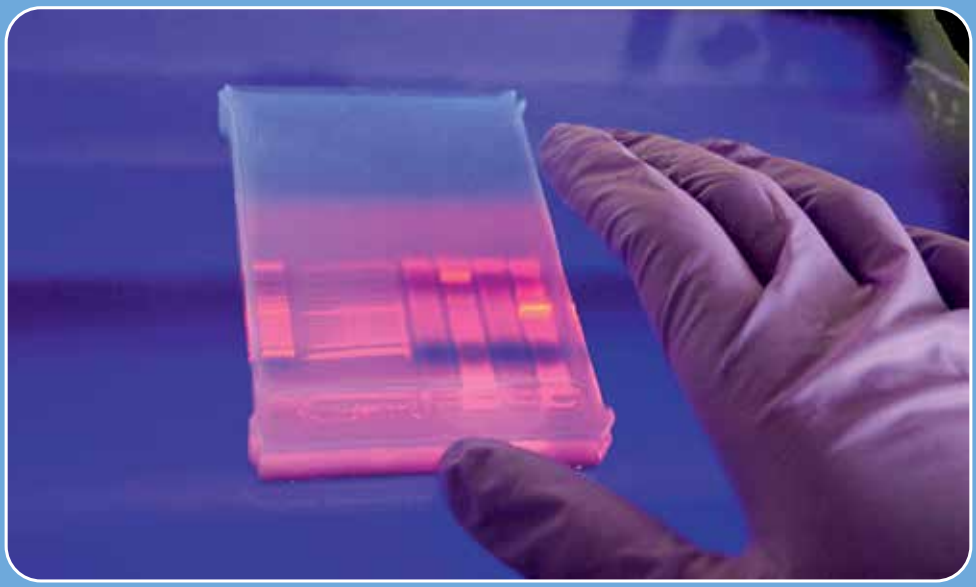
CHECK IT OUT

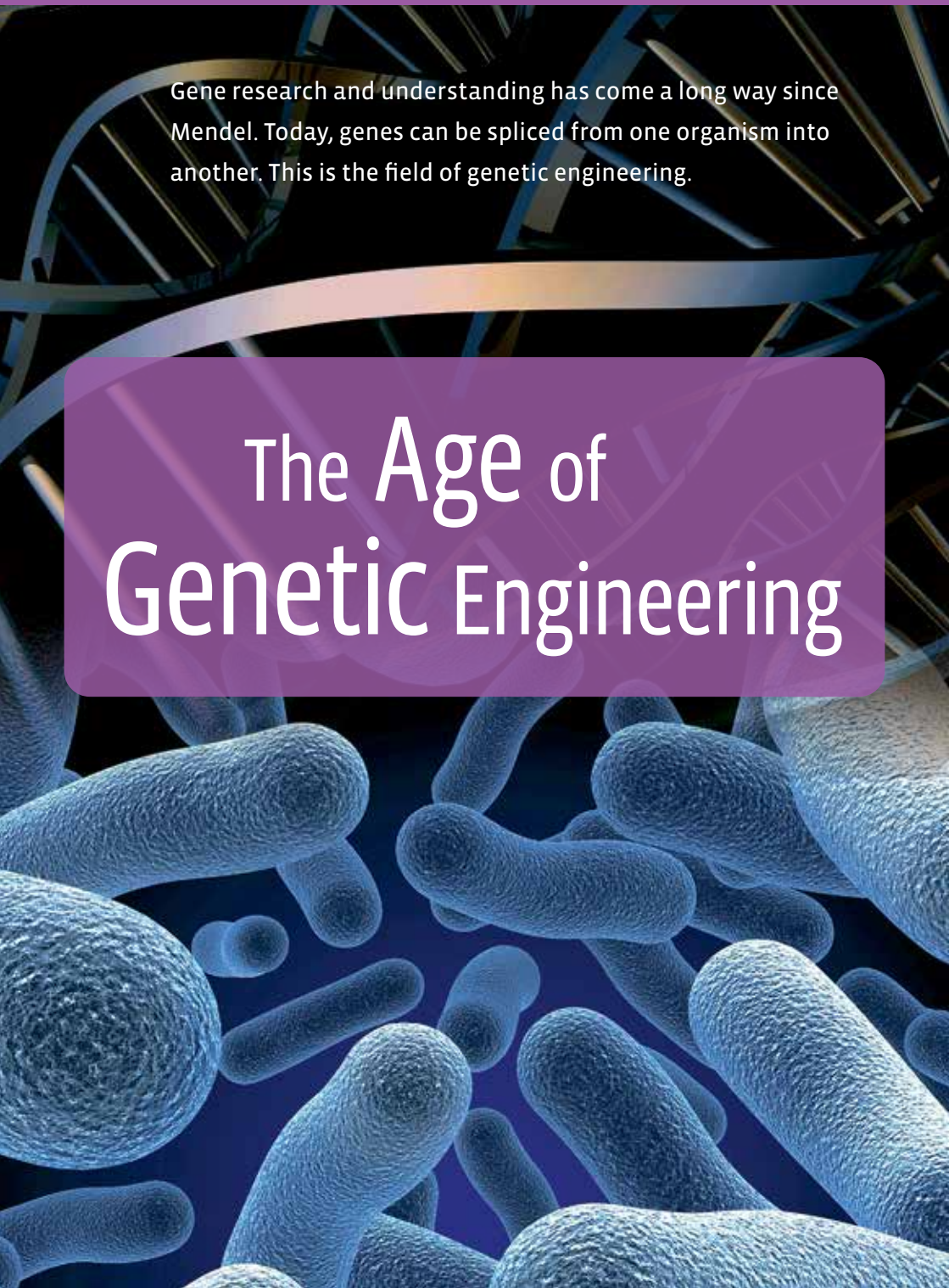
THE GENETIC FINGERPRINT...

