UNIT 2
LIVING THINGS: CHARACTERISTICS AND EVOLUTION

"I am almost convinced (quite contrary to opinion I started with) that species are not (it is like confessing a murder) immutable."

– Charles Darwin

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1. THE CHARACTERISTICS OF LIFE

What is a living thing? This is complicated question. As is easy to know, in most cases, what is a living thing and what's not a living thing, it's not so easy to define a living thing.

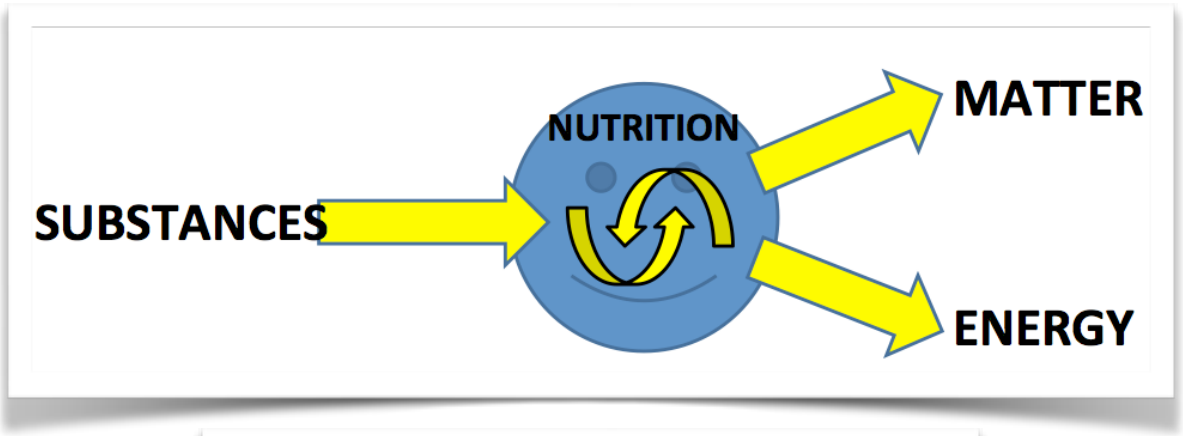
To define a living thing we must use its unique characteristics or processes.

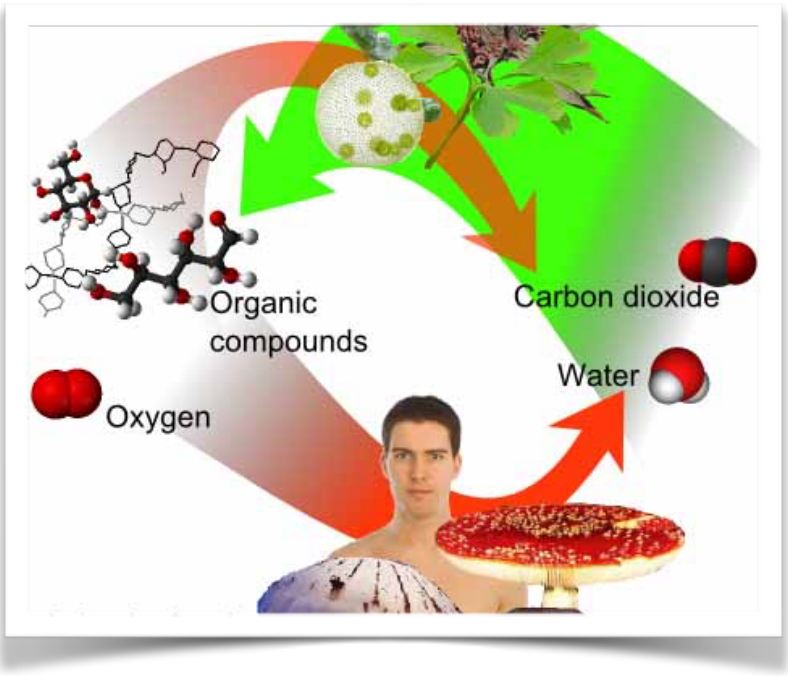
Biology is the science that studies the living things. Biologists agree on what are the basic life processes.

1.1. Living things do life processes

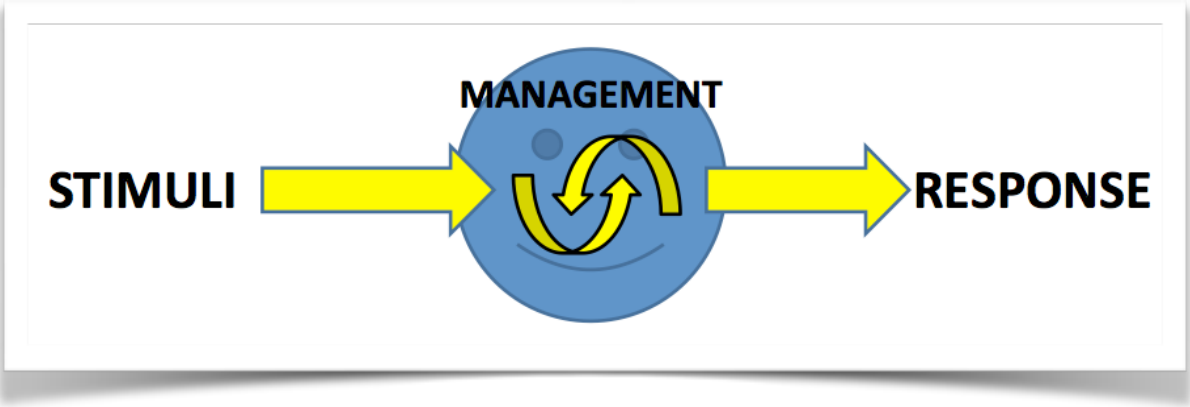
One of the main characteristics of living things is their ability to perform the life processes: nutrition, sensitivity and reproduction.

