EASY EXPERIMENTS TO UNDERSTAND A COMPLICATED EARTH

1. ATMOSPHERIC PRESSURE AND FALLING BODIES

Susana A. Alaniz Álvarez and Ángel F. Nieto Samaniego

Illustrated by Luis D. Morán

Translated by Ma. Elena Delgado Ponce de León

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Introduction

The place Homo sapiens occupies in the history of the Earth can be considered very, very small because our species has only been around for the last 200,000 years out of the 4,500 million years the Earth has existed. Besides, Homo sapiens, who is less than 2 meters tall, has been living on the superficial layer of a planet with a radius of more than 6380 km of a solid-liquid layer and under a layer of almost 120 km of atmosphere. Nevertheless, we humans have insisted on learning about our planet in depth, calculating or estimating the value of its physical attributes: mass, volume, density, temperature, pressure, etc., which are well beyond the limits of our senses.

So one could ask, why does this insignificant creature know so much about the nature of his planet and what drives him to untangle the laws that govern it? A possible answer could be: - it is the result of the curiosity of some who dared to visualize beyond the horizon. One of those people was, without a doubt, Galileo Galilei.

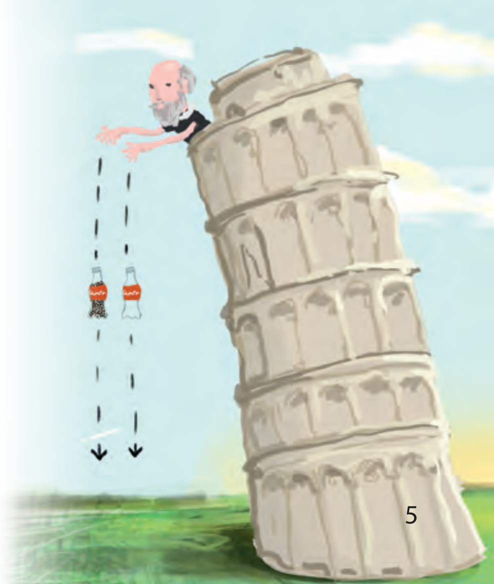
Galileo Galilei (1564-1642)

A large part of our understanding of classical Physics is thanks to the works of Galileo Galilei. He is considered the father of experimental science. A Math professor born in Pisa, Italy, he was the first son of a virtuoso lute musician. Galileo´s main interest was not limited to asking how the movement of the Earth worked, but also about how the solar system functioned. His fame is due to the phrase ¨and yet it moves,¨ that supposedly he said before a jury of the Inquisition.

Whether he said it or not, what we do know is that he discovered (during a mass ceremony), why a pendulum moves by observing the oscillations of a lamp in the cathedral of Pisa and by measuring the time with his pulse. During the XVII century, there were no measuring systems like the ones we have now, but he managed to time his experiments nonetheless, first with his pulse, and then with the pendulum. He also measured time with the amount of water dropping from a graduated cylinder and used a melody he played in the lute to register in the music sheet how far he had made it.

He managed to study the sky and design a telescope capable of magnifying normal vision by eight times. With this instrument, he discovered the craters of the moon, sunspots, the ring of Saturn and the moons of Jupiter. He also realized that Copernicus was right and that the Earth revolved around the sun, but unlike Copernicus, Galileo published his breakthrough finding. This caused him a lot of problems with the Catholic church and great sorrow in his successful life.

Galileo's brilliance consisted, among many things, in measuring space and time; with these measurements he was able to establish the mathematical formulas that describe movement, from falling objects in the Pisa tower to Jupiter´s displacement.



Experiment with ..... presence of air

1. IS THE BOTTLE EMPTY?

Do you realize that air exists even if we cannot see it? And that you breathe it through your mouth and nose?

MATERIALS

1 plastic bottle
1 balloon
2 containers
hot water
cold water (with ice)

WHAT TO DO

1. Stretch the balloon to cover the top of the bottle.
2. Fill one of the containers with hot water and the other with cold water.
3. Place the bottle inside one of the containers and then put it inside the other container.

WHAT HAPPENED?

In one of the containers the balloon expands and in the other it deflates.

• **Variations**

* Place the bottle with the balloon in the freezer.
* Do the same experiment with a soda bottle.