... was developed in 1985 by British researchers. It makes use of the up to 97.5% of our DNA that contains no genes. That ensures that these tests don't betray anything about the genetic features of the test subject. Instead, it renders patterns visible that are relatively unique to the person being investigated. If the genetic fingerprints from a sample, such as the DNA from a blood sample or a cigarette butt taken from the scene of the crime, match the pattern of a suspect, then the probability is usually over 200,000 to 1 that the samples from the crime scene also come from the suspect. If the patterns fail to match, however, then the accused may be free of suspicion.

A genetic fingerprint alone is not sufficient for a conviction, but the individuals involved will often offer a confession once they are confronted with the data. In the case of serious crimes, if there is a danger that the culprit will re-offend after release, then his genetic fingerprint can be stored by the government in a central DNA database. In the United States, this database is called the Combined DNA Index System. Currently, it houses over 6 million profiles, including data from individuals and pieces of evidence found at crime scenes. Comparison against these data sets makes it increasingly possible to solve crimes even years after they occurred.

Today, genetic fingerprints also serve to clarify whether two people are related — for example, if two men are arguing about which one of them is the father of a child, they can test their DNA to see if it matches that of the child.





Gene research and understanding has come a long way since Mendel. Today, genes can be spliced from one organism into another. This is the field of genetic engineering.

The Age of Genetic Engineering

CHECK IT OUT

BACTERIA

In the production of pharmaceuticals, genetically altered bacteria are no longer out of the question. For decades, the insulin medication needed by diabetics was obtained from animals. But in the early 1980's, a kind of insulin came onto the market that was derived from bacteria — which normally do not produce this substance at all. Genetic engineers spliced the human insulin gene into harmless bacteria, which then produced the material in great quantities and at a high level of purity.

Bacteria are amazing. They consist of just one single cell. They are tiny and reproduce simply by dividing. But that's where they accomplish a lot. If each cell divides once an hour, then 16,777,216 bacteria are produced in a single day.

