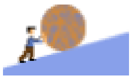
THE FORCE OF GRAVITY

 By looking at phenomena known to everyone, like the motion of bodies in free fall, or object's weight, we will understand the general notion of gravitational field.

We will then try to use this notion to explain more complex phenomena, like tides, the orbit of satellites around the earth or the orbit of the planets around the sun.

Objectives of the teaching unit

* To understand the laws of free fall.

* To differentiate the mass and the weight of a body.

* To understand the meaning of field strength.

* To understand that the earth's gravity does not have a constant value.

* To make simple calculations about the value of g, the weight of bodies or the movement of satellites.

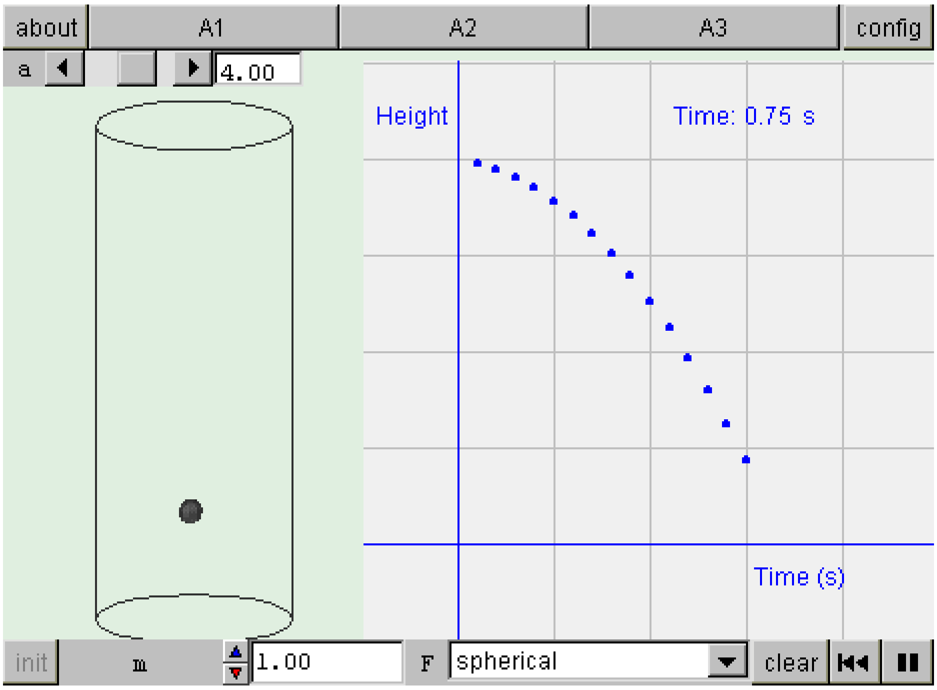
* To explain phenomona like the tides or planetary movement in the solar system.

Free fall in a vacuum.

Aristoteles stated that all bodies fall to the earth with a velocity which is proportional to their weight. In the following visual we can find out if he was right or not. This is something mankind took 2000 years to prove!

When Galileo did this experiment, modern Physics was born as a science in which statements, however reasonable they may seem, are not considered true until they are verified.

The experiment is supposed to be performed in a receptacle containing a vacuum, so that the air does not interfere with the results. Later on we will compare these results with the ones obtained in free fall in the atmosphere.



A1: We drop spherical bodies with different masses from the same height. What can we deduce from the observation of their movement and the time it takes them to hit the ground?

A2: We drop objects of the same mass but different shapes from the same height. What can we deduce from the observation of their movement and the time it takes them to hit the ground?

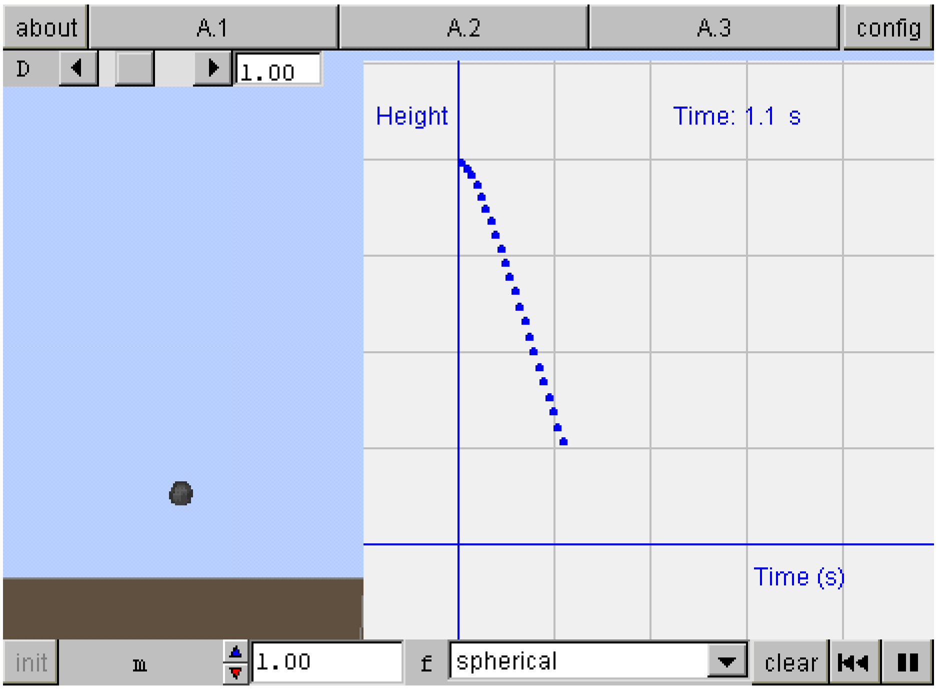
A3: According to your previous experiments, how does the mass or the shape of a body influence its free fall in a vacuum? Try changing the mass and shape of the body a few times to make sure that your conclusion is right.