The experiment may fail if there is an air leak between the balloon and the bottle or if the change in temperature is not drastic enough to change the volume of air inside the bottle.

EXPLAIN IT

Air is a gas, and like all gases, it expands with the increase of temperature and takes up more space.
On the contrary, when it is cold it contracts and takes up less space. Notice that it is the same amount of air.

EXAMPLES IN EVERYDAY LIFE

Hot air balloons fly because hot air expands until it weighs less than the air around it.

Scuba divers can breathe underwater thanks to the compressed air in the tank. This means there is a lot of air in a small space.

Charles and Gay-Lussac law: "The volume of a gas is directly proportionally to the temperature at a constant pressure"

DO YOU WANT TO KNOW MORE?

Gases can change their volume due to a change in temperature or pressure. As the temperature increases and the pressure decreases, gases expand.

OBSERVE IT IN NATURE

The atmosphere

The atmosphere is the covering of gas that surrounds the planet. It is mainly a mixture of gases that we call air.

The temperature of the air diminishes with altitude at a rate of 6.5 degrees centigrade per 1000 m; if we consider that the average temperature at sea level is 20 degrees centigrade, we can conclude that we reach the freezing point of water at 3000 m above sea level.

The atmosphere is composed of approximately 78% nitrogen, 21% oxygen and 1% other gases. To these components we need to add the water vapor that may vary between 0% and 5% of the total amount. As water vapor increases, the amount of the other gases diminishes proportionally.

Gay- Lussac's law on the expansion of gases: ¨The pressure of a gas is linked to temperature and it is independent of the nature of the gas¨.

Experiment with the holding capacity of air

2. THE GLASS THAT DOES NOT SPILL WATER

Have you noticed that your glass of milk empties when you turn it upside down?
Does this mean we are at the bottom of a sea of air?

MATERIALS

1 glass with water
1 piece of paper

WHAT TO DO

1. Cover the glass of water with a piece of paper bigger than the opening. Moisten the paper around the rim.
2. Place one hand on the paper and turn it upside down; take away your hand holding the paper but keep holding the glass.

Watch!!!

It may be a good idea to try this out in the patio in case it does not work.

WHAT HAPPENED?

The water stays in the glass even if the glass is upside down, or if the glass is full or half full.

Variations:

* Place a straw in a glass of water and cover the top of the straw with your finger. Take out the straw and you will see the water does not drop until you take your finger away from the top of it.

The experiment may fail if air gets into the glass.

EXPLAIN IT

The air close to the surface of the Earth has a layer on top several kilometers high known as atmosphere. The closer you live to the sea, the thicker this layer is. This layer of air pushes in all directions, even upwards, which is why the air is trapped inside the glass and the water does not drop. The air is stronger than the weight of the water.

EXAMPLES IN EVERYDAY LIFE

When babies drink from a baby bottle, the bottle must have an air opening for the milk to come out when the baby sucks.

Cans containing liquids must have two openings, one to allow air in and the other for the liquid to go out.

Height (m)		Pressure (atmospheres)	Pressure (millibars)
0	At sea level	1	1013
1000			89 836
2000	Mexico city	.78	794.8
3000	La Paz, Bolivia	.70	700.9
4000		.61	616.2
5000	Top of the Popocatepetl	.53	540
10 000	Height of the transatlantic flights	.26	264.1
15 000		.12	120.3

DO YOU WANT TO KNOW MORE?

Atmospheric pressure

The atmosphere is composed of several layers. Air, like any other material, has weight, not much but it does weigh. The weight of the column of air that is above us exerts pressure in all directions. The layer of the atmosphere close to the surface of the Earth is called the troposphere. It is 9 km thick at the poles and 18 km thick at the Equator. It has been calculated that the weight of air is 0.0001 “kilo” per liter (1 liter is the same as 1 cubic decimeter). You can compare that value to the weight of water, which is 1 kilo per liter, or with that of an average rock which is 2.3 kilos or with the human body which is 0.95 kilos for the same volume (very close to that of water). The weight of the column of air will produce a much higher pressure at sea level than way up in the mountains.

* Note: In everyday language we measure weight in ¨kilograms¨ and it is indicated with a number on a scale. In technical language, weight must be given in units of force (kilogram-force or gram-force).