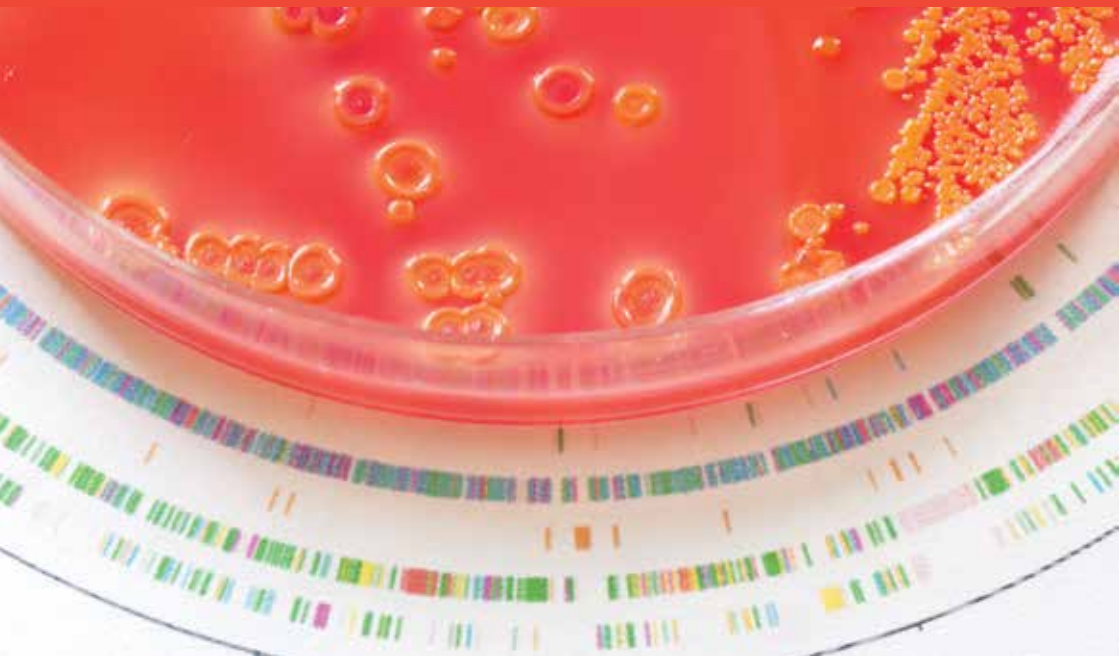
It's no wonder they are practically everywhere. We are even filled with them. Somewhere around 100,000,000,000,000 bacteria live on and inside each one of us. That's 100 trillion. 100 billion live in the mouth. One trillion live on the skin.

But the greatest number live in our intestines. Bacteria there make up 99% of all the bacteria cavorting in and on us.

How do you prove the presence of bacteria, when you can't even see them because they are so tiny?

That is actually quite simple: Give them a good foundation to grow on, and pretty soon so many of them will have reproduced that you'll actually be able to see them due to their mass.

Now let's collect some bacteria from your environment and make them visible.



EXPERIMENT 19

Preparing the growing medium for the bacteria

YOU WILL NEED

- → 2 petri dishes (keep them closed until use!)
- → LB-agar growing medium
- → lid opener
- → plastic spatula
- → measuring cup
- → *empty jelly jar*
- → *old small cooking pot (or microwave oven)*

HERE'S HOW

1. You must do this experiment with adult supervision! Measure 50 ml of water with the measuring cup and add it to the cooking pot.

2. Pour in all the growing medium and stir with the spatula. Carefully bring everything to a boil, continuing to stir a little, until all the powder is dissolved. It works even better with a microwave. Take a well-rinsed, used jelly jar, add all the ingredients to it as explained above, and bring it to a boil in the microwave. Leave the jar in the microwave for a minute before removing it. It could still be hot and boil over!

3. Now we'll fill the petri dishes. Get both petri dishes with their lids ready, in a quiet location where they will be able to sit a while afterwards.

4. Carefully remove the pot from the stove or the jar from the microwave.

5. Briefly remove the lid of each petri dish and pour in just enough liquid medium to cover the bottom, but still leaving two millimeters of space below the rim.

6. Immediately put the lid back on. We don't want to capture any bacteria yet, before the experiment has even begun.

7. Wait at least half an hour, until the medium has cooled and hardened.

→ WHAT'S HAPPENING?

This is why the growing medium hardens: The growing medium contains agar, which is obtained from algae and is something like gelatin, which is what makes vanilla pudding or gelatin desserts so jiggly yet firm. While the warm agar is liquid, it can be poured into molds, where it will cool and harden.

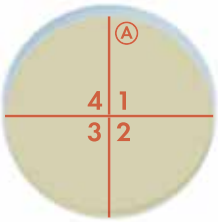
Cultivating bacteria

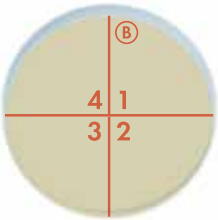
YOU WILL NEED

→ agar dishes from Experiment 19
→ *permanent marker*
→ *plastic wrap*
→ *paper*
→ *pen*

HERE'S HOW

1. In order to know later on which bacteria we have in which parts of the dishes, we must divide each dish into quarters. Do this by drawing a cross on the outside of the dish's bottom. Write a number in each quarter of the dish, from one to four. Finally, give one dish the letter A, and the other dish the letter B.





