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ESCUELA DE ESTRELLAS
material didáctico

EVOLUTION

3º y 4º de ESO / Bachillerato

planetario de pamplona

FECYT

FUNDACIÓN CAJANAVARRA

Obra Social "la Caixa"

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SCHOOL OF STARS

This didactic material has been developed by the teaching team at the Planetarium of Pamplona.

It has been designed as support material for use before and after the visit to the Planetarium and its completion is optional. It is not an activity guide designed to be followed in the order shown, or entirely. The teacher can choose the activities that they deem to be most attractive and useful.

We decided that it was a good idea to offer a wide selection of proposals that give more options to the teaching staff when it comes to selecting those which they find most useful.

We hope you enjoy it.

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Presentation

Introduction

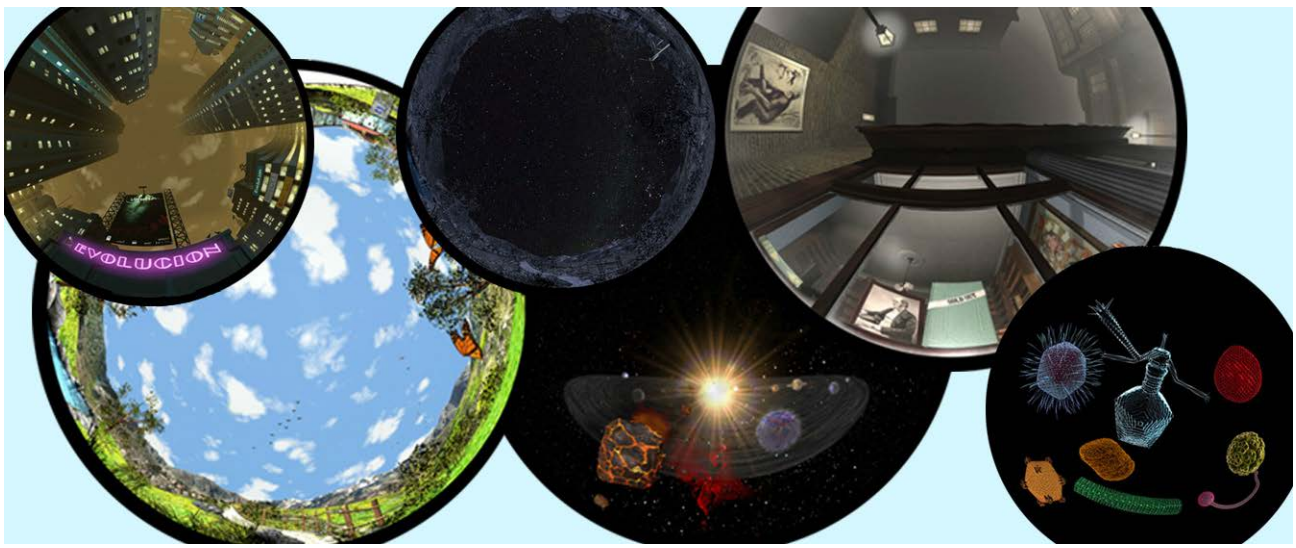
If we look to nature it appears that we find ourselves trapped in an endless circle in which events are repeated invariably through the course of time. The two most important cycles for us are those of day and night and of the seasons. Each day the Sun rises in the East and after travelling across the sky, it sets in the West. Every year the cycle of the seasons is repeated and despite the weather imposing certain changes, in general, the cycles of sunshine and the cold/hot periods are repeated more or less at the same time of year. At a glance we could be led to believe that we are trapped within an endless loop from which we cannot escape.

Nevertheless, apart from these cyclical processes, there are other natural processes which superimpose themselves in quite a subtle way. The most evident of them is felt by ourselves, within our lives. Over the course of a year, our bodies, our particular circumstances, our lives have changed, and those changes are irreversible and not cyclical, they are changes which follow one single direction. Our bodies and our personal environments evolve with time and these changes cannot be undone.

Evolution is a process which produces irreversible changes, in a way that those systems which have undergone evolutionary change will never be the same again. This happens in people and in all living things in general, but also in physical systems such as those of the stars, the galaxies and the Universe as a whole. The evolutionary processes are natural and not cyclical and flow with the course of time in a single direction, without any possibility of a return to the conditions of the past.

In the mid 19th century Charles Darwin published "The origin of the species by means of natural selection, or the preservation of favoured races in the struggle for life" a work of extreme importance in our history. In it Darwin offered an explanation for the enormous diversity of life on Earth as a result of the complex process of evolution.

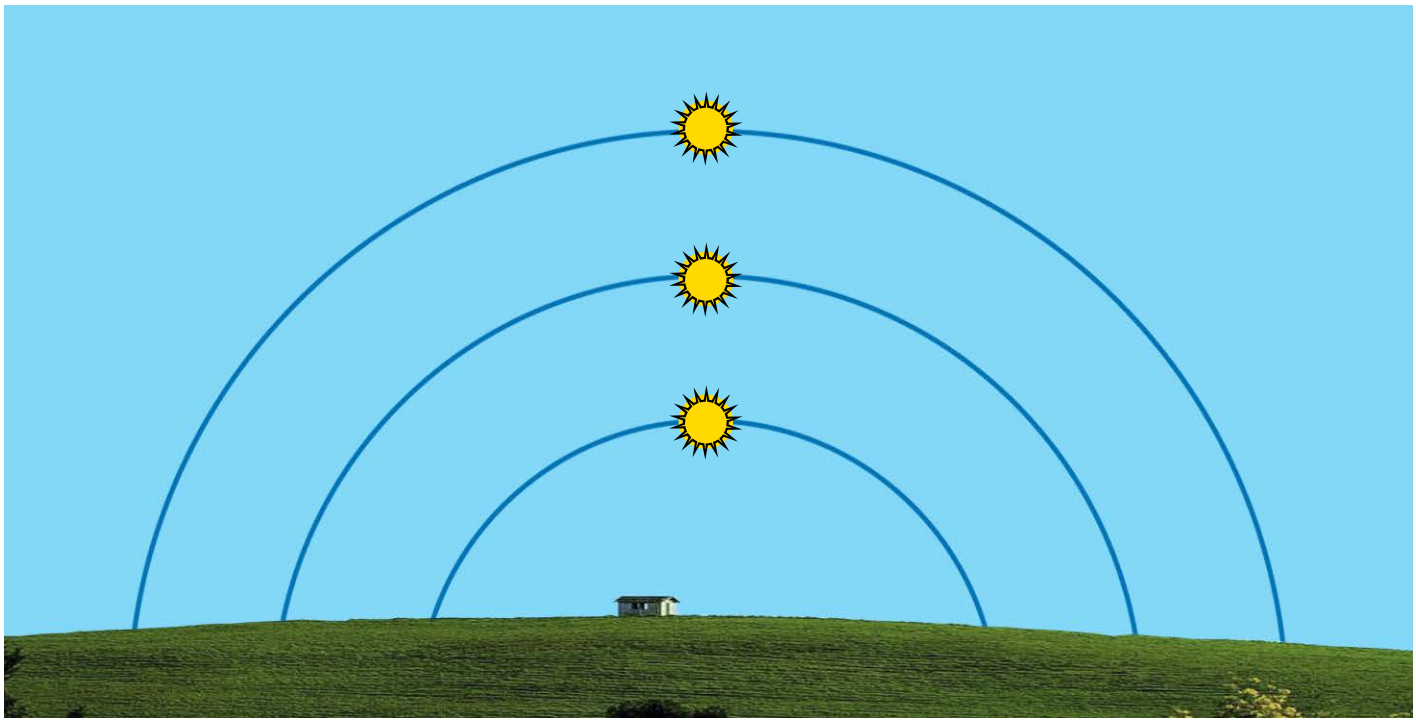
In this unit we will be studying certain events related to the natural cycles in which we are immersed (the cycle of day and night and that of the seasons) and we will look into the evolutionary processes which affect us, our environment and the Universe in which we live.



Activity 1 *The seasons as from the Earth*

Answer the questions in your exercise book

The movements of the Sun which are represented in the image below correspond to a place on a medium latitude within the northern hemisphere. They correspond to the path that the Sun takes as it passes across the horizon on the longest and the shortest days of the year, and a day where day and night last the same time. Look at them in order to improve your understanding of the differences between the seasons.



a) Which are the four seasons? What is it that makes them occur?

b) Every day of the year at midday, the Sun is situated at the highest point of its trajectory. Above which cardinal point is it situated?

c) Indicate on the image what would be the Sun's trajectory on the equinoxes and solstices, which are the days on which the seasons begin. Write them down above the trajectory.

d) Consult the website of the **Observatorio Astronómico Nacional** and answer the following questions relating to this year.