Experiment with... change in the volume of air

3. THE CANDLE THAT PUSHES WATER UP

Have you noticed? The water surface in a vessel (whether in an inclined glass or in a lake) is always horizontal.

MATERIALS

A candle
a transparent glass
3 coins
deep dish with water

WHAT TO DO

1. Glue the candle with its own wax to the center of the dish
2. Place some water in the dish, about 3 centimeters high, place the coins on which the glass will rest.
3. Light the candle and place the glass upside down on the coins, cover the candle making sure water can get in the glass.

WHAT HAPPENED?

The candle light extinguishes a few seconds after you cover it with the glass and the water level rises inside the glass.

EXPLAIN IT

The candle light goes out when there is no more oxygen. During combustion, the existing oxygen is consumed and the carbon is released from the candle turning into carbon dioxide. Once it cools, the air with carbon dioxide has a lower pressure allowing water to flow.

EXAMPLES IN EVERYDAY LIFE

You can stop combustion if you isolate a burning item; for example, you can cover the burning item with a wool blanket. You may have seen how some healers cure people by placing a lit candle on the back of the sick person and a glass on top. The skin is pulled when the candle light goes out. This is a very impressive physical phenomenon.

OBSERVE IT IN NATURE

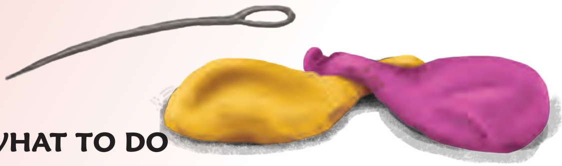
Winds and sea currents

There are many factors that influence the movement of fluids (like air and water). Among these are changes in temperature and in pressure. Hot fluids tend to rise and displace cold fluids which in turn tend to drop. Air flows from areas with more pressure to low pressure areas giving way to winds and sea currents.

4. HOW TO PIERCE A BALLOON WITHOUT BURSTING IT

MATERIALS

1 Pin or pointed toothpick
2 balloons



WHAT TO DO

1. Inflate some balloons. Find the middle part and pierce through one of them.
2. Now pierce another balloon through any of its ends.

Watch!!!

WHAT HAPPENED?

1,2: When you pierce the balloon through the middle part it bursts.

3,4: When you pierce the balloon on either end nothing seems to happen. If you get close, you will notice the air is escaping slowly through the hole you made with the pin.

If you inflate the balloon a lot, it will burst even if you prick it through the ends, also if the balloon is not very inflated it may not burst even if you prick it through the middle part.

EXPLAIN IT

The air you blow into a balloon makes it stretch unevenly. The air inside the balloon is pushing in all directions, and the more air the balloon has, the higher the pressure there will be. When you pierce the balloon through the middle part, the material is very stretched, close to its limit, whereas on the ends, the material is still very strong.

EXAMPLES IN EVERYDAY LIFE

When a material expands and returns to its original form without changing shape, it is known as elastic deformation, like that of an elastic band. Balls bounce because when they hit the ground they change form and when their original shape is restored they are pushed in the opposite direction.

When we have an earthquake, the surface of the Earth suffers an elastic deformation. The movement you feel is due to a momentary change in shape caused by the seismic waves.

OBSERVE IT NATURE

Air density

In the atmosphere, pressure, temperature and density are inversely proportional to height. The higher you go, the less pressure there is, as well as a lower temperature and less density.

On the Earth's crust, pressure, temperature and density are inversely proportional to depth. The deeper you go, the greater the temperature, pressure and density will be.

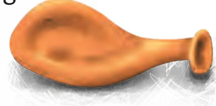
With this experiment you can see that with the same amount of air, balloons can inflate more or less depending on the resistance of the material. Air could have a higher density (mass/volume) in a more resistant balloon. Inside the balloon, the air pressure will be the same in all directions and will be at a steady temperature.

Boyle´s law: ¨At a constant temperature, the volume of a gas is inversely proportional to the pressure exerted”.

Experiment with… pressure transmission

5. HOW TO SINK AN EMPTY DROPPER

Have you ever wondered why steel vessels float on water? Have you noticed that you float or sink in water depending on the amount of air in your lungs?