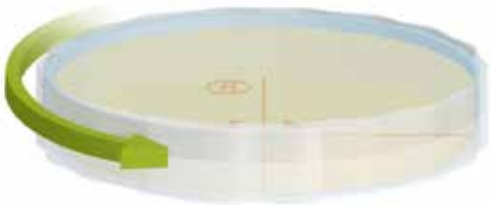
2. Now we will introduce a bacteria sample into each quarter. Think about where bacteria might be found and where to take a sample from. Here are a few ideas:
   • Probe between your teeth with a toothpick and then carefully wipe the toothpick on the agar in the dish.
   • Dab the agar with the corner of a kitchen sponge that you use to wash dishes.
   • Lightly press your fingertip onto the surface of the agar.
   You will certainly be able to come up with more ideas. The important thing is to remove the lid only briefly, so that as few germs as possible get inside. Even the air is full of bacteria.

3. When you are done, seal both dishes with a strip of plastic wrap wound around the edge of the dish.

4. Place the dishes in a quiet, room-temperature location.

5. Draw up a table in which you can write down what you put in each area. It is best to create a weekly schedule into which you can make an entry every 24 hours indicating what you see. Also note what the bacteria look like and how much has grown.

Be absolutely sure to leave the dishes closed!



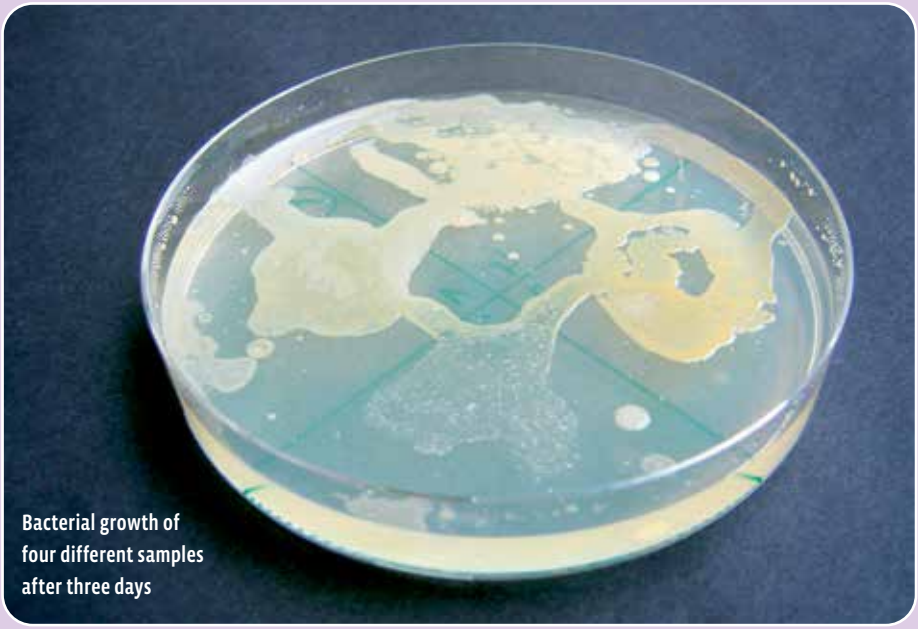
EXPERIMENT 20

→ WHAT'S HAPPENING?

As if by magic, here and there on the dishes you will see mostly yellowish, round colonies growing, which will probably spread out more with every day that passes. Even in places where you may have applied only a few individual bacteria, they will multiply so quickly that they become visible to the eye. After a week at the most, the dishes will probably be filled with bacterial growth, and it will be time to toss them into the garbage. Do not open them.

When you are finished, you can draw your conclusions: From which samples were you able to cultivate the greatest number of bacteria the most quickly?

It's their lightning-fast reproductive abilities, which you just witnessed, that make bacteria so interesting for genetic engineering. Today, many medicines are produced from bacteria, as well as many ingredients for foods. Genetic engineers introduce a desired gene into a single bacterium, which automatically multiplies in an appropriate culture medium, and soon trillions of bacteria are producing the desired substance, which can then be extracted from the medium again and purified. Almost 4% of all medicines on the market are produced by genetic engineering. In the future, it will probably be a lot more.



Bacterial growth of four different samples after three days

CHECK IT OUT

Genetic Engineering with Food...