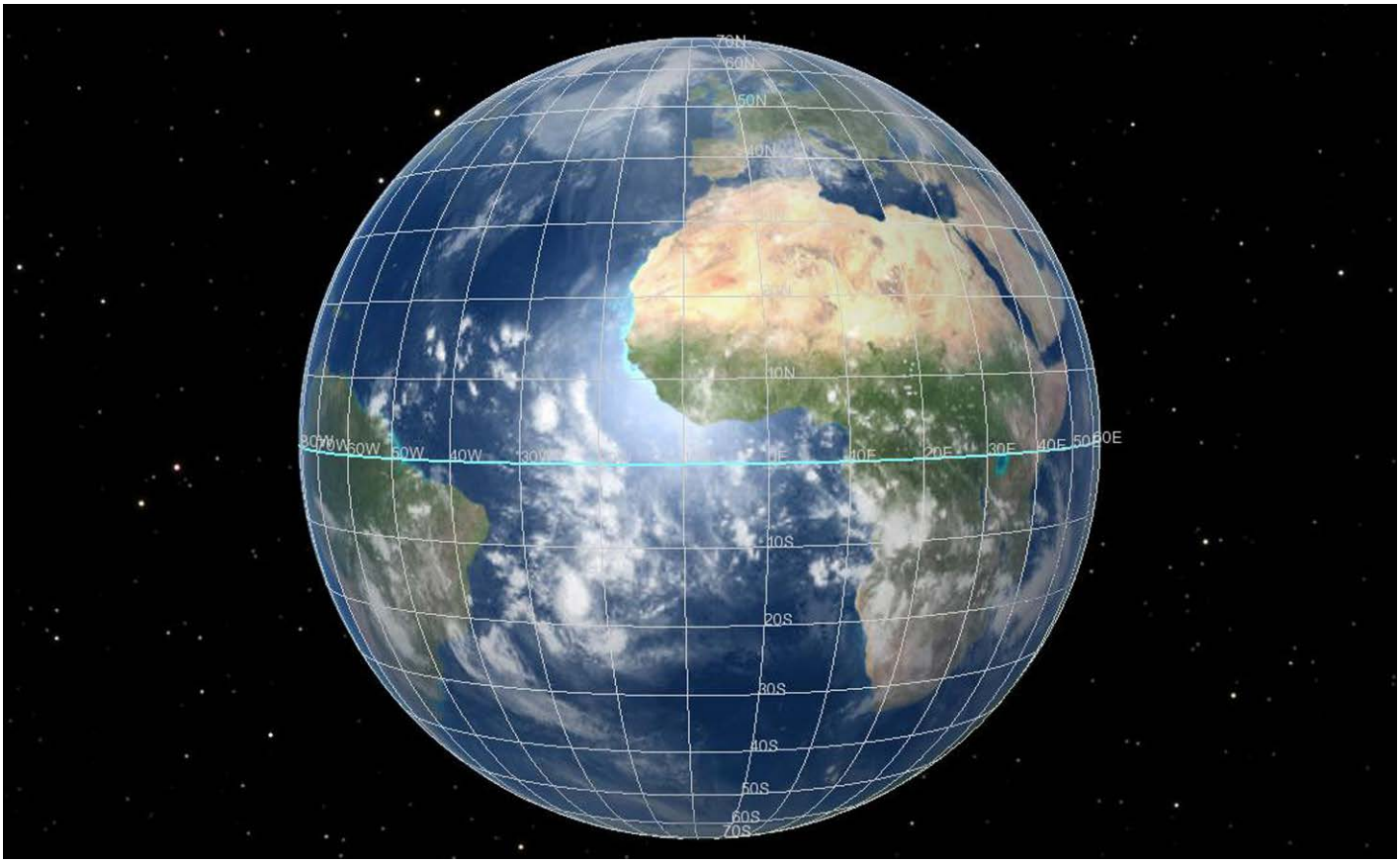
- When does spring in the northern hemisphere begin? And in the southern hemisphere?
- When does summer in the northern hemisphere begin? And in the southern hemisphere?
- When does autumn in the northern hemisphere begin? And in the southern hemisphere?
- When does winter in the northern hemisphere begin? And in the southern hemisphere?

e) **Equinox** comes from the Latin Aequinoctem and means "the same as night". We havetwo equinoxes per year; on these two days the Sun is above the horizon for 12 hours an below it for another 12. For this to occur, the sunrise and the sunset happen exactly on the cardinal points of East and West. Mark on the image the position of 3 of the cardinal points that can be seen.

Actividad 2 *The Earth's coordinates*

Answer the questions in your exercise book

Teacher's note: use decimal points and consider the number 23.5 in this exercise



a) What is the tilt of the **axis** on which the Earth rotates?

Draw a table containing the following information on the planets of the solar system:

- The tilt of the axis on which they rotate
- The tilt of their orbital planes in relation to the Earth's orbital plane.

b) Define the term **parallel** or circle of latitude

- There are 5 major parallels (circles of latitude) on Earth, can you name them?
- What is the latitude of the *Tropic of Cancer*? And the *Tropic of Capricorn*?
- There is a parameter called the **colatitude** which is defined as: **90º- latitude**. Calculate the colatitude of the two polar circles.
- What tilt would the earth's axis need to be in order for your town or city to be in the tropic of Cancer?

c) Define the term **meridian**.

- What is the Prime Meridian?
- What is the relation between the Prime Meridian and the different time zones?
- When we refer to a certain hour of day we often use the abbreviations AM and PM. What do they mean?

d) With a red marker, draw on the image the most well known meridian and parallels.

Composition. Describe what the cycle of day and night and the seasons would be in these imaginary situations:

a) If the Earth's axis was perpendicular to its orbital plane (as is nearly the case with Jupiter).
b) If the Earth's axis was on its orbital plane (as is nearly the case with Uranus).

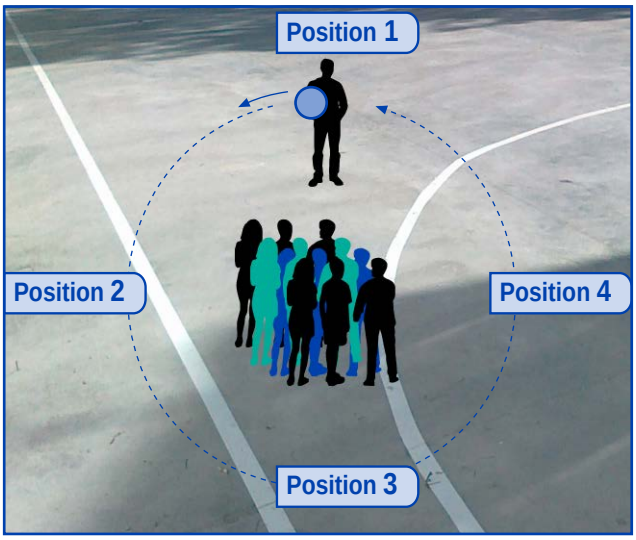
Activity 3 *The seasons as from the Sun*

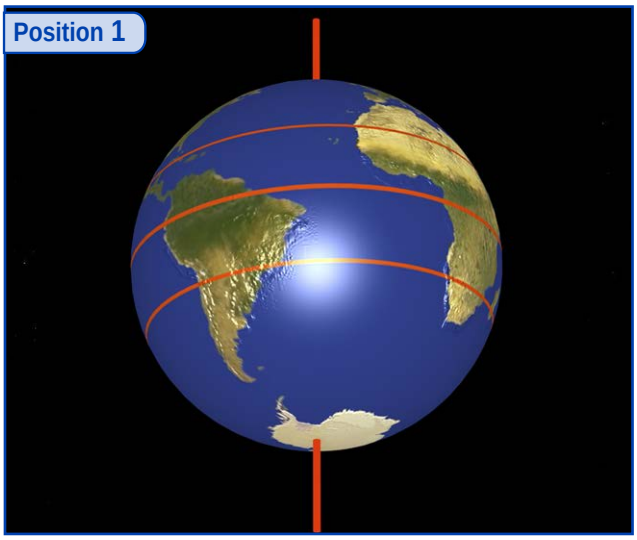
Simulation 1

For carrying out this simulation we need a globe and a wide open space such as the school playground. The students stand together at the centre of the chosen space. They will be representing the Sun, whilst the teacher will stand some distance away holding the globe. The students at the centre must always be looking towards the Earth.