a) Nutrition: this process consists in taking substances from the environment and using them to make their own matter and energy. From the point of view of nutrition, living things can be divided into two groups: autotrophs and heterotrophs.

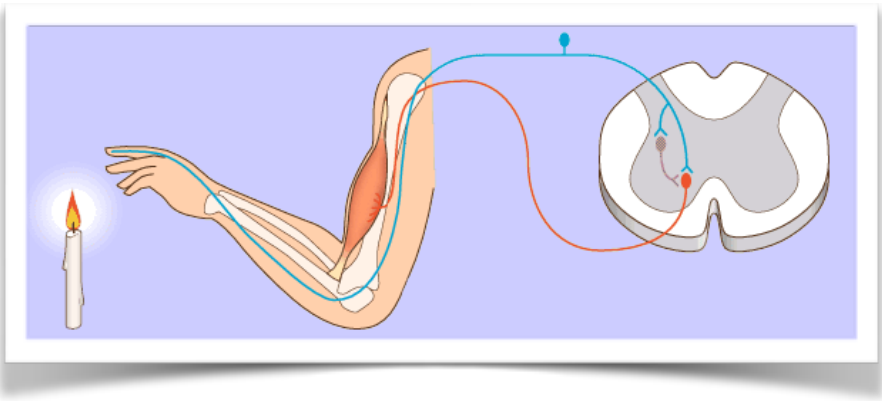




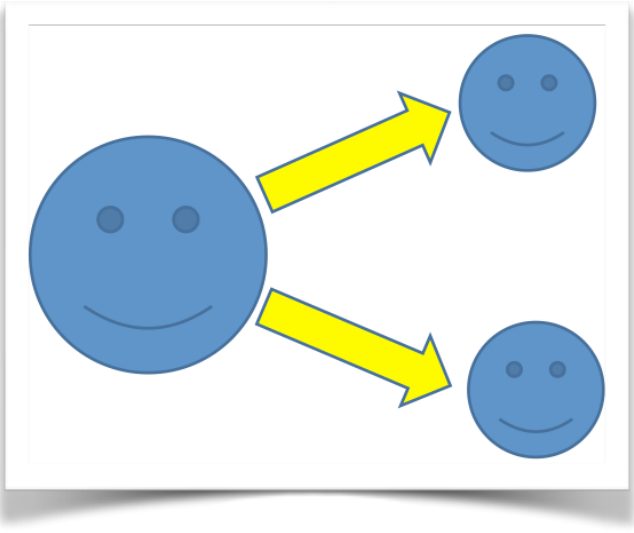
b) Sensitivity: living things are able to take information from their environment and responding properly to it.



Body reflexes are examples of this vital process



c) Reproduction: living things are able to make new organisms of the same species. There are two types of reproduction: asexual reproduction and sexual reproduction.



For *asexual* reproduction only one parent is needed and the offspring are all identical and identical to the parent. They are **clones**.

For *sexual* reproduction two individuals are needed and the offspring are similar, but not identical, and similar but not identical to the parents.