Free fall in the air.

The fall of a body through the air shows different characteristics from that of a fall in a vacuum. These differences are what deceived us for so long about the way in which free fall occurs.

You can study this phenomenon in the following visual which simulates an object falling from a height of about 4 m.

By following the activities suggested by the visual you can discover the different properties of the body and the environment which influence a falling body in our atmosphere. You will also easily be able to deduce in which cases falling in the air and in a vacuum show a similar behaviour.



A1: Drop bodies of different mass but the same shape. Make a note of the free fall time. What conclusions can you draw from these observations?

A2: Without changing the value of the mass, drop bodies of different shapes. Can you extract any relation between the free fall time and the shape? How are these results justified?

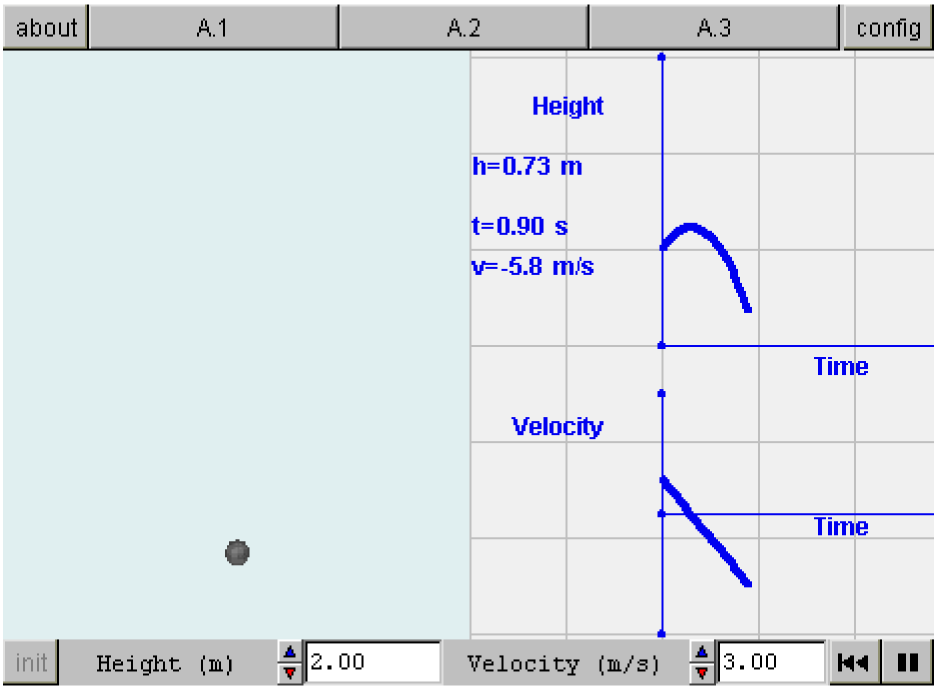
A3: Drop bodies of the same shape and mass. You must only change the density of the medium between experiments. How does the free fall time vary? What conclusions can you draw?

In this case, the body does not fall in a glass cylinder as we have not produced a vacuum. This is a normal fall in the atmosphere.

Free fall kinematics

Using the position-time and velocity-time graphs we can deduce the properties of the free fall. We will not only study the case where we let a body fall from rest; we will also take into account whether it has acquired a certain velocity both from ascending and from falling.

We will do this experiment for a vacuum, but the results are valid when the friction of the air is negligible; for example when a relatively heavy aerodynamic body falls from a low altitude.



A1: Drop the body from different heights, without an initial velocity, writing down the initial height and the free fall time t. Are the free fall times proportional to the initial heights? Are the speeds at which the body hits the ground proportional to the free fall time? With your data, calculate the acceleration of the freely falling bodies.

A2: Now throw the body upwards, always from the same initial height, with different speeds. What do the graphs that you get have in common? What is different? Do you see any relation between the moment at which the body reaches the highest point and its speed?

A3: Try to answer the following question: If we throw an object upwards with a certain velocity, and another towards the ground, from the same height and with the same speed, which of them will have a greater speed when they hit the ground. Why?