Bearing in mind that the Earth's axis is tilted in relation to its orbit, the teacher will simulate the movement of the Earth's orbit, whilst making sure the direction in which the axis tilts stays the same (the Earth's axis is always pointing to the pole star). The direction of the Earth's orbit is anti-clockwise as seen from above (from the North). The direction of the Earth's rotation is the same as that of its orbit. In order to visualise this properly it is best to make sure that when moving the globe, that both movements are done at the same time whilst observing the following point.

Note: we must not forget that although the Earth's orbit is ecliptic, it is almost CIRCULAR. Therefore, in order to carry out this simulation, it would be best if the teacher who is holding the globe, moves around describing a circumference.





The teacher will then pause in four positions within the orbit (every 90º) in order to reproduce the situation in which the Earth is found on the four days of the year which mark the beginning of the seasons (see image).

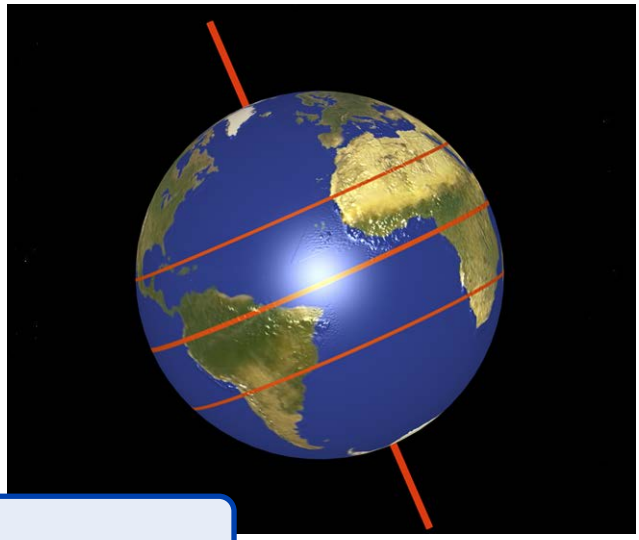
Answer the following questions which refer to each of these positions:

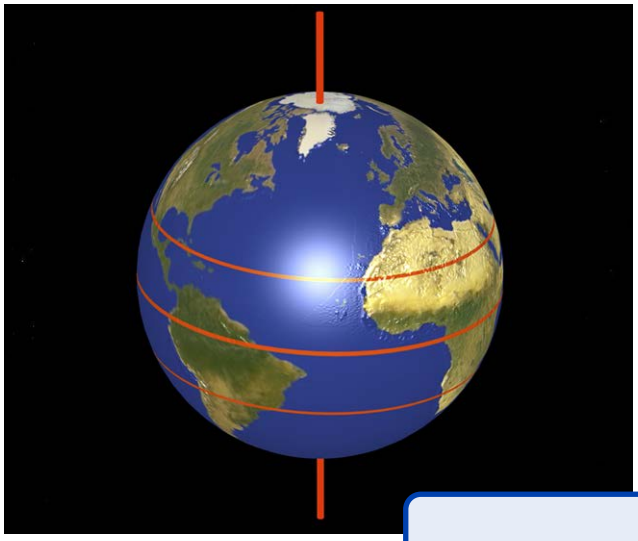
Positions 1, 2, 3 and 4.

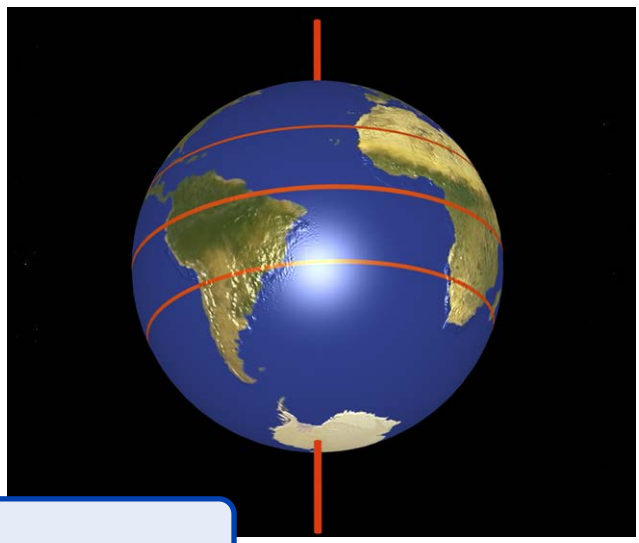
- Which of the poles is seen from the Sun?
- Is it day or is it night at the North pole?
- At midday the Sun perpendicularly illuminates which circle of latitude?
- Which season begins in the northern hemisphere? And which one in the southern hemisphere?
- In which of the Earth's hemispheres are the days longer than the nights?

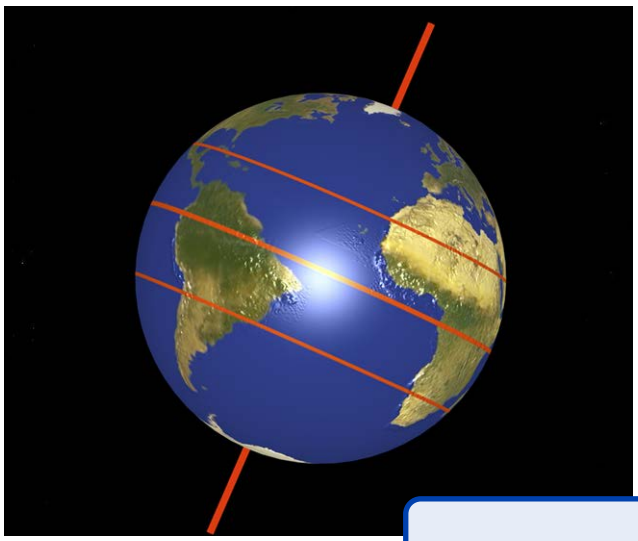
Activity 3 *The seasons as from the Sun*

These images would be what "photos" of our planet would look like if taken from the Sun. Each image corresponds to one of the 4 positions simulated in the previous activity. Work out which of the images corresponds to each of the seasons.

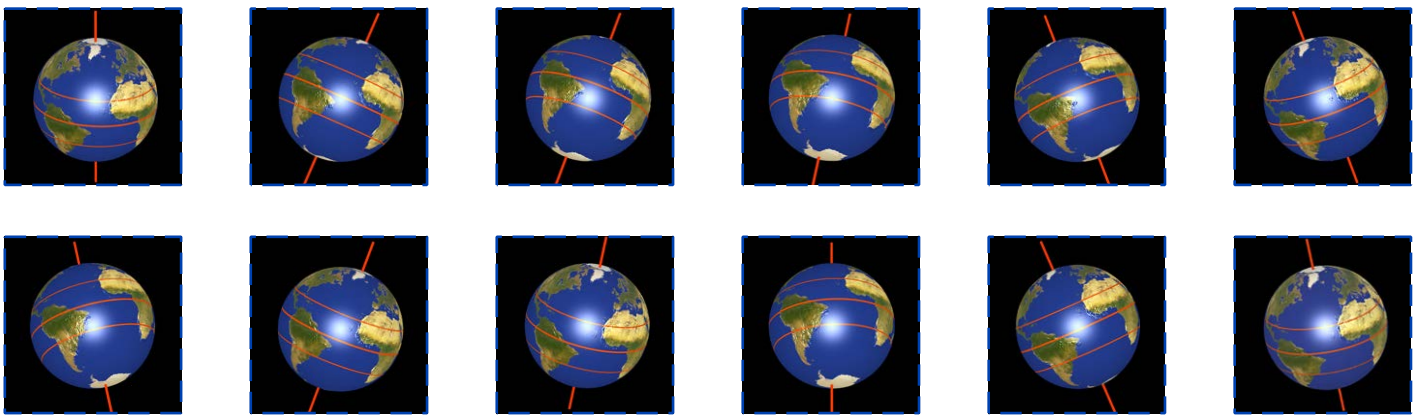








This sequence shows "photos taken from the Sun" one per month. Cut them out, put them into order and stick them onto a sheet of paper in order to represent one sidereal year.



Activity 3 *The seasons as from the Sun*

- Besides its orbit, the Earth also spins on its axis: this is the rotation. Looking towards the Earth as in the simulation exercise (from the northern pole of its orbital plane):

  - In which direction is the Earth's rotation? Clue: What is the area of Levante also called? Where does the Sun rise first, in Barcelona or in A Coruña?
  - How many times does the globe have to rotate on its axis in order to go once around the Sun (one year)?

- Search on the Internet and answer the questions: Why do the directions of the movements of orbit and of rotation virtually coincide?(except for the tilt of the Earth's axis).

  Does this direction of rotation and orbit coincide for the rest of the planets in the solar system? What do you think causes it?

- Besides rotating in the same direction, the planet's orbits are almost exactly on the same plane. If we extend this orbital plane into the celestial sphere it defines a very well known strip of constellations.