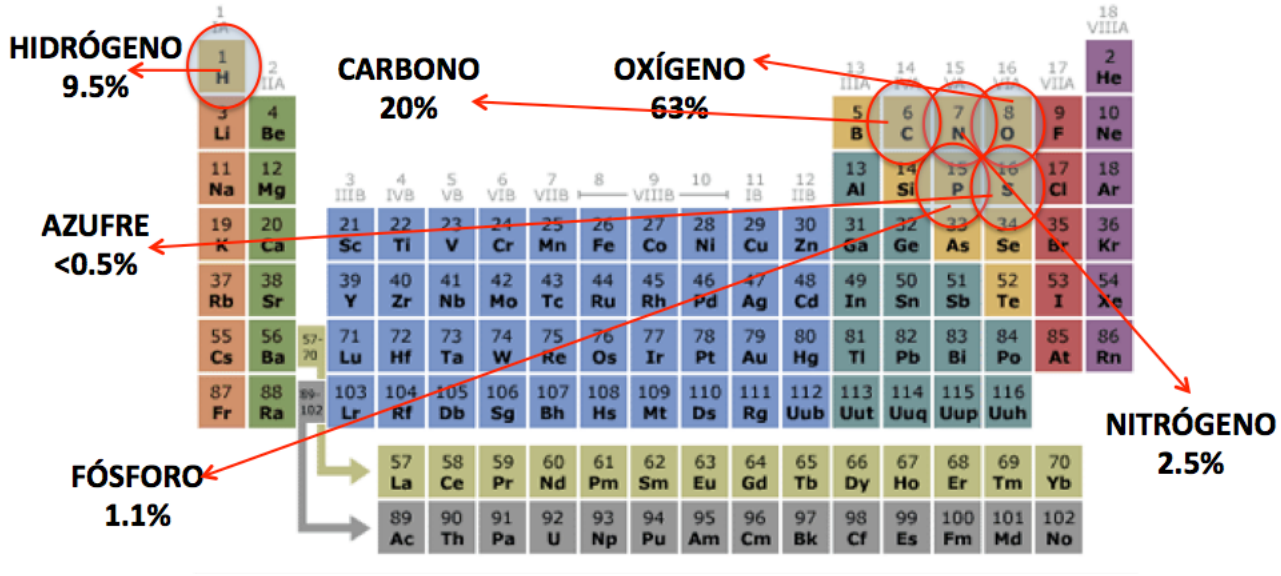
1.2. Living thing are made of bioelements.

All matter is made of atoms. Living things are made of matter, so they are made of atoms. Atoms that are present in living things are called bioelements. They join together to form biomolecules.

Bioelements are divided into two groups: primary bioelements and secondary bioelements.

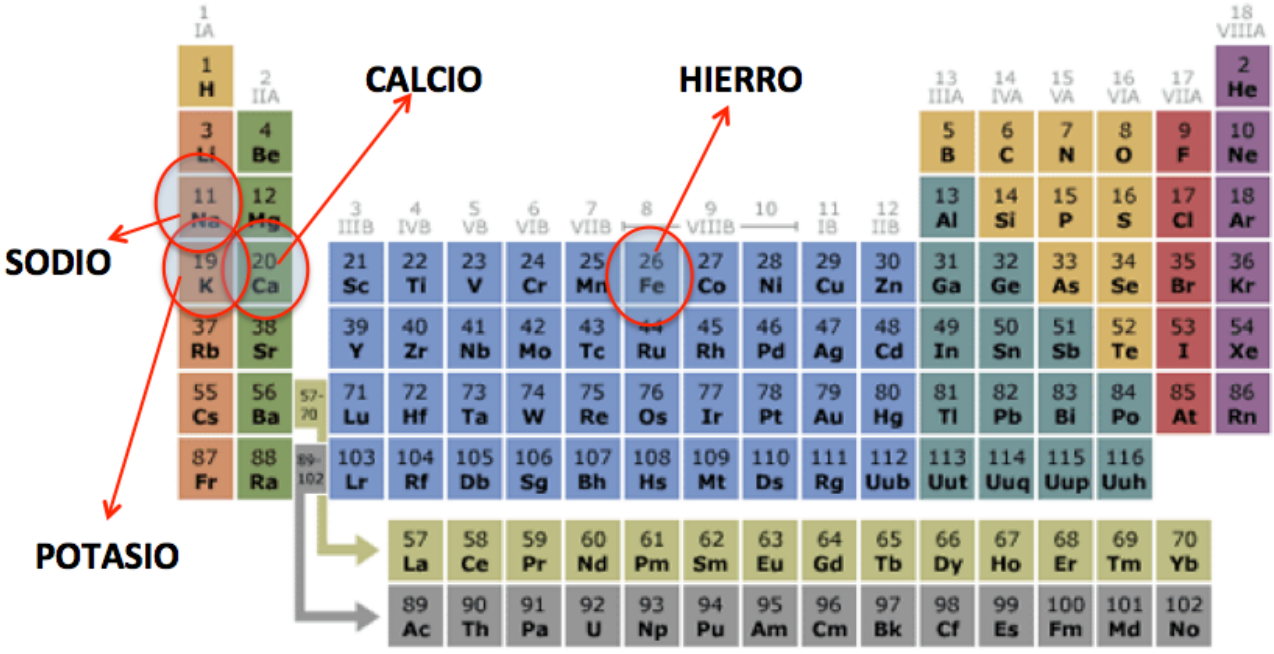
Primary bioelements are those that form 96% of the mass of the living things.