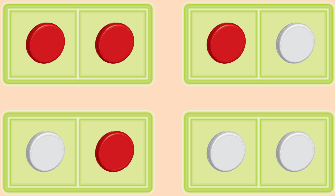
Since 1996, genetically modified food plants have gained entry into supermarkets. Worldwide, more and more plants are being developed that researchers are making resistant to pesticides or pests by means of genetic engineering. For example, there are corn plants being grown with a genetic resistance to insect pests. In cases such as this, the plants have genes that originally come from bacteria.

The use of genetic engineering in foods is a matter of serious controversy around the world. Many people simply don't want genes to be exchanged in this way between different species. Scientists are researching both the applications of genetic engineering to various fields as well as the possible risks of this technology. In some countries, genetically modified foods have to be specifically identified on their labels, but yet not in the United States.

...and Medicine

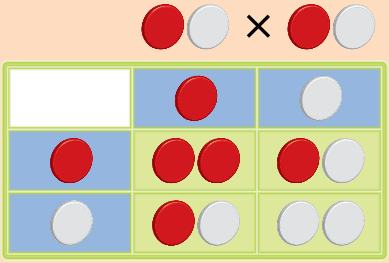
Since 1990, there have been ongoing experiments to develop therapies that supply an intact copy of a certain gene to people who have an illness due to the lack of the gene. The compelling idea is to address genetic illnesses right at their source. So far successes have been rare. It has been possible to help patients only in a few specific cases, and even then only temporarily.

EXPERIMENT 7 (PAGE 14):



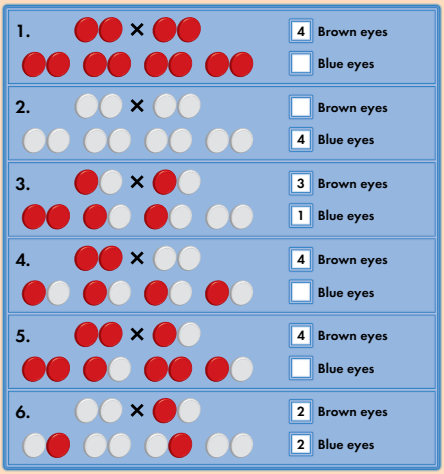
There are three possible combinations, because red/white and white/red are the same.

EXPERIMENT 8 (PAGE 16):



From red/white and white/red parents, all possible combinations will result: red/red, red/white, white/red, white/white. However, only the white/white child will have white flowers.

EXPERIMENT 9 (PAGE 18): INHERITANCE WORKSHEET



EXPERIMENT 17 (PAGE 34):

AAA	TAA	GAA	CAA
AAT	TAT	GAT	CAT
AAG	TAG	GAG	CAG
AAC	TAC	GAC	CAC
ATA	TTA	GTA	CTA
ATT	TTT	GTT	CTT
ATG	TTG	GTG	CTG
ATC	TTC	GTC	CTC
AGA	TGA	GGA	CGA
AGT	TGT	GGT	CGT
AGG	TGG	GGG	CGG
AGC	TGC	GGC	CGC
ACA	TCA	GCA	CCA
ACT	TCT	GCT	CCT
ACG	TCG	GCG	CCG
ACC	TCC	GCC	CCC

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First Aid Information

Important: In case of injury, always seek medical help.

When conducting experiments with chemicals:

→ In case of eye contact: Wash out eye with plenty of water, holding eye open if necessary. Rinse from the nose outward. Seek immediate medical advice.

→ If swallowed: Wash out mouth with water, and drink some fresh water. Do not induce vomiting. Seek immediate medical advice.

→ In case of inhalation: Move person into fresh air, for example, into another room with open windows or outside.

→ In case of skin contact and burns: Wash affected area with plenty of water for five minutes. Cover burns with a bandage. Never apply oil, powder, or flour to the wound. Do not lance blisters. For larger burns, seek immediate medical help.

→ In case of cuts: Do not touch or rinse with water. Do not apply any ointments, powders, or the like. Dress the wound with a germ-free, dry first-aid bandage. Foreign objects such as glass splinters should only be removed from the wound by a doctor. Seek the advice of a doctor if you feel a sharp or throbbing pain.

→ When in doubt, seek medical advice without delay. For accidents involving chemicals, always take the chemical with its container to the doctor or tell the doctor the name of the chemical.

In case of emergency, contact the United States Poison Control Center at

1-800-222-1222

Record the telephone number of your local hospital or poison center here:

665007-03-171220