  How many are they? What are they called? Two of these constellations are associated with two of the Earth's parallels, which ones are they?

Simulation 2. We now repeat in the classroom the simulation carried out earlier in the playground, but this time applying the following changes:

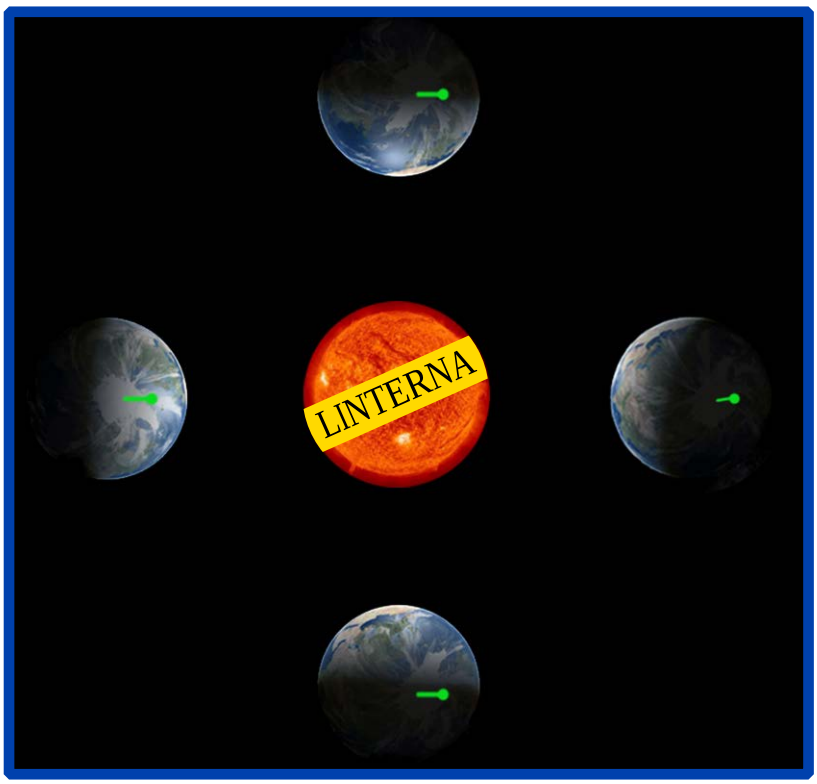
- With a piece of plasticine or similar material, stick a toothpick (broken in half, or even smaller) onto the globe on the Iberian Peninsula, and protruding out at 90º.

- Close the window blinds of the classroom and switch off the lights.

- One student (the Sun) has to stand at the centre of the classroom with a torch and shines it towards the Earth; the rest of the students and the teacher then simulate the Earth's orbit around the Sun.

- Repeat the movements of the previous exercise, whilst observing the shadow: how the shadow (night time) moves with the different positions of the orbit; also the length of the shadow made by the toothpick on the globe during the different seasons of the year, just as the amount of light received by each hemisphere during the seasons.

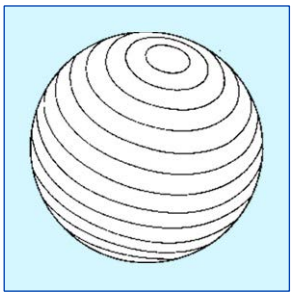
- Look at the poles. Do you know which season is represented by which of the Earth's positions in the image?



Activity 4 *Positions on the Earth's surface*

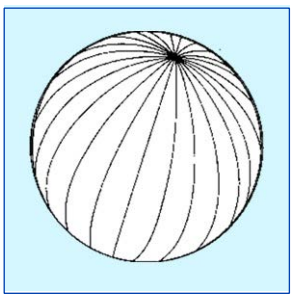
The position of a certain point on the surface of the Earth is defined in 3 ways This is explained below. Answer the questions

LATITUDE marks a place's angular distance from the Equator as seen from the centre of the Earth.The amount is measured in degrees and in a northerly or southerly direction.



- What is the name of the parallel at 0º latitude? And at 23.5º? And at 66,5º?
- What is the latitude of your town or city?
- Search on a map:
    - For 2 cities with the same latitude: one of them to the East and the other to the West of your town or city.
    - Make a list of the countries on the same the latitude as your town or city.
    - Name 1 place on the same latitude as your town or city.
    - Name 1 place in the southern hemisphere which is on the same latitude as your town or city. In which country is it?

LONGITUDE. A meridian is a great imaginary circle on the Earth's surface perpendicular to the Equator. On the Earth, all of the meridians pass through the poles: they also end at the poles (see illustration). Longitude, which is the second way in which we define a point on the Earth's surface, is measured in degrees and in an easterly or westerly direction.



What is the Greenwich meridian? Which meridian is it? Why does it have this name? What is it that makes this place so special? Does it have anything to do with the observation of stars?

Each place on the Earth has its longitude: but not all the places

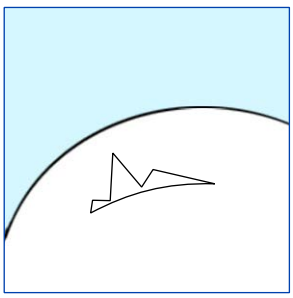
which are on the same meridian have the same longitude, which is what occurs with latitude (all the places with the same parallel have the same latitude), with longitude, half of the points which are on the same meridian have an eastern longitude and a western longitude. Their values are complementary. Half of the points on the Greenwich Meridian have a 0º longitude and the other half 180º.

- Look for two cities on a map which are on the same meridian as your town or city, one of them with the same longitude and the other without.
- Make a list of the countries which are on the same meridian as your town or city.

ALTITUDE. The third way in which we identify the position of a point on the Earth's surface is that of the altitude. Its definition is not so obvious, as first it is necessary to establish the point of zero altitude from which to measure it from. In most places the altitude is measured from sea level at a specific point, for example, on the columns of the front wall of Pamplona's city hall we can read the following inscriptions: on the left hand column "*444.67 above sea level at Alicante*"; and on the right hand column "*443.80 above sea level at Santander*".

- What conclusion can we reach by comparing these two pieces of information?

As the surface of our planet is irregular, reference is usually made to an ellipsoid, bearing in mind that the Earth is slightly flattened out at the poles.



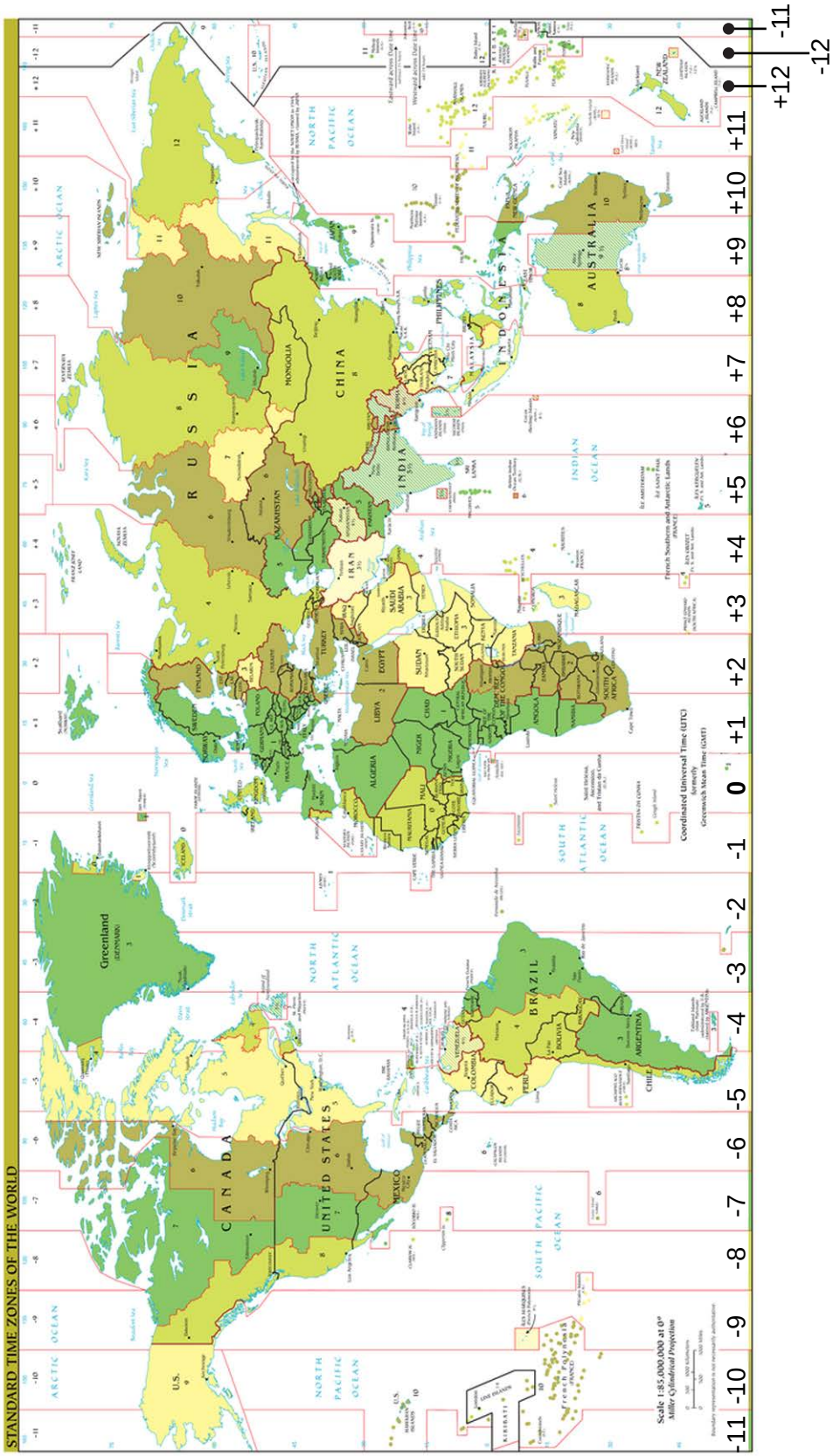
- Search on the Internet for information on this certain ellipsoid.
- What is the difference between the polar radius and the equatorial radius of the Earth?