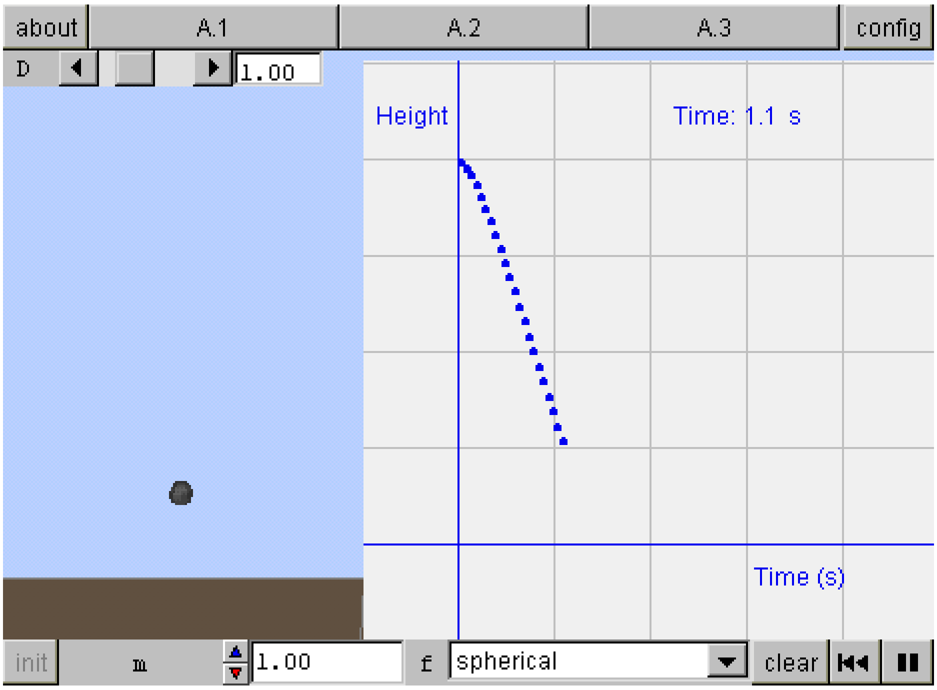
As this is a movement in a vacuum the shape or the mass of the object is not important.

Conclusions about falling bodies

The earth attracts all bodies left near it, so that::

· If the medium is a vacuum, the body falls to earth with a constant acceleration of 9.8 m/s2
· If the fall is through the air, there is resistance which depends on the shape of the body and the density of the air.
· When heavy aerodynamic bodies fall from a low height, the resistance of the air can be ignored.

We suggest that you investigate on your own the mistake that is made when the resistance of the air is ignored in the fall time of the heaviest body in each of the three shapes the experiment allows you to use.



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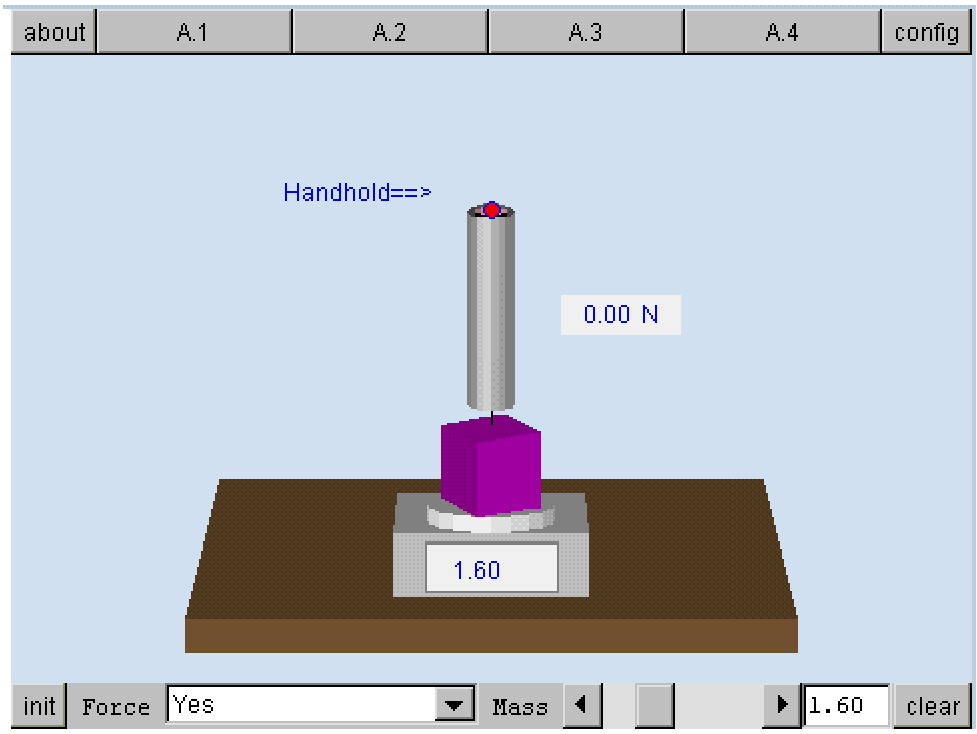
The weight of bodies



A1: Observe the cube in the visual. If it is under the influence of gravity, why isn`t it falling? Draw the visual in your copybook with the forces that act on the cube making it remain at rest.