Primary bioelements



Secondary bioelements are present in low percentages, but they are vital for living things

Some secondary bioelements



These elements are the same that we can find in the crust, but they are in different percentages, as you can see in the following table:

Elemento	Corteza (%)	Elemento	Seres vivos (%)
Oxígeno	47	Oxígeno	63
Silicio	28	Carbono	20
Aluminio	8	Hidrógeno	9.5
Hierro	5	Nitrógeno	3

More than their composition, living thing are different due to their **organization**. There are several levels of organization in living matter. As we go from one simpler level to a more complex one, new characteristics appear. In increasing order of complexity, the biological levels of organization are:

Subatomic particles

↓

Atoms (bioelements)

↓

Molecules (biomolecules)

↓

Cells

↓

Tissues

↓

Organs

↓

Organ systems

↓

Organisms

1.3. Living thing are made of biomolecules.

Biomolecules can be classified in two groups: inorganic and organic biomolecules.

a) Inorganic biomolecules can be found in living and non-living things and they don't contain carbon in their composition. Organic molecules are water and mineral salts.

   i. Water is the most abundant molecule in living things, although not all organisms nor all tissues have the same percentage of water. The average water quantity in living things is 70%, but a jellyfish is about 95% water, bone tissue is 15% water and nervous tissue is 85% water

   ii. There are many different mineral salts. They can be found in two forms: precipitated and dissolved.

      a) Precipitated salts (in solid state) are in hard parts of organisms, like teeth, bones, shells, etc. They give resistance to the structures where they are.

      b) Dissolved salts play very different roles in living things functions: muscle contraction, nervous signals, oxygen transport, etc.

b) Organic biomolecules can only be found in living things and they contain carbon in their composition. There are four types of organic biomolecules: carbohydrates, lipids, proteins and nucleic acids.

   i. Carbohydrates: made of C, H and O. They can have an energetic function (glucose) or structural function (cellulose)

   ii. Lipids: made of C, H and O, they are not water-soluble and can have an energetic function (fats), thermic isolation (in polar animals) and structural function (cell membranes)

iii. Proteins: large molecules formed by the union of many amino acids. There are only 20 different amino acids, but the number of possible combinations is almost infinite. They perform lots of functions.

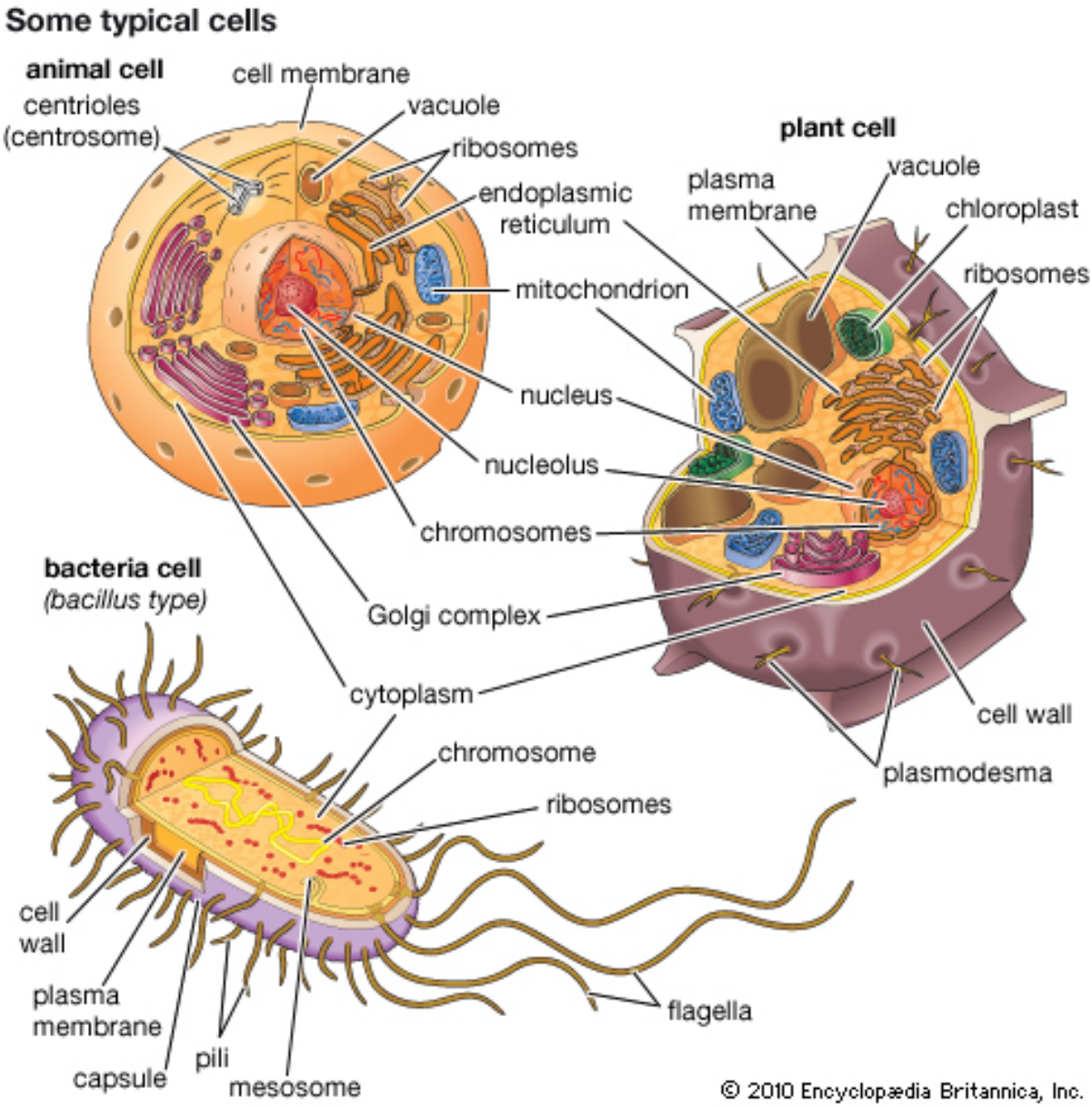
iv. Nucleic acid: large molecules formed by the union of many nucleotides. There are two types: DNA (DeoxyriboNucleic Acid) and RNA (RiboNucleic Acid). Their main function is to contain and transmit biological information.