In the audiovisual resource "Evolution", there is a part about the Astronomical Observatory of Roque de los Muchachos on La Palma, in the Canary Islands. The trigonometry point which is found at the highest point there marks an altitude of 2,426 metres. Because of the altitude, there are stars that can be seen towards the south which are not visible from the towns on the coast of that same island. The same occurs with the nearest star to our solar system.

- What is the name of that star? How far away is it? How many elements make up this system? How do they move amongst one another?

Activity 5 *Time zones*

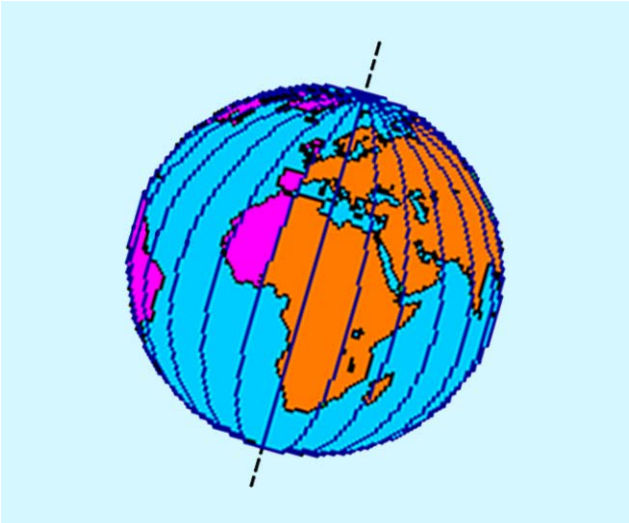
This image shows the different time zones. Draw the Greenwich meridian with a marker and closely study the illustration



Activity 5 *Time zones*

What time is it?

a) When and how were the time zones established?



b) Look for a website where you can compare the different time zones and answer the questions:
- If it is 12 o'clock midday in your town or city on the day of the spring equinox, what time is it in the following cities? Mark the times on the map on page 8.

London: _____; Warsaw _____;
Windhoek (Namibia): _____;
Tokyo: _____; New York:_____;
Santiago de Chile:_____; Rabat:_____.

- What difference in geographical longitude is there between them?

c) In 2011 in Samoa, what decision was taken? Look for news items relating to this.

- What happened? Do you agree with the decision?
- Is it the first time this has ever happened or has something similar happened before? Discuss it in class.

d) Consult the Observatorio Astronómico Nacional's website and answer the following questions relating to this year.

(NOTE: if you live on the Spanish mainland, the Balearic Islands, Ceuta or Melilla do not include the Canary Islands in this exercise. If you live in the Canary Islands, only include your autonomous community in this exercise).

- In which provincial capital does the earliest sunrise of the year occur? At what time does it occur? on which day does it occur?

- In which provincial capital does the latest sunrise of the year occur? At what time does it occur? on which day does it occur?

- Look for the capital of your province and answer the questions.

- What time does the sunrise on the 13th of June? What time does it set?

- What time does the sunrise on the summer solstice? What time does it set?

- What happens? On which of these two days is the Sun above the horizon for the longest time?

- What is the time difference between the earliest and the latest sunrise? And between the earliest and the latest sunset? How long is longest and shortest day and night? On which days does this happen?

- On which days of the year does the Sun set 12 hours after it has risen?

Activity 5 *Time zones*

What time is it?

At first it appears to be an easy question to answer: look at your wristwatch, the corner of your computer screen or your mobile phone, and that's that. But establishing the time, something that we are so familiar with, has not always been so easy. Let's think about it a little:

The time zones are conventions, decisions taken with the purpose of organising and unifying time over the course of the day. All of us wherever we are in the world associate 6:00 a.m. as a time very early in the morning; and anywhere in the world we associate 17:00 p.m. as mid afternoon. 12:00 is the middle of the day, midday: half of the day has gone by from when the Sun rose and the other half until it sets is about to begin; at midday on any day, the Sun is found at the highest point it will reach within the sky. Nevertheless, have you thought about what would happen if the conventions that define the time zones had never been established? What would happen if we were to travel from Madrid to Mexico without changing the time? instead of the time zones, other methods or orders could have been established, for example, one in which 7:00 a.m. *in Madrid was early morning, the time when we get up and go to school* whilst in New Zealand it would be *the time we leave school, have our afternoon snack, hang about with our friends or do an after-school activity, etc.* How would that affect us? Think about it and discuss it in class.

Also in some countries, in order to save energy they adopt different times for summer (summertime) and for winter (wintertime). As if that was not enough, there are some countries that decide on having a different time to a neighbouring country, simply in order to be different from them.

So, what time is it? is not so easy to answer is it?

Activity 5 *Time zones*

What time is it?

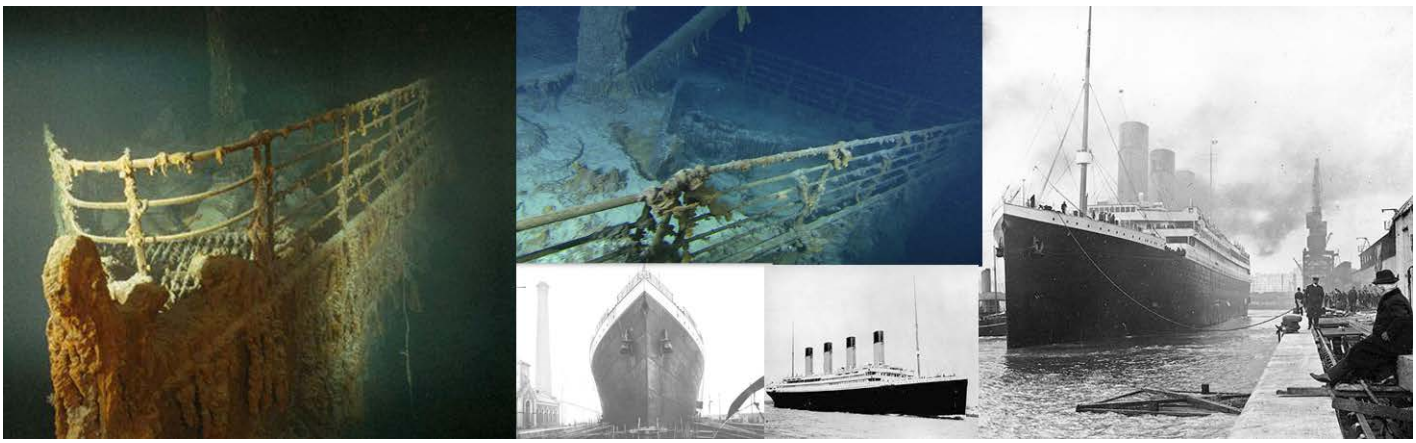
On the 10th of April 1912, the Titanic set sail from Southampton. 4 days later, on the night of the 14th it fatally struck an iceberg and a few hours later on the 15th it sank; which without a doubt was one of the worst maritime disasters of the last century.

We are going to remember the sinking of the Titanic at your school. Imagine that today is the centenary and we want to ring a bell at exactly the same time that the ship sank.

The Titanic sank at 2:20 a.m. (ship's time) at the following coordinates:

- Latitud: 41º 43' 35 " North - Longitude: 49º 56' 54" West.