MATERIALS

1 A transparent jar
1 dropper (or the cap of a ballpoint pen or a transparent straw with play-doh)
1 balloon
A pair of scissors

WHAT TO DO

1. Fill the jar with water, then put the dropper in and stretch the balloon so that you can cover the top of the jar (you can cut the top of the balloon to adapt to the size of the jar opening).
2. Press the balloon downwards and watch the dropper fill with water. If you want the dropper to sink more, put some water in the dropper before you place it inside the jar.

Watch!!!

WHAT HAPPENED?

When you push the balloon downwards, the air inside the jar pushes the water inside the dropper.

If the dropper has water, it will weigh more than when it has only air, and it will be more inclined.

When the water gets into the dropper, it may sink.

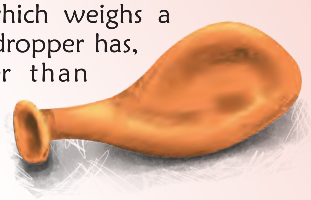
If you are using a plastic dropper, it will not sink because the total weight of the plastic + water is still less than the water that occupies that same volume.

EXPLAIN IT

This experiment uses two principles, Pascal's principle: ¨Liquids transmit pressure with the same intensity in all directions¨ and Archimedes´ principle: ¨A body immersed in a fluid experiences a vertical upward force equal to the weight of the fluid that the body displaces".

When you push the lid of the jar downwards, the air inside the jar pushes the water into the dropper. When you release the pressure on the lid, the air expands and the water comes out of the dropper.

The dropper floats because it contains air, which weighs a thousand times less than water. The more air the dropper has, the lighter it will be. Lighter objects float higher than heavy objects.



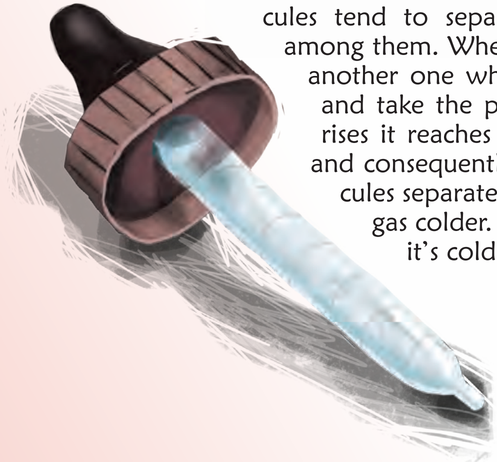
EXAMPLES IN EVERYDAY LIFE

The hydraulic brake in cars, the hydraulic car jack and the hydraulic press are excellent and valuable applications of Pascal's principle.

Although ships are made of steel or other heavy materials, they float because the space they occupy in the water contains a lot of air following Archimedes' principle.

The containers used for ketchup, creams and shampoo are made of a flexible and thin plastic so that when you squeeze them, the liquid is pushed out.

OBSERVE IT IN NATURE



Hot air tends to rise. When air temperature rises, molecules tend to separate and there is more space among them. When an air mass rises, it substitutes another one which, if colder, will come down and take the place of the first one. When air rises it reaches a layer which has less pressure and consequently the air expands. When molecules separate, they deploy energy that makes gas colder. This is why up in the mountains it's colder even though hot air rises.

Experiment with... air resistance

6. I BELIEVE YOU CAN FLY

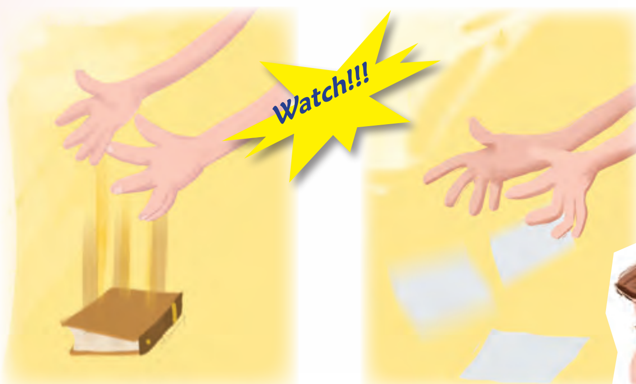
Heavy objects sometimes fall faster than lighter ones. Why does this sometimes happen?

MATERIALS

1 Book
1 sheet of paper

WHAT TO DO

Hold the book and the sheet of paper side by side and simultaneously drop them.



Now do it again but place the sheet of paper on top of the book and drop them.