1.4. Living things are made of cells.

Cells are the basic structural and functional units of all known living things:

- Functional unit because they perform all life processes.

- Structural unit because all living things are made of cells.



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There are two types of cells: prokaryotic and eukaryotic cells. Eukaryotic cells can be classified into two groups: plant cells and animal cells. Although cells may do very specialized functions, they have certain common features; they all have a cell membrane, cytoplasm, ribosomes and genetic material (DNA).

2. ORIGIN OF LIFE ON EARTH

One of the most difficult questions is: How did life begin on Earth? From ancient times, humans have tried to answer it. One of the first scientific hypothesis was spontaneous generation: life appears directly from non living things. There were interesting recipes to produce living things, such us this one:

Jan Baptista van Helmont recipe for mice:

Place a dirty shirt or some rags in an open pot or barrel containing a few grains of wheat or some wheat bran, and in 21 days, mice will appear. There will be adult males and females present, and they will be capable of mating and reproducing more mice.

In the XVIIth Century, **Francesco Redi** designed an experiment to demonstrate that spontaneous generation was not true.

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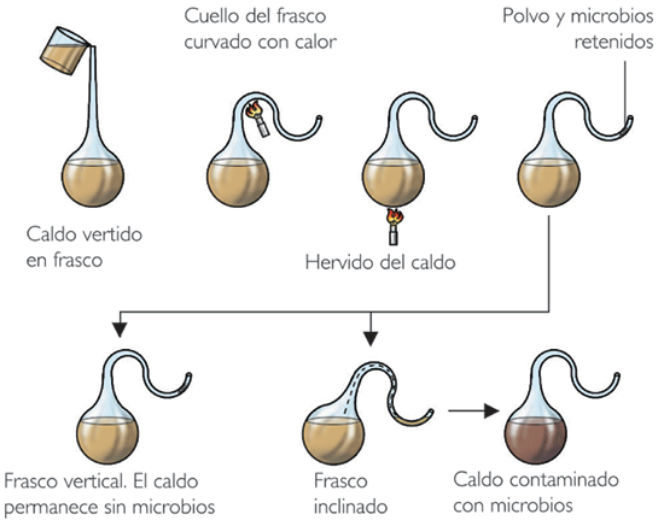
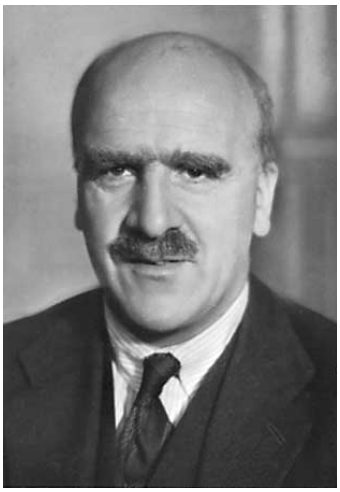
Louis Pasteur (XIXth Century) did another experiment that helped to definitively demonstrate that spontaneous generation was not a valid hypothesis.



As a consequence, scientist agreed that all living things come from another living thing of the same type. So, the next question was: How did first living things appear on Earth for the first time?

Some scientist think that life didn't begin on Earth, but in the outer space. This hypothesis is called panspermia. Life reached the planet on a meteorite that contained bacteria or other simple cells. Although it could be true, this hypothesis only moves the question to other place in the Universe, but it doesn't answer it.

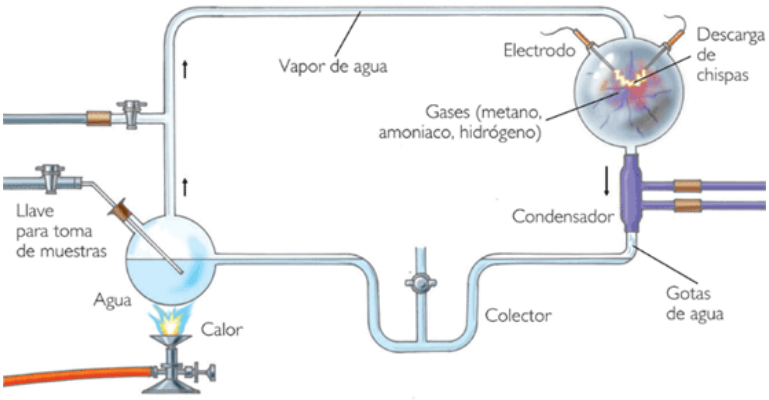
2.1. Origin of biomolecules.