What time must we strike the bell in our classroom? You need to calculate what time it is here, when it is 2:20 a.m. in the North Atlantic. Also bear in mind that In April we apply summertime, which is where we put our clocks two hours ahead of the time specified by our time zone.



In 1872, the novel *Around the world in 80 days* by Jules Verne was published. Using the Internet find out what the route of that journey was, and make a list of the most important cities visited by Phileas Fogg.

- Was the journey carried out from East to West or from West to East?
- Was completion of the journey in any way influenced by this? In what way was it done to make it quicker?

Why? Did anything significant happen to the time on the journey? When?

- Nowadays, the means of transport are much faster. Work out, more or less, how many days it would take you to travel around the world. Write a composition about the journey.

Activity 6 *Evolution*

The age of the Earth

The remains of animals from the past are very difficult to find. According to expert scientists in the field, **it is estimated that only one bone from every 1,000 million actually became a fossil**. In comparison, we could imagine that, of the 46 million people living in Spain today, who each have 206 bones, in the future only 9 bones would become fossils. Besides, for the people of the future it would not be easy to find them: they would be spread out over an area of more than 500,000 square kilometres. Another way of calculating it, would be, that of the 6,500 million humans on the Earth, in the future, perhaps only 1,200 fossilised bones would exist, which would hardly be enough bones to make up six complete skeletons, and these would be spread over the entire planet. It is also estimated that only one species for every 10,000 of those that once existed on our planet, have reached the fossil record. That is not very many, but it is better than none at all.

- It is curious how the age of the Earth has been calculated throughout history, fossils have helped, but they need to be dated. **Look up these historical figures and explain what they did within this field.**

Fossil remains tell us of great mass extinctions that have caused affects to biodiversity. The audiovisual resource **Evolution** helps us to visualize the cause of the 5th great extinction which caused the disappearance of approximately half of the species which inhabited the Earth.

- Search for information of where the impact of the comet or asteroid could have taken place and what happened afterwards.

It is said that the 6th mass extinction started 10,000 years ago.

- Which species are being affected by it and how? Who or what is causing it?

List of extinct species. Competition to be carried out in pairs: each pair has to make a list of as many extinct species as possible. Who has won?

Composition. Choose your favourite animal from these lists, do some research on it and describe a typical day in its life: where and how it lived, its habits, the food it ate, etc. Would you keep one as a pet?

Activity 6 *Evolution*

Humans have always wanted to know about their origins and the reasons behind this world. Wishing to give an answer to this, we can find numerous explanations that have been given throughout history: from the animist cultures, through to the different religions and beliefs, there are theories for all tastes. The scientific way to explain our existence or origin and the enormous biodiversity of our planet, is through the **Theory of the Evolution of the Species.** Read the following text, and then answer the questions

THE AGE OF THE EARTH (Paul Elouard)

Contrary to the artificial selection which we humans carry out with animals and plants, improving on certain characteristics in order to maximise productivity, natural selection does not pursue any objective.

What's more, there is no genetic variation which is any better than any other, as it all depends on the circumstances in the environment. What is favourable at a certain moment, may not be so at another. Besides, because of a phenomenon known as mutation, from time to time, specimens are born with new variations, but in no way whatsoever do the habits or needs of these specimens determine what kinds of mutations are produced. Nevertheless, these mutations are a constant source of new specimens which natural acts upon, which, with time modifies different species and continues their evolution. Mutation does not only produce new species, but also increases the variability of existing ones.

Randomness also plays a fundamental role in evolution; for example, when a small number

of specimens luckily survive an ecological or environmental catastrophe which decimates almost all of the members of that species, or a few individuals are passively transported or swept away by the forces of nature (by the wind, by an animal, by rivers or sea currents) to establish a new colony. The characteristics of these randomly selected specimens may not be the same as that of the original population, however, they are the starting point from which their evolution continues. Sometimes a catastrophe of huge proportions can eliminate one or numerous perfectly adapted species with a stroke.

Randomness has a fundamental role in the evolutionary process.

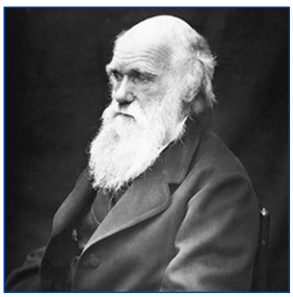
- Define randomness and describe the role it would play:

If life were to again appear on a planet such as the Earth, just as it did here 3,600 million years ago.

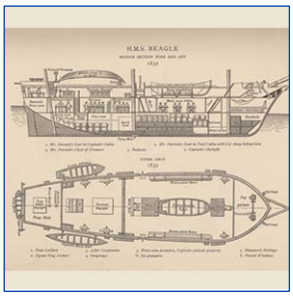
- Would the process be the same? After the same period of years would we be here? Explain your answers.

Activity 7 *The Theory of Evolution*

In order to understand the theory of evolution, we need to put it into context. Divide the class into four groups: each of them has to work on one of the four options below. Then each group has to prepare an oral presentation to give to the rest of the class

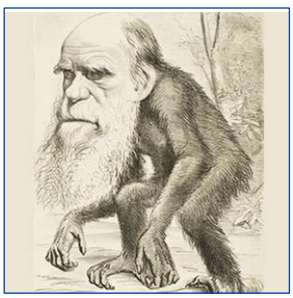


Group 1. Charles Robert Darwin was born in Shrewsbury on the 12th of February 1809. Find out about the social, cultural, economic and political context of the time.



Group 2. *The Beagle* set sail on the 27th of December 1831. Describe Darwin's journey: why he went on this adventure, how long it took, what he did whilst on this journey, which places he visited, etc.

Group 3. The figure of Alfred R. Wallace. Who was he? What was his contribution to the theory of evolution? Do you believe that Darwin's treatment of him was fair? Was it the right option to take?



Group 4. When Darwin published "The origin of the species" it caused great controversy among society, the church and the political and scientific world. Samuel Wilberforce was a strong critic of Darwin, whilst Thomas Henry Huxley became one of his staunch supporters. Search for information on the debates from that time.

Debate: Divide the class into three groups. After doing the necessary research, each group has to defend, with solid arguments one of the following options. The teacher can be the moderator.

Option 1: Creationism and intelligent design
Option 2: Evolution and modern evolutionary synthesis
Option 3: Lamarckism

Activity 8 *Life and the Moon*

Read the following text, and then answer the questions. Not all the answers are found in the text

WHAT INFLUENCE DOES THE MOON HAVE ON EARTH?

In 1974 William Hartmann, an unknown and inexperienced astronomer explained his theory to a group of scientists at Cornell University. He shyly told his story of the apocalyptic moment when a planet about the size of Mars struck the Earth. He explained how almost immediately, the incredible heat generated by the collision melted the surfaces of both bodies into molten lava. Huge clouds of dust formed from the over-heated lava would have been thrown into space from both the lone planet and from the Earth. What was left of the shaken Earth would have absorbed the remains of the lone planet. He calculated that the expelled molten debris would have fused together with incredible speed, perhaps in as little as 1,000 years to form the Moon.

The Moon is usually referred to as Earth's natural satellite. Any object which orbits around a planet is called a natural satellite. Satellites in general are much smaller than the planet and accompany it in the same orbit around its star. In the case of Moon, which has approximately 81 times less mass than the Earth, we could consider it as a system in which two planets are in orbit together (a double planet system). This is due to the fact that the relative sizes between the masses of any of the moons that orbit planets in the solar system are far less than in the case of the Earth-Moon system. The same occurs with the dwarf planet Pluto and its moon Charon.

One of the consequences of living on a planet with such a large moon, is the influence that we can see it has on the Earth. The most noticeable of these are the tidal cycles. It is true that the Sun also has an influence on the oceanic tides, but the most significant effects are caused by the Moon. Thousands of millions of years ago, the Moon was much nearer and the influence that both celestial bodies had on each other was far greater. Therefore, the presence of very strong tides was very beneficial to the adaptation of species in their journey from the sea out onto dry land, as they are periodically covered and uncovered by water, creating combined ecosystems in which the living organisms need to be able to survive within both environments. This means, that the Moon is a driving force in the evolution of species as it plays a fundamental role in the changing of conditions. Both the deformation of the Earth caused by the tides and the rising of the water in the oceans are are processes that dispel energy. This is done at the moment when the force of the Moon and the Sun is exerted upon the deformed part of the Earth and the oceans. This dispelling of energy ensures that the major axes of the ellipsoids of the Earth's hydrosphere are not perfectly aligned with the Moon or the Sun, but have a slight phase delay. This moment slows down the rotation of the earth and the day is lengthened by 17 microseconds per year (approximately 1 second per 59,000 years).