A2: Use the option Force=Yes. With a 1 kg. cube increase the force to the dynamometer`s maximum. Why does it say 0 on the scales? Draw the forces acting on the cube.

A3: As you can see, the scales do not really measure the mass of the cube, they measure the force with which one pushes on the other. The dial measures this force in a unit known as kilopond. How many Newtons are there in a kilopond?

A4: Calculate, on your own, the force (in N) with which you have to pull the dynamometer so that the scales measure 1.5 kg if the mass of the cube is 2.2 Kg. Then verify it with the visual.

The acceleration of freely falling bodies is explained by the existence of a force directed towards the centre of our planet: weight.

This force is not apparent when the body is not free to fall.

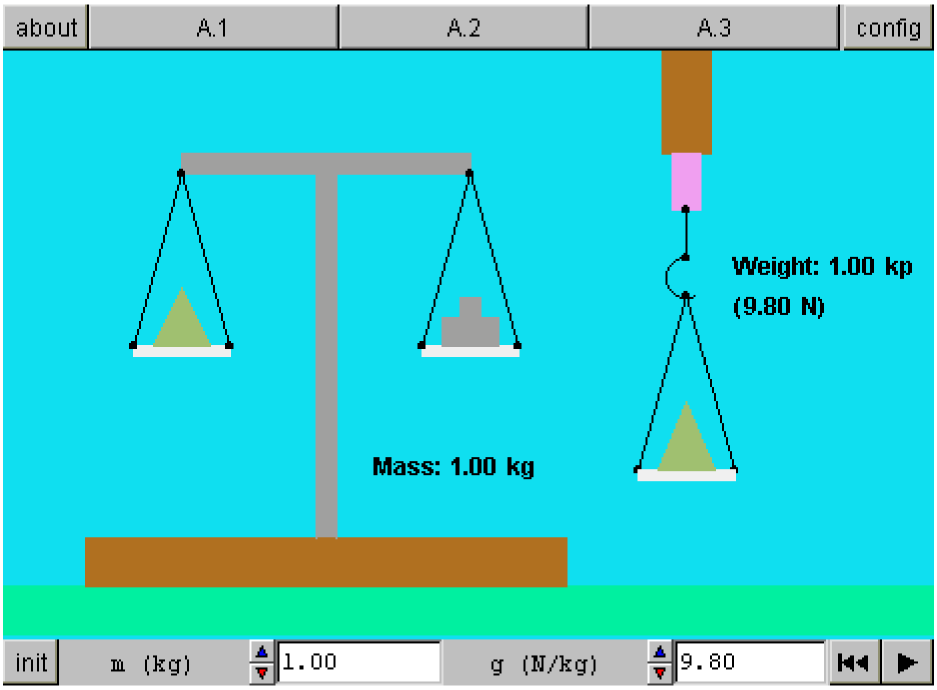
This is the phenomenon that we are studying in the visual.

Difference between mass and weight

Many people confuse the magnitudes of mass and weight, in spite of the fact that mass is a scalar magnitude (it is expressed with just a number) and weight is a vectorial magnitude (it has orientation and direction).

The reason for this confusion is the common use of a unit of force called a kilopond or kilogram weight, which is the force with which the earth attracts a kilogram of mass situated on its surface.

In the following visual we try to analyze this confusion and explain the different behaviour of a body's mass and its weight.



A1: Why is mass confused with weight? Without altering the value of g, change the value of the mass a few times. Note that weight is measured in two different units. Do you find any relation between the values?

A2: Try changing the value of the field strength. Does the mass of the body change? Does its weight change?

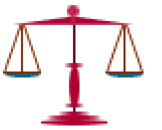
A3: How could you use this visual to calculate your weight, expressed in kiloponds, in different places: the moon (g=1.6 N/kg), Mars (g=3.8 N/kg)?

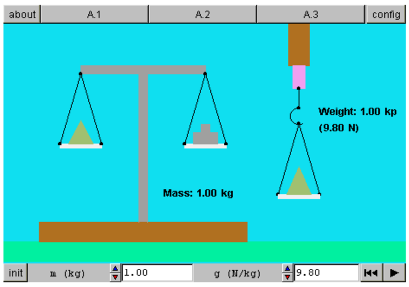
Conclusions about mass and weight of bodies

The mass of a body measures the quantity of matter that it contains, while the weight measures the force with which the planet attracts it.

The weight of a body is the force with which the planet attracts it. Its value is: **F=m·g** where **g is the intensity of gravity**, that is, the force experienced by the unit of mass.

Mass always has the same value, while weight depends on the value of g, which is not identical in all places.

	The scales measure mass, because on both sides the value of g is the same.
	The dynamometer measures force. If it is used to measure weight, it will give different values depending on the altitude of the place we are in or the planet we are on.



If you still don't understand the difference between mass and weight revise the experiment here.