WHAT HAPPENED?

You will probably see that the book falls much faster than the sheet of paper.
But when the sheet of paper is on top of the book, they fall at the same time.
Nothing can go wrong in such a simple experiment.

EXPLAIN IT

In the second step, the book is heavier and it eliminates the air resistance while in the case of the sheet of paper, the air resistance pushes the paper up, slowing its fall. In step 4, the book blocks the air resistance against the sheet of paper and consequently they both fall at the same time.

EXAMPLES IN EVERYDAY LIFE

You have probably observed that some things can fly, for example birds and planes, while others are suspended in the sky like dust, skydivers and clouds. Both items in each category can fly or be suspended thanks to the support of the air. Although the mechanics of a flying plane can be complicated, you can simulate the force of air against a plane by holding your hand out of a car window when the car is in motion (be careful!). You will see that if your hand takes the shape of the wing of a plane and you incline it upwards, the wind (air in motion) will push your hand downwards.

DO YOU WANT TO KNOW MORE?

The law of gravity vs air resistance:

There are two factors that affect the fall of objects. Of them, the most important is gravity. The other is air resistance which depends on:

* Velocity (the faster an object moves through the air, the more air resistance there will be).
* The shape of the object (the bigger the surface, the higher the block of air it has to move through, thus increasing the resistance.
* The contrast of densities between the air and the object (if the object is very light, it will be suspended in the air).

Experiment as Galileo

7. FALLING DOWN

Did you notice? In the scene broadcasted from the Moon by Apollo 15 you could see an astronaut dropping a feather and hammer and both falling at the same time. Now, prove here on Earth that two objects with different weights can fall at the same speed.

MATERIALS

2 plastic bottles
sand, beans or any other material that can make the bottle weigh more.

WHAT TO DO

1. Fill one of the bottles with sand or any other material and leave the other bottle empty.
2. Drop the bottles at the same time from a second floor.

Look for a soft surface (for example a box) to stop the bottles from breaking. You can use them several times with different weights.

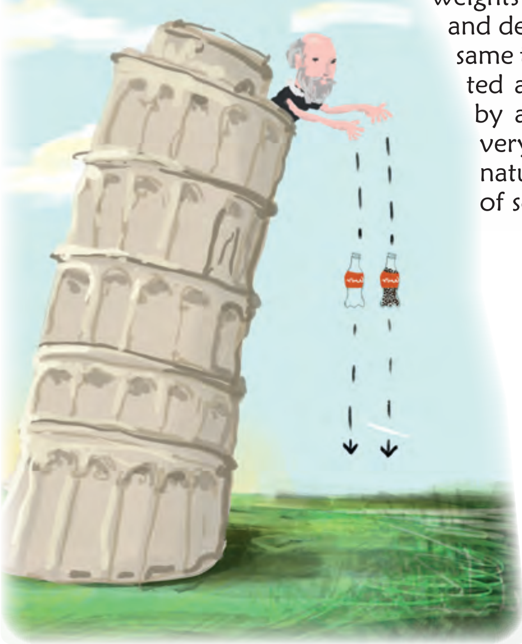
WHAT HAPPENED?

Both bottles land at the same time even if they have different weights.

It may fail if one of the bottles is too light or the surface is flat. Air resistance may diminish the speed of the fall.

THIS EXPERIMENT IN HISTORY

Before the XVI century it was believed that heavier objects fell more rapidly than lighter objects, as Aristotle had claimed 19 centuries earlier. Galileo Galilei, a Math professor at Pisa University, questioned those beliefs. He dropped two objects with different weights from the leaning tower of Pisa and demonstrated that they fell at the same time. This experiment was selected as the most beautiful in history by a group of physicists because a very simple exercise proved that nature has the last word in matters of science.



Experiment with the law of gravity

8. WHICH ONE FALLS FIRST?

Have you noticed that there is a strong attraction hidden inside the Earth that makes everything stick to the floor? No matter how high you jump you always come back to Earth. This force is known as gravity.

MATERIALS

2 marbles, lemons or balls the size of a lemon. The two objects must have the same shape and weight.

WHAT TO DO

1. Hold the two objects in your hand between your index finger and your thumb, making sure the palm of your hand is facing down.
2. With the other hand, hit one of the objects; the blow has to be horizontal to make the object fly to the front.