Activity 8 *Life and the Moon*

On the other hand, the moment of force which the Earth exerts on the Moon transmits energy. Because the Moon is in orbit around the Earth, this increase in energy results in an increase in the distance between the two celestial bodies and reduces the length of the lunar month. The Earth-Moon distance increases by some 38 mm per year. This increase in distance means that they were once far closer to each other.

Because the of the Moon's relative size to the Earth, it has another effect on our planet, which although it is subtle, is fundamental to life. The gravitational influence which the Moon has on the Earth's axis, means that it is constantly tilted in relation to its orbital plane; to be precise the axial tilt changes its direction in a cycle of almost 26,000 years (the movement of precession), but this is done conically in a way that ensures that the tilt in relation to the orbit is constantly maintained. This stability means that the cycle of the seasons is maintained year after year. If this did not occur, the axis would have changed its tilt considerably and the Earth's climate would have been subject to important changes, with long periods of extreme heat or others of extreme cold which would have frozen the entire planet for millions of years. In other words, without the Moon, it would have been far more difficult for life to have evolved into the complex forms in which it exists today. Our planet, especially in regards to life, would have been a very different place.

The evolution of the species over the course of history is conditioned by external elements. One of the most influential is that regarding climate conditions. Extreme climate change can condition the evolutionary process of natural selection and limit the appearance of advance or complex species. Complex species such as our own and others need a certain stability in climate conditions in order to succeed on the planet on which they have appeared. So in a sense, the Moon has contributed to the stability in the climate which has made it able for us humans to appear here on Earth.

Perhaps from now on, when you see it in the sky, when you follow its phases and its movements, you will see it in a different light.

- Do you believe that the Moon is vitally important to life? Which are the most important effects of the Moon? Make a list.

- Is the Moon getting nearer to or is it getting further away from the Earth? Has it ever been closer than it is now? When?

- The tilt of the Earth's axis and its stability is fundamental in the development of life on our planet. Using the table of the tilt of the axes which you did on page 3, choose one of the images and write about what you think the climate conditions would be on that planet (bearing in mind the tilt of its axis).

- What is the diameter of the Moon? And of the Earth?

- Do you consider the size of the Moon to be large or small in relation to the planet it orbits?

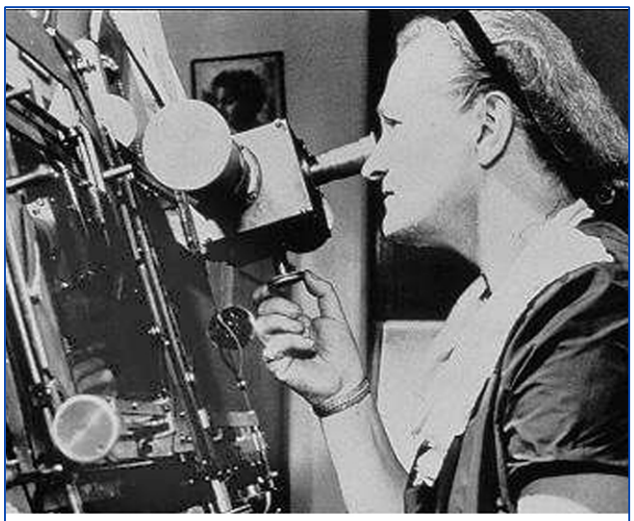
- Choose the largest moon from each of the planets in the solar system which have moons and draw a table showing the diameter of the planet and of its moon and the relative sizes between them (moon/planet). Order the table according to this information. What conclusion can you come to?

Activity 9 *Evolution and the chemistry of the Universe*

This activity is different. Carefully read the text; the exercise is set at the end

Cecilia Payne-Gaposchkin (1900-1979) was the person who discovered that Hydrogen and Helium are the elements found in most abundance in the stars and the Universe.

In 1925, Cecilia Payne-Gaposchkin presented her doctoral thesis at Radcliffe University (now part of Harvard) and became the first woman to acquire a P.h.D. in astronomy. In her work on the composition of the atmosphere of the stars, she proved that Hydrogen and Helium were without a doubt the most abundant elements in the Universe. This discovery was contrary to what scientists believed at the time, which was that stars had the same chemical composition as the Earth. Later investigations confirmed Cecilia's thesis, which also went to suggest that the origin of the Universe had been a very "hot" one.



Cecilia Payne

The beginning of the chemical evolution of the Universe.

We know today that the only elements that were formed in the primordial Universe were Hydrogen, Helium and tiny traces of Lithium. The other atoms we can observe on our own planet and in other places in the Universe such as Oxygen, Carbon, Nitrogen, Silicon, Iron, Uranium, etc were formed later, inside the stars.

The first stars were born from the primordial matter, even before the first galaxies. The fragmentation of the matter created by the Big Bang within a rapidly expanding Universe led to the appearance of clouds of Hydrogen and Helium which collapsed in on their own gravity. Many of those first stars only lived for a short period of time because they were so large, and had far more matter than they could stand to keep them stable. These giant stars were extremely bright and consumed the Hydrogen, their energy source very quickly. They all died violently in a terrific explosion which dispelled the new elements generated during their short and hectic lives throughout space. Therefore, a little after the Big Bang, the stars began the long and continuous process that is behind the chemical evolution of our Universe.

The clouds of gas which came after that first generation of stars contained the raw materials used to form new stars, a material containing atoms of elements other than Hydrogen and Helium. But, the birth of these new stars took place in the heart of even larger structures: the galaxies. We could consider galaxies to be the essential component of our Universe.

The formation of the stars

Stars are born when huge clouds of gas and dust which are found in the galaxies compact. Several hundred stars are usually born out of one of these stellar nebulae. In a part of the sky which we can see from our latitude throughout the night and during winter, we find three examples where we can observe many other stages of this process.

1. The Orion nebula. It is easy to recognise the great hunter's belt in the constellation Orion; from it hangs the dagger in which we can see the cloud of gas and dust which is forming new stars. Some of them have already been born and they light up and heat the gas around them. Others are in the final stages of the compaction process, still half hidden by the clouds of gas and dust around them. In some, we can even notice the presence of structures which could go on to form planetary systems. In these kinds of nebulae, the stars that are born first tend to be the largest, and the ones that accumulate the most matter.

2. The Pleiades. Further North, standing out in the constellation of Taurus is a group of stars that can be seen from virtually anywhere on earth. The star cluster the Pleiades, commonly known as the seven sisters, the seven hens, the ice princesses, etc. are a group of around 500 stars which are found some 450 light years from Earth and occupy an area of about 30 light years in diameter. Part of the original nebula can still be seen in long exposure images. The brightest stars are the most massive and were born 100 million years ago: in the Mesozoic era.

3. The Hyades. Forming the "V" shaped head of Taurus the bull, we have the star cluster the Hyades. This group of stars are found some 150 light years from Earth and occupy an area of at least 80 light years in diameter. The age of this cluster is estimated at around 790 million years, meaning, it is older and therefore more dispersed into space than the cluster of The Pleiades. The brightest star in Taurus is the giant red star Aldebaran which is found in the same direction as the Hyades, but is not part of it. Aldebaran is nearer to the solar system than the Hyades, some 65 light years away.

The life of stars

Stars spend the most part of their cycle within a very stable balance between the forces which try to disperse their matter and the forces of gravity which try to compress it. At this stage, within the core of a star, at millions of degrees and under enormous pressure, nuclear fusion of the atoms of Hydrogen (protons) takes place until it produces nucleuses of Helium, dispersing particles of huge quantities of energy, which contribute to the forces which maintain the star.

This balance created by the fusion of the Hydrogen is upset when a certain percentage of it has been consumed. From that moment on, the star becomes unstable and a process begins which has several stages, and which depends mainly on the amount of matter that the star has, that is to say, its mass.

The smaller mass stars can remain in balance for thousands of millions of years. The Sun will last for about 10,000 million years and we know that now it is more or less half way through its life. But the really massive stars consume the Hydrogen at such a rate, that they only need a few million years to use it all up, that is why, even though they have far more Hydrogen than the smaller stars for creating fusion, they use it up far quicker and they are stable for a lot less time.