In 1920s, Alexander **Oparin** and John **Haldane** proposed a new hypothesis about the origin of life.

They observed the atmospheric composition of other planets and supposed a primitive Earth atmosphere composition very different to the current atmosphere. They said that atmosphere was made of H_2, HN_3, CH_4 and H_2O. In this time, there was no protection against dangerous radiations and temperatures were higher than today. These conditions made the molecules react and produce the first biomolecules on Earth. They couldn't prove their idea.

But in 1953, Harold **Urey** and Stanley **Miller** did an experiment that proved the hypothesis of Oparin and Haldane.



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2.2. Origin of cells.

Aunque estos experimentos pueden explicar el origen de las biomoléculas, no explican el origen de las primeras células, estructuras de alta complejidad que son la base mínima de todo ser vivo y que están hechas de millones de moléculas que interactúan continuamente unas con otras. Tratar de explicar como un grupo de biomoléculas se transforma en una célula es un reto gigantesco para la ciencia.

Si bien se ha logrado sintetizar materia orgánica a partir de materia inorgánica en los laboratorios, los intentos por generar una célula en el laboratorio a partir de un grupo de biomoléculas han sido, hasta hoy, en vano. El mismo Oparin consiguió crear unas estructuras llamadas coacervados, que consistían en una membrana con un grupo de moléculas dentro que mostraban un metabolismo bastante simple, pero que distaba mucho de ser una célula ya que ni siquiera poseían material genético.

En la década de los sesenta, el bioquímico Sidney Fox consiguió obtener unas estructuras que él bautizó como microesferas proteinoides, formadas a partir de aminoácidos y que él consideró que se parecían a las células primitivas. En cualquier caso, tampoco resolvió el problemas del material genético.

Actualmente se cree que las primeras moléculas que fueron usadas como material genético fueron de ARN, como es el caso de algunos virus que existen en la actualidad.

Así, nos encontramos actualmente sin una teoría convincente y demostrada acerca del origen de las primeras células. Sí se acepta de forma general que las primeras células que aparecieron tuvieron que pertenecer al tipo más simple: células procariotas.

Pero la mayor parte de seres vivos está formado por células eucariotas. La bióloga estadounidense Lynn Margulis (en la fotografía de la derecha, fallecida en 2011) postuló que las células eucariotas proceden de células procariotas que se asociaron en simbiosis. Nace entonces la llamada teoría endosimbionte nade Lynn Margulis, que se basa, entre otras cosas, en que algunos orgánulos celulares, como las mitocondrias y los cloroplastos, tienen una membrana similar a la de los procariotas y material genético propio.

2.3. Chronology of life on the Earth.

Las etapas de la evolución de la vida en la Tierra se podrían resumir como sigue:

I. Evolución prebiótica: existió una evolución química previa a la aparición de los seres vivos: las sustancias químicas inertes pudieron combinarse y formar las biomoléculas más sencillas.

II. Primeras protocélulas: la mezcla de las distintas biomoléculas en un caldo primitivo formó estructuras aún sin vida, pero similares a células, como los coacervados o las microesferas.

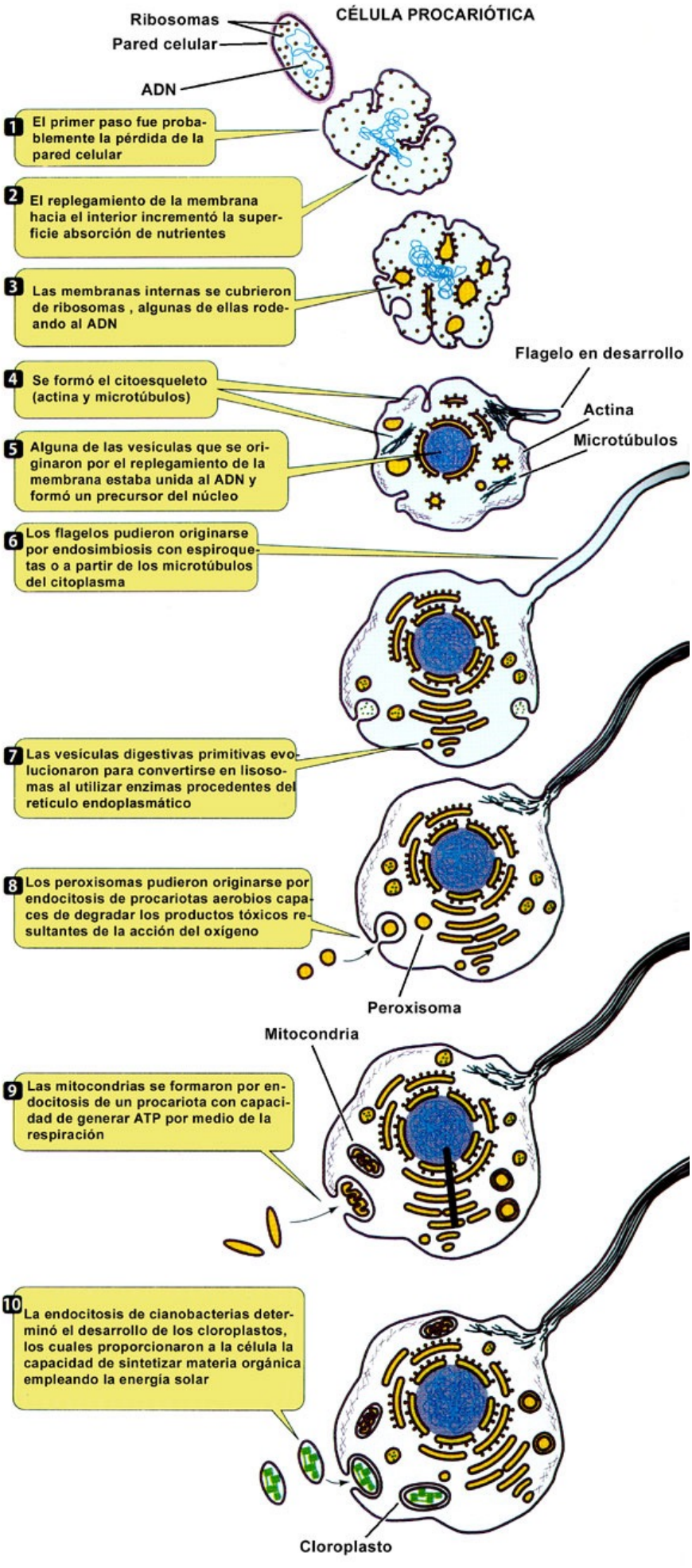
III. Primer material genético: algunas moléculas de ARN pudieron contener algún tipo de información genética y reproducirse.