A simple apparatus for measuring the intensity of gravity

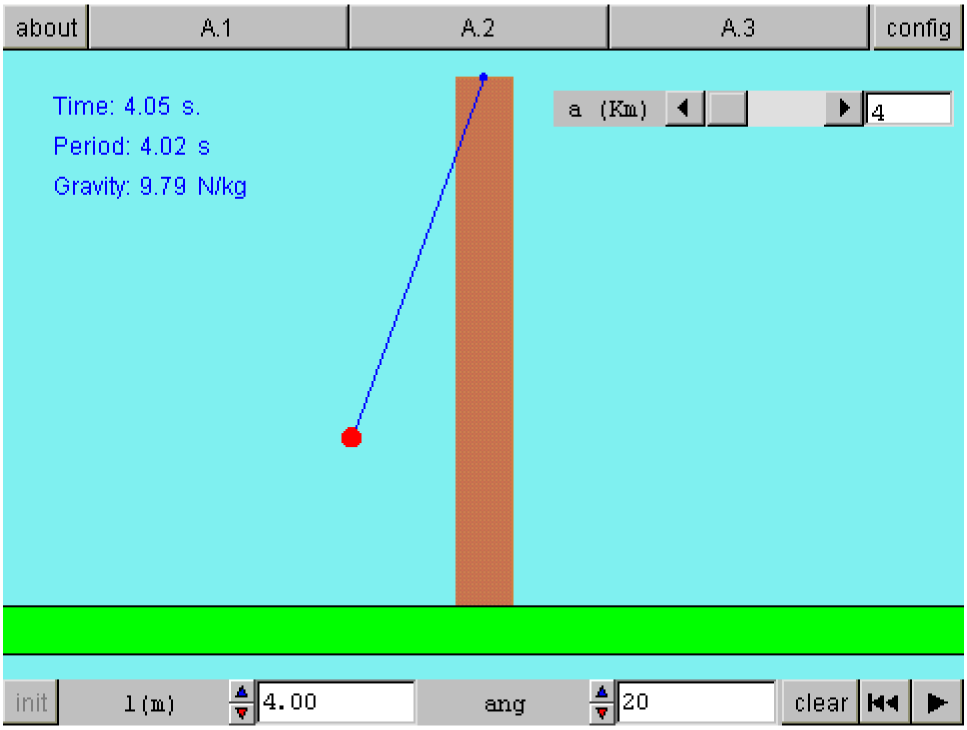
Measuring the intensity of gravity is not as simple as it may seem. If we try to measure it by letting a body fall and measuring its acceleration, the speed of the fall makes it difficult to take exact measurements. It is simpler to measure the weight of a body with a dynamometer, but dynamometers are not usually very exact either.

An instrument which is easy to use and is quite exact is a simple pendulum: a small heavy body (called a bob), hanging on a strong thread with little mass. We are going to see some of its properties below.

Although we are not going to demonstrate it in this course, you should know that the period of a pendulum obeys this expression:

$$T = 2\cdot\pi\sqrt{l/g}$$

where l is the length of the thread and g is local gravity.



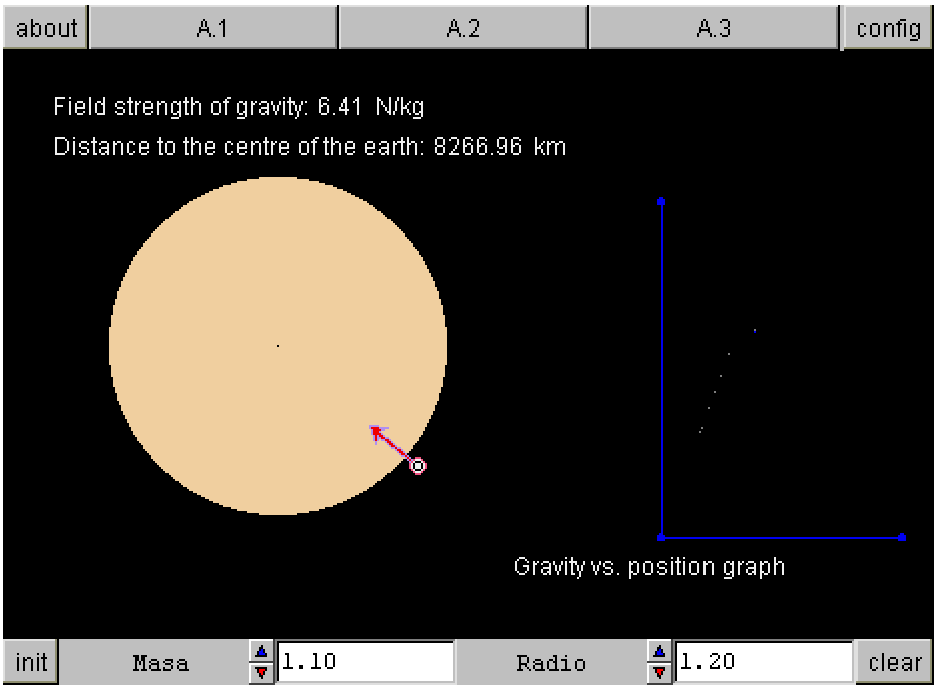
A1: Without changing the height of the place or the length of the string, take measurements of the period of the pendulum with different angles. How does the period vary? How about when we change the length of the string? Draw a data table with the lengths of the string and the periods that correspond to each length. Find a relation between these magnitudes.