The death of stars

When a star such as the Sun has used up all of the Hydrogen from its core, the production of energy is reduced drastically and the centre of the star collapses due to the action of gravity. This compression or collapse increases the star's temperature until it reaches a level where the atoms of Helium, which were the ashes from the fusion of the Hydrogen, begin to fuse to create much heavier atomic nucleuses, mainly of Carbon. In this process the outer layers of the stars expand and they cool down to form a red giant. Aldebran in Taurus and Arcturus in Bootes are two examples of stars of this kind that can be easily seen in the sky. When the proportion of Helium at the centre reduces and there is enough Carbon to make the fusion of Helium impossible, the star goes out. As the production of energy is again reduced, the centre of the star collapses, and even though the temperature rises again, it does not rise sufficiently to ignite the next thermonuclear reaction which fuses the Carbon atoms. Finally the collapse of the star's core stops due the pressure exerted by the gas made up of free electrons leaving a compact object, that is very hot but produces no energy. These are called White Dwarfs because of their size, which is similar to that of the Earth and their mass which is similar to that of the Sun and they are very hot, and are the corpses of stars such as the Sun. Whilst the core compresses, the outer layers of the star continue the process of expansion until they form a brightly coloured nebula which finally dissolves into interstellar space. This is called a planetary nebula, though it is not a place where planets are born.

Activity 9 *Evolution and the chemistry of the Universe*

Stars which have several times more mass than the Sun suffer from a much more violent fate. After all the Hydrogen from the centre has been used up, the core contracts and the fusion of Helium begins,but around the core, the Hydrogen fusion continues. The outer part of the star expands and cools, whilst the core is compact and much hotter, so the star now has two sources of energy, which is what makes it much brighter. When the helium is used up, the core contracts again and now the pressure from the electrons is not enough to stop it collapsing, because the temperature rises until the Carbon begins to fuse to create even heavier elements. The star becomes structured like the layers of an onion with different areas producing different kinds of thermonuclear reactions depending on the temperature. The outermost layers expand more and more as they cool down. Stars that are at this stage are called red supergiants. Two good examples are Antares in Scorpio and Betelgeuse in Orion. This process of successive contractions does not go on forever: when a nucleus of Iron56 with a mass similar to that of the Sun has formed in the star's centre, it collapses and the entire star explodes. In the short moment in which a Supernova (SN II) explosion is produced, tons of atomic nucleuses even heavier than Iron are synthesized. These elements are dispersed all over space at thousands of kilometres per second and end up mixing together with the interstellar matter.

It is possible that a compact object called a "neutron star" (basically an atomic nucleus with a radius of about 10 kilometres) can remain at the site of the centre of the explosion, or a "black hole" if the mass that has survived the explosion is above a certain amount.

The matter trapped in a black hole disappears from the visible Universe, but the remains of the explosion which are expelled into space form an expanding nebula which eventually dissolves into the molecular clouds of the galaxy, enriching the environment with the elements of the periodic table. Supernovas are the main driving force of the chemical evolution of the Universe.

Stardust

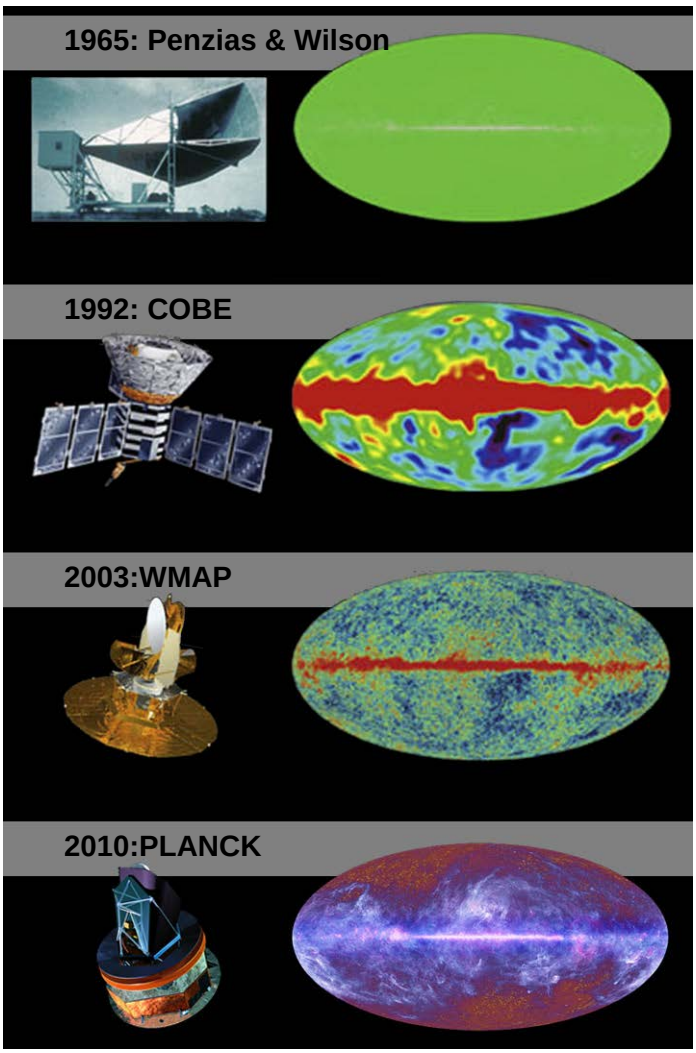
Sometimes we say poetically that we are stardust. The expression has more to it than just a poetic phrase, it contains a truth which science has revealed to us. Our bodies have atoms of Calcium, of Carbon, of Iron, of Phosphorus, of Oxygen, etc. and these elements did not exist in the Universe until the first stars were formed. Planets such as the Earth and all they contain including us, is evidence that the remains from supernovas are concentrated together again in new stars and planets. The fact that I have written this text and that you are reading it, proves that the matter that was created inside stars that have now died, can be organized in a very complex way so much so that it gives rise to living beings, or even beings that are conscious of their own existence. Beings such as Cecilia Payne, or such as you or me.

Swapping roles. The student has to take the place of the teacher and prepare an exam. The questions should be related to this text, in a way that they can define which of the sections are to be valued in a kind of test, in which they have to develop the questions...and all of these should add up to the typical value of any exam: 10 points.

Activity 9 *Evolution and the chemistry of the Universe*

Important moments of discovery of the Universe

The progress of scientific knowledge has allowed us to deepen our understanding of the Universe and although there are many questions still to be answered and each time there are more and more questions awaiting a scientific explanation, the reality is that, now we have methods and theories which explain with a fair amount of precision everything that nature presents to us.



These are three of the most decisive moments in the discovery of the knowledge of the Cosmos:

In 1965, Arno Penzias y Robert Wilson discovered cosmic microwave background radiation. It is an emission of microwaves that fill the Universe uniformly in all directions (meaning that they are isotropic) and have a thermal black body at a temperature of almost 3K. They are the clearest observational proof that the Universe began with a huge explosion of space-time.

1992. With the observations of the COBE satellite (http://lambda.gsfc.nasa.gov/product/cobe/) George Smooth and his team identified irregularities in the isotropy of the background radiation. These irregularities are needed to explain the spatial distribution of the great clusters of the galaxies in the present Universe..

In 2003 information from the WMAP satellite (http://map.gsfc.nasa.gov/) revolutionised our idea of the Universe. The precision with which the temperature of the background microwaves is measured and the resolution which is obtained (0.2º) allows us to reach the following conclusions:

- The Universe is millions of years old.

- The Universe is made up of three major components:

  - Ordinary matter (baryons): 4,6%
  - Dark matter (of an unknown nature): 23,3%
  - Dark energy (of an unknown nature and anti-gravity): 72,1%

Meaning, that we only have laws of matter to describe 4.6% of everything that makes up our Universe.

- The fluctuations in the density of the primordial Universe help us to explain how the first galaxies were formed.

- The expansion of the Universe today is accelerating it towards its heat-death (the Big Rip).

Compare the information from the text. Search different sources and point out where there is a consensus, and where there is not, etc. bearing in mind that the information is being constantly updated, collect the latest news related to this subject.

This text does not contain information from PLANCK. Look for information on this mission and on the scientific results of its observations: Do the results confirm or deny previous cosmological information? What new contributions is this mission making to our knowledge of the Universe?

Links

Planetarium of Pamplona:
www.escuela.pamplonetario.org , www.pamplonetario.org

Audiovisual resource EVOLUTION:
www.evolucion2009.es

Observatorio Astronómico Nacional (National Observatory)::
www.oan.es

Google Maps:
maps.google.es

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Images for the activity *Life and the Moon* pag 15:
http://3.bp.blogspot.com/-myvMmt76EzU/TbinU5nJg6I/AAAAAAAAA6g/S1iSLSEpbZc/s400/early-earth-ocean-moon-asteroids.jpg

Images for the activity *Evolution and the chemistry of the Universe* pag 17:
http://www.browsebiography.com/images/1/7847-Cecilia%20Payne-Gaposchkin%20bio.jpg
http://amazingsky.files.wordpress.com/2011/02/hyades-and-ngc-1647-135mm-bino-field.jpg
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