IV. Células procariotas: la evolución y combinación de las sustancias anteriores aumentó en complejidad hasta obtener una primera célula simple: es el umbral de la aparición de la vida. Los primeros seres vivos fueron unicelulares.

V. Células eucariotas: la simbiosis entre células procariotas llevó a la formación de células más complejas.

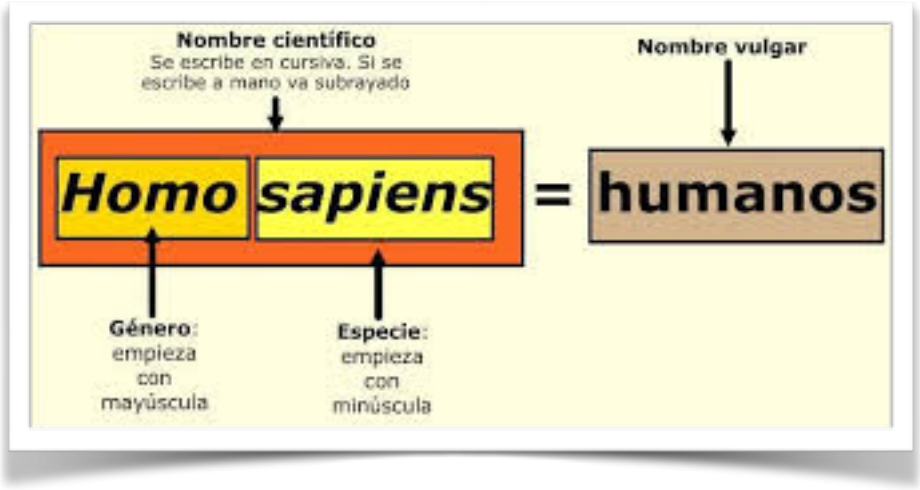
VI. Organismos pluricelulares: la agrupación de células para formar organismos constituidos por un elevado número de células llevó a que se especializarán y se dividieran las funciones vitales.

VII. Aparición de vida inteligente: el desarrollo del cerebro de algunos primates llevó al desarrollo de la inteligencia compleja y del lenguaje.


CÉLULA PROCARIÓTICA
Ribosomas
Pared celular
ADN
1 El primer paso fue probablemente la pérdida de la pared celular
2 El replegamiento de la membrana hacia el interior incrementó la superficie absorción de nutrientes
3 Las membranas internas se cubrieron de ribosomas , algunas de ellas rodeando al ADN
Flagelo en desarrollo
Actina
Microtúbulos
4 Se formó el citoesqueleto (actina y microtúbulos)
5 Alguna de las vesículas que se originaron por el replegamiento de la membrana estaba unida al ADN y formó un precursor del núcleo
6 Los flagelos pudieron originarse por endosimbiosis con espiroquetas o a partir de los microtúbulos del citoplasma
7 Las vesículas digestivas primitivas evolucionaron para convertirse en lisosomas al utilizar enzimas procedentes del reticulo endoplasmático
8 Los peroxisomas pudieron originarse por endocitosis de procariotas aerobios capaces de degradar los productos tóxicos resultantes de la acción del oxígeno
Peroxisoma
Mitocondria
9 Las mitocondrias se formaron por endocitosis de un procariota con capacidad de generar ATP por medio de la respiración
10 La endocitosis de cianobacterias determinó el desarrollo de los cloroplastos, los cuales proporcionaron a la célula la capacidad de sintetizar materia orgánica empleando la energía solar
Cloroplasto

3. DIVERSITY OF LIVING THINGS. EVOLUTION.

In 1753, the Swedish naturalist Carl von Linné wrote a book about the classification of all known living things. To do that, he gave each organism a scientific name (he invented binomial nomenclature). This way of naming living things is still used today. Humans were named *Homo sapiens* for the first time.