A2: By applying the formula on the previous page, it is possible to measure the field strength anywhere on earth. It is particularly easy to check how it changes with height. Try changing the height of the place where the pendulum is. How does the period change? How does the value of g change?

A3: According to what we have seen, would a grandfather clock with a pendulum maintain its accuracy if it were taken to a very high place? How could we make it continue to work correctly? Calculate, for example, what we would have to do to make a grandfather clock work after it has been taken from sea level to the top of Mont Blanc (almost 5 km above sea level)

g is not a true constant.

In the previous section we have seen that g, the intensity of gravity, is not a true constant, as it changed with altitude. In the following visual you can see how its value varies in different points, even within the planet.



A1: Without changing the value of the observation point (on the surface of the planet), nor its radius, copy down the values of g for different values of the mass. What relation can you observe between the magnitudes?

A2: Without changing the observation point, give the planet`s radius values under one. What happens to the field strength of gravity? How about if we give the radius values greater than one? Formulate hypotheses that explain these results.

A3: Restore the initial values. Drag the observation point to different parts of the visual. In what direction does the vector g always point? How does it change as we move away from the planet? How does it change when we move into the planet?

Measuring the intensity of gravity

The intensity of gravity g is easy to measure with a pendulum and it is not equal in all places.

Gravity at the centre of the planet is nil and it increases linearly until it reaches the surface.

The value of g, away from the surface of the planet decreases with distance.

Although we are not going to demonstrate this, you should know that the value of g is determined by the law:

$$g = G\frac{M}{r^2}$$

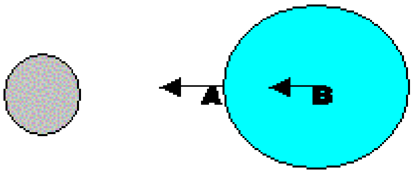
Where G is the universal gravitational constant, M is the mass of the planet and r the distance to the centre.

The force of the tides

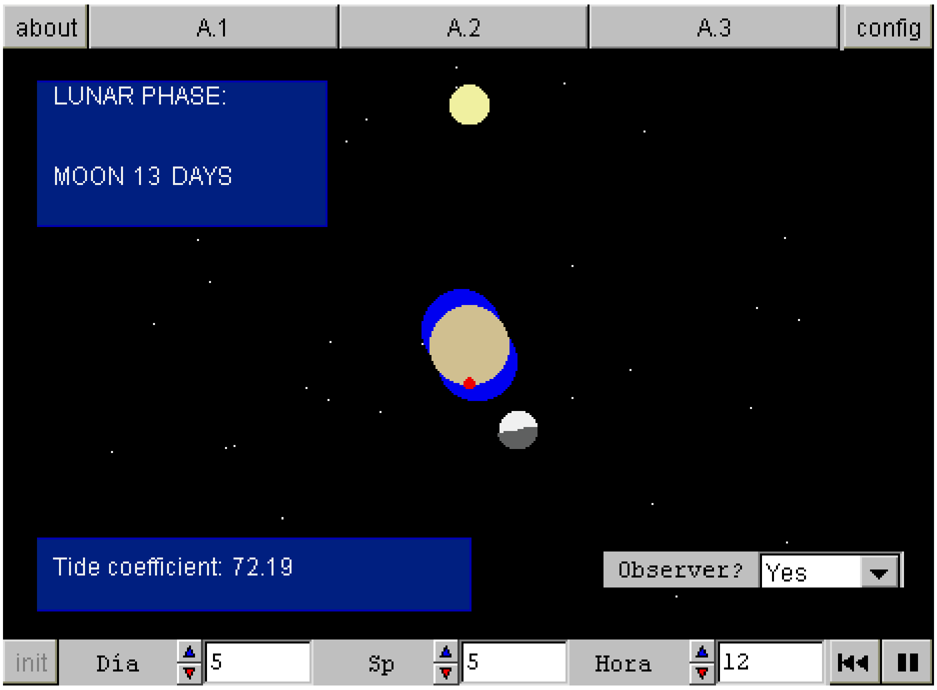
Not only does the earth create a gravitational field around it, the other bodies in the universe each create their own field.

In our daily lives we can directly see the effect of the gravitational force of the moon and the sun in the tides.

The force of the tides is what we call the difference between the gravitational intensity created by a heavenly body on the surface and in the centre of another one.



The difference in the gravity created by the moon on the surface A and in the centre B of the earth is the lunar tide, which is responsible for the variations in the level of our seas.



A1: Change the day of the lunar month and observe the corresponding tide. How many zones of high tide appear on the earth? Where are they situated?

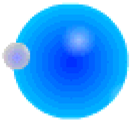
A2: Press the animation button. The tides do not always rise by the same amount. In which cases is the high tide higher (high coefficient)? When are there dead tides (low coefficient)? Invent a hypothesis that explains it.

A3: Activate the observer and change the solar time. How many high tides does he see during the day? Press the animation button. Do the high tides always come at the same time of the day? How do tides move along the surface of the earth?