WHAT HAPPENED?

The moment you separate both objects, one of them falls vertically and the other falls to the front. Both fall at the same time although one of them travels a longer distance.

This experiment will fail if one of the objects does not fly horizontally.

EXPLAIN IT

There are two forces that control falling objects: the force of gravity and air resistance. If both objects are the same and air resistance is minimum, then only the force of gravity will have an impact on the amount of time it will take them to reach the ground, although one of them travels horizontally for a few seconds.

EXAMPLES IN EVERYDAY LIFE

Gravity is a very important force in our lives, we are pulled down to the ground because of it. The vertical line is that line perpendicular to the surface of the Earth in which you are standing. That is why it does not matter if you are standing in the Northern or Southern hemisphere, at the poles or at the Equator--the sky will always be above you when you are standing.

DO YOU WANT TO KNOW MORE?

The Law of Gravity

Gravity is the force of attraction towards the Earth that objects experience. The force of attraction between two objects, M^1 and M^2 is directly proportional to the mass and inversely proportional to the square of the distance, R, that separates them.

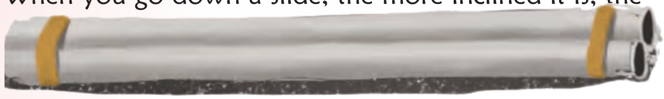
The gravitational force, which we call ¨weight,¨ is present in our everyday life since it is the one that pulls us down to Earth. You have probably realized that the mass of the planet is much higher than that of any object around us and that the distance to the center of the Earth is the same for any object. In this way, the gravity pull is maximum on the surface. It diminishes, naturally, the farther away from the planet because it increases the distance between the masses involved. However, it also decreases towards the interior of the Earth, because a bigger portion of the planet remains ¨on top¨ and there is less mass ¨under¨.

In the center of the Earth, there is a huge amount of pressure due to the weight of the entire planet, but gravity is zero, like in outer space.

Experiment with an inclined plane

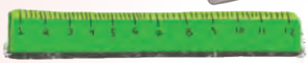
9. AT THE PLAYGROUND SLIDE

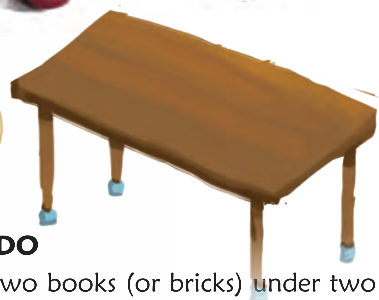
Have you noticed? When you go down a slide, the more inclined it is, the faster you go.



MATERIALS

2 pieces of PVC tubes 2 meters long
5 marbles
1 ruler
1 marker
1 table
2 books of equal width, wooden blocks or bricks





WHAT TO DO

1. Place the two books (or bricks) under two legs of the table to incline it.
2. Place the two tubes parallel to each other, fixed to the table with adhesive tape.
3. Put a mark on the tubes every 30 centimeters.
4. Place a marble on the highest part of the tubes and release it, check that it rolls to the floor.
5. Take the time (from the beginning to each mark) with a chronometer and record it on a table similar to the one on the opposite page.

Repeat the procedure several times.

WHAT HAPPENED?

When the marble starts rolling downwards, the time it takes between each mark is shorter, that is the marble rolls faster traveling the same distance in a shorter time. The change in velocity is called acceleration.

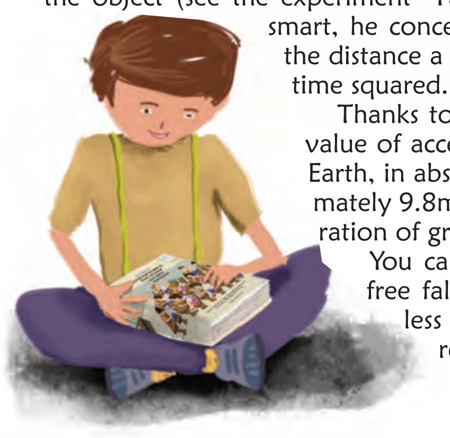
Table

	TIME 1	TIME 2	TIME 3	TIME 4	TIME 5	Difference of time between consecut-ive distances
30 cm						
60 cm						
90 cm						
120 cm						
150 cm						
180 cm						
210 cm						

THIS EXPERIMENT IN HISTORY

Galileo was trying to understand how bodies behave when falling, but the movement was very fast: An object took one second (more or less) to fall from a height of 10 meters. That is why he designed an experiment: he would have an object roll in an inclined plane, the less inclined the plane, the longer it would take the object to get to the end point and he would be able to measure time with more accuracy.