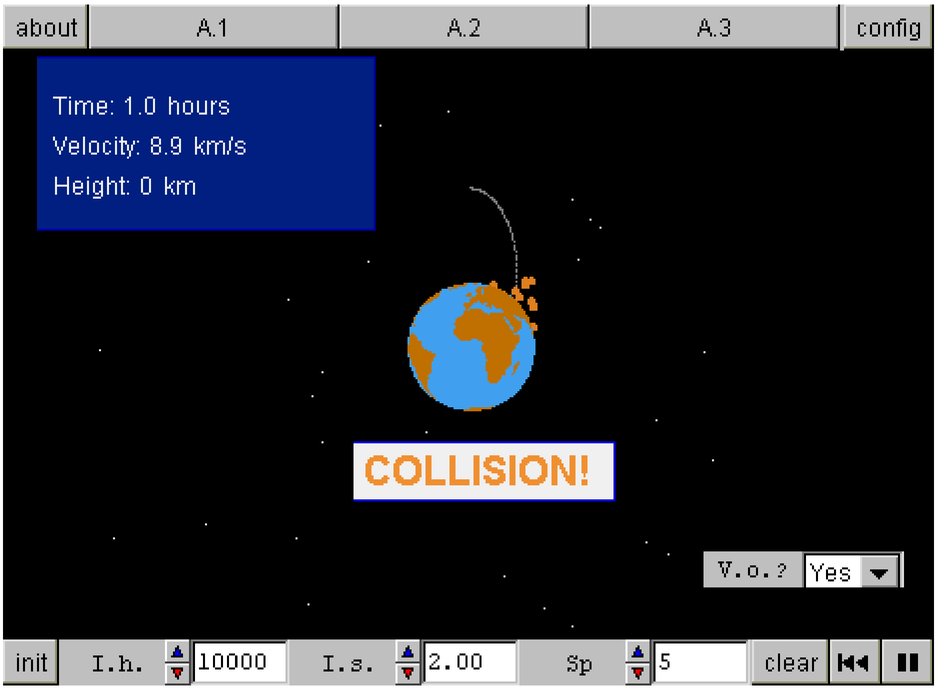
The blue zones over the earth represent high tide zones.

The movement of satellites

Not only do the sun and moon have a gravitational effect on the earth, our planet also exerts its attraction on all types of distant heavenly bodies.



An interesting application of knowledge of the earth's gravitational field has been the creation of artificial satellites. Once they have been put into orbit with the necessary velocity and height, the force of gravity keeps them there.



A1: Set the ship at the minimum height that the programme allows (500 km). Test different speeds, gradually increasing, until you get an orbit that is approximately circular. Copy down the speed and the time that it takes the satellite to circle the planet. If you keep increasing the speed, what happens to the orbits? Try to find the minimum velocity at which the body escapes the earth`s attraction. This velocity is known as escape velocity. What mathematical relation can you see between both velocities? Repeat the experiment for heights of 1000 and 5000 km. Can you draw a general conclusion?

A2: You can use the data from the previous exercise or take new measurements. How does the period vary with height? At the right height, a satellite would take 24 hours to circle the earth. If it were circling the equator, what would its movement seem like from the earth?

A3: Give the satellite the right velocity to make the orbit visibly elliptic. What happens to the speed of the satellite along its orbit? Try to note the speeds when the satellite is at the maximum and minimum distance from the planet. Multiply this speed by the distance. What can you observe?

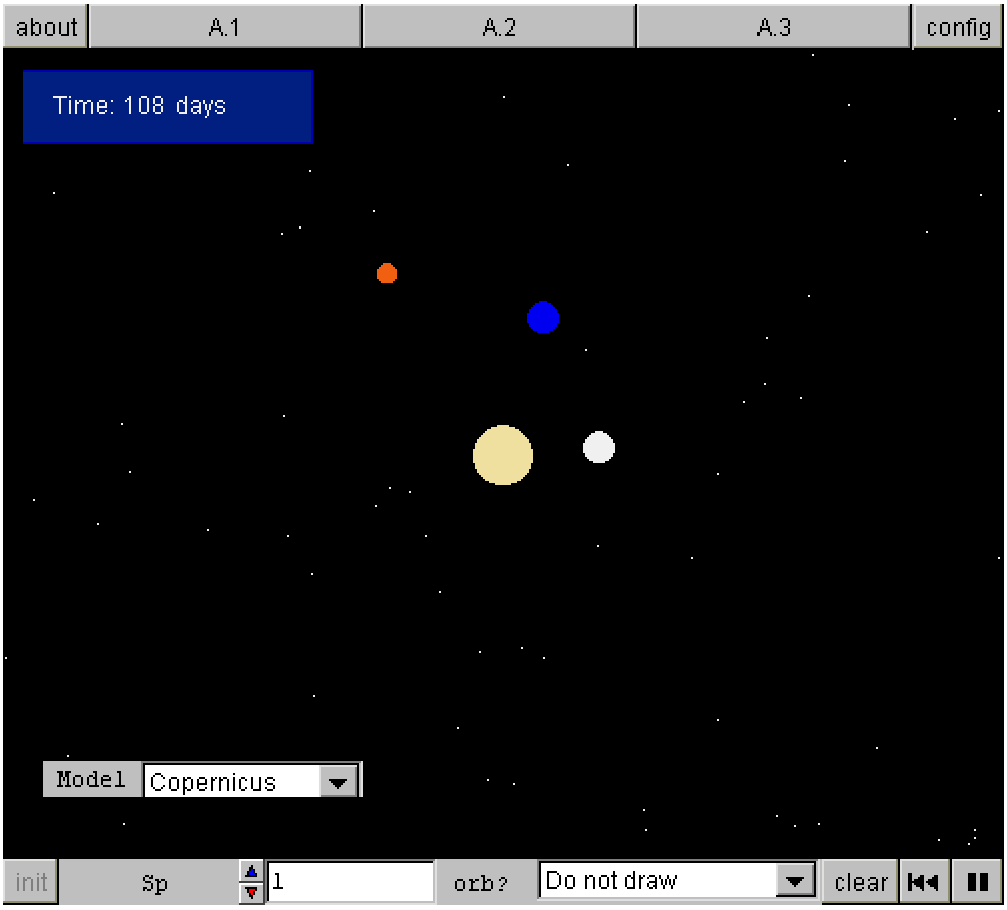
The solar system

In the same way that artificial satellites revolve around the earth due to the gravitational force of our planet, the planets revolve around the sun. This fact which nowadays seems trivial, took many centuries to become established.

From ancient Greece to the Rennaissance period, the opinion of the wise men tended towards a geocentric universe, with all the heavenly bodies revolving around the earth. Starting from the work of Copernicus and Galileo, and with a great many difficulties, the heliocentric model began to dominate, and the sun moved to the centre of the system.

In the following visual, you can see the most advanced of the geocentric models, Tycho Brahe's, and the heliocentric model of Copernicus.

The sun is the yellow sphere, Venus is the white planet, the earth is blue and Mars is red.



A1: Select the Copernican model and watch the simulation. What do the planets move around? What planets move faster?

A2: Select Tycho Brahe`s model. When we choose this model, we can see the solar system as it is seen from our planet (as we feel that we are at rest). What can you see regarding the sun`s movement? What about the planets` movement?

A3: Closely observe the movement of Mars in Copernicus` model and then in Tycho Brahe`s model. Can you see any difference in the speed of the planet? Can you explain the reason for this difference?

Gravity beyond the earth

All bodies attract each other according to Newton's principle of universal gravitation:

$$F = G \frac{m \cdot M}{r^2}$$

Where F is the force of attraction, M and m the mass of the bodies, and r is the distance between them. G is the universal gravitational constant.

This force is what permits us to put satellites into orbit, governs the tides and controls the movement of the planets around the sun.

If you want to revise the corresponding experiments, click on their name:

Satellites, tides, solar system

Evaluation

Choose the right answers:

1. Where is the field strength of gravity greater?

   A On the surface of the earth

   B It is the same everywhere

   C At the centre of the planet

   D At an infinite distance from our planet

2. If we were to go to the moon, what would happen to our weight?

A It would be the same as on the earth.Weight is the same always.

B It would be greatly reduced, because the moon is much lighter than the earth, so its gravity is smaller

C It would completely disappear. Bodies do not weigh anything on the moon.

D It would increase because the absence of atmosphere on the moon increases gravity.

3. Artificial satellites...

A Move faster when they are in closer orbits

B when their orbit is elliptic, move faster when they are further away from the earth

C Move faster when they are in more distant orbits

D Satellites move at the same speed no matter where they are in their orbit.

4. The solar system, as seen from the earth:

A is made up of heavenly bodies that move in circles around our planet.

B Only the sun seems to follow a perfectly circular path, the planets move in loops along their way.

C We can clearly see how all heavenly bodies move around the sun

5. The weight of a body and its mass

A are magnitudes proportional to each other

B are invariant magnitudes

C are two different names for the same magnitude

D are magnitudes with no relation with each other

E are equal, although weight is a vector and mass is a scalar

6. When a body is dropped, it falls with a speed proportional to its weight.

A False in every case

B This is only true if the objects fall in a vacuum

C This is only true if the object falls through air

D Always true

7. All bodies fall to the ground with an acceleration of 9.8 m/s2

A Always true

B Only true in a vacuum

C It is never true

D Only true if the bodies fall through air.

8. Which of the following statements about tides is correct?

A At the seaside you can observe two high tides every day

B Tides are higher during the first quarter.

C Dead tides are produced when there is a full moon

D The highest tides are observed when the sun, moon and earth are aligned

E All tides reach more or less the same height

9. The solar system as we know it

A Is described by a perfected geocentric model

B The planets move around the sun, but without a force attracting them towards it, as otherwise they would fall to the sun

C Is described by a heliocentric model in which all planets are held by the gravity of the sun.

10. The force of gravity attracts bodies towards the earth.

A True.

B True only in air

C True only in a vacuum

D It is true only if we are holding up the body to prevent it from falling

E True only when the bodies are free to fall.