With a similar experiment, Galileo discovered that the speed changes with time and that the acceleration has nothing to do with the weight of the object (see the experiment "Falling Down"). Since he was very smart, he conceived it in mathematical language: the distance a body travels is proportional to the time squared.



Thanks to Newton, we now know that the value of acceleration for free-falling objects on Earth, in absence of air, has a value of approximately 9.8m/s², which is known as the ¨acceleration of gravity¨.

You can visualize it by observing that in free fall, the same distance is traveled in less time or that more distance is covered in the same amount of time.

APPENDIX

This explanation is just for adults or for very smart kids

To finish this book, let´s theoretically prove that the falling speed is independent of how much the object weighs. So, we are going to use three concepts: acceleration of gravity, the law of universal gravity and Newton's second law.

A)
Galileo demonstrated that the distance a body travels when falling is proportional to the square of time; for example, an object will travel four times the distance in twice the time. This acceleration is due to gravity.

B)
Seventy years after Galileo's experiments in the Pisa tower, Newton proposed the laws of universal gravitational. He established that the force of attraction between two bodies is explained with the equation:

$$F=GM_1M_2/R^2 \qquad (1)$$

where G is the universal gravitational constant (it is the same for everybody), F is the force of attraction force between two objects with mass M1 and M2, separated by distance R. In the human and Earth case, F is Earth's gravitational pull (attraction) on mass M1 in relation to an individual of mass M2 and R is the distance between the center of gravity of both bodies. That is, R is the distance between the center of the Earth and the center of the individual close to the belly.

C)
On the other hand, Newton formulated his second law of movement, in which he established that the acceleration of an object is directly proportional to the net force acting upon it and inversely proportional to its mass, that is:

$$a= F/M_2 \text{.... or .....} F= aM_2 \qquad (2)$$

When the initial velocity is zero, we can obtain the final speed by multiplying acceleration and time.

$$v= at \qquad (3)$$

If we take F as the same pull force of the Earth on an individual, then in equation (2), a is the acceleration of gravity and in (3) v is the falling speed, or velocity. Then F in the equations (1) and (2) is the same and we can write:

$$GM_1\, M_2/ R^2 = aM_2 \qquad (4)$$

In the equation (4) M2 is eliminated and if we substitute (3) and we clear the speed, we can demonstrate that in the equation that determines the falling speed (v) the mass of the individual is not involved:

$$v= at= tGM_1/ R^2$$

ACKNOWLEDGEMENTS

The idea of writing a booklet on scientific experiments came about after reading Manuel Lozano´s book called ¨From Archimedes to Einstein, in which the author proposes a way to carry out at home the 10 most beautiful experiments in history. With this idea in mind, we wanted to do not a book but many booklets.

The experiments included in this booklet are intended to demonstrate the importance of Galileo Galilei´s experiments: ¨The falling bodies¨ and ¨The inclined planes¨ for the concept of gravity, pointing to all the physics principles involved and how they apply to nature.

We want to thank Yuria and Emilia Cruz for their contributions to the idea of writing this book. PhDs Susana Orozco, Gerardo Carmona and Rosalba Fuentes examined the content to make sure it was accurate and it could be reproduced. The booklet was designed by J. Jesús Silva and Federico Cruz and Timothy F. Lawton kindly reviewed this English version.

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Special Edition for the Escuela Nacional Preparatoria UNAM

The collection of booklets entitled “Easy experiments to understand a complicated Earth” is based on the list of the most beautiful experiments published by Physics World magazine in September 2002. These experiments were chosen for their simplicity, elegance and the transformation they caused in the scientific thought of their time.
Each issue of this collection is dedicated to one of those experiments. Our purpose is to make you understand, through experimentation, phenomena that occur both in our daily lives and on our planet.

The complete collection can be downloaded from the website:
http://www.geociencias.unam.mx

This issue is dedicated to Galileo´s experiment on falling objects.