But, how is such a huge diversity possible on Earth? This is a question that humans have tried to answer for centuries.

3.1. First theories: creationism and catastrophism.

According to Linné's ideas about the origin of biodiversity (creationism), all known species were created as they are now through an act of creation by God. From that moment till now, species haven't changed at all.

In 1798, another French naturalist, Georges Cuvier, modified that previous theory to explain the existence of fossils. He said that after creation, a series of catastrophic events (p.e universal deluge) made some species extinct.

3.2. Evolutionist theories.

Evolutionist theories explain biodiversity through a series of gradual and continuous changes from the first living things. Thus, all current species come from others that don't exist now. The most famous evolutionist theories are: Lamarckism, Darwinism and Neo-Darwinism.

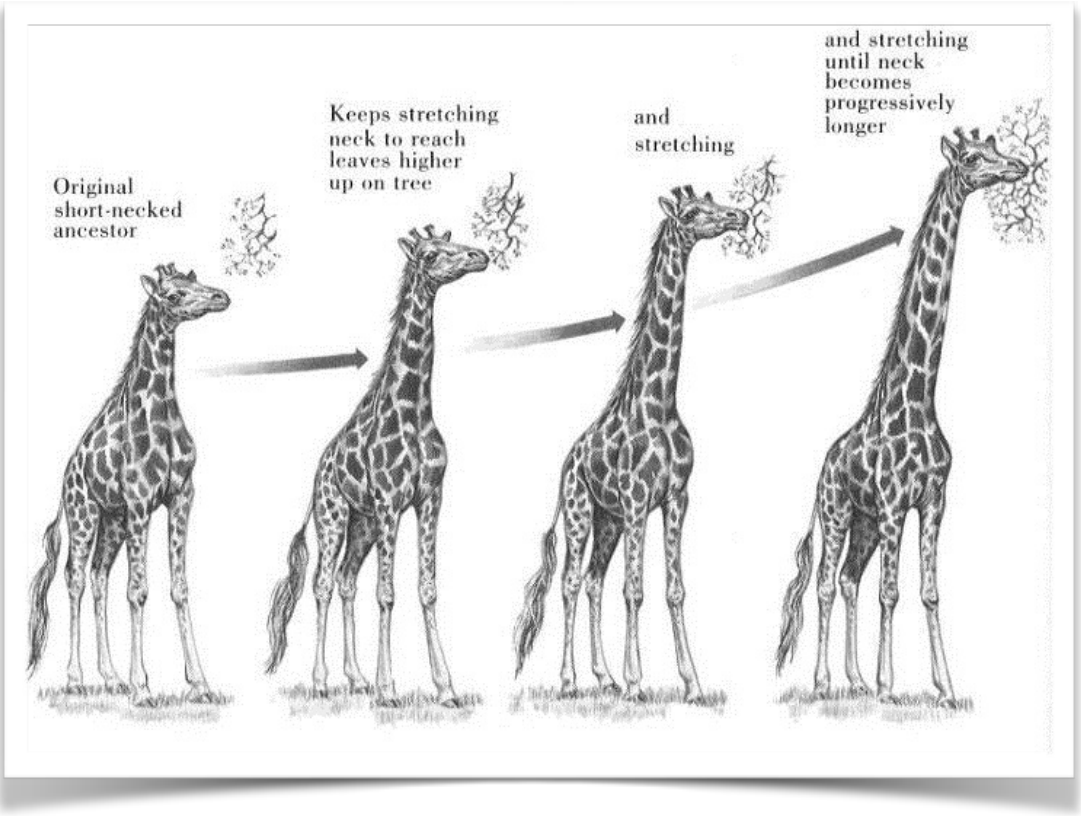
(a) Lamarckism.

In 1809, a French naturalist called Jean-Baptiste Lamarck published *Filosophie zoologique.* In that book, he affirmed that species can change through time as they adapt to the environment. The gradual accumulation of those changes caused the appearance of new species.

Lamarck based his theory on two main arguments:

- “The function creates the organ”: according to Lamarck’s observations, a lot of species are perfectly adapted to the place in which they live. Every organism seems to have developed organs specially prepared to obtain resources from the environment. Lamarck supposed that if a species needs to perform a specific function, it will strengthen the organ needed for that particular function.

- “Acquired characteristics can be passed on the offspring”: connected to the previous argument, Lamarck believed that the offspring received from the parents that more developed organ. That organ will be used again in the same way and it will develop a little more in that new generation, and so on. After lots of generations, the accumulation of changes can make possible the appearance of new species.



But Lamarck couldn’t prove his hypothesis and two objections helped to discredit his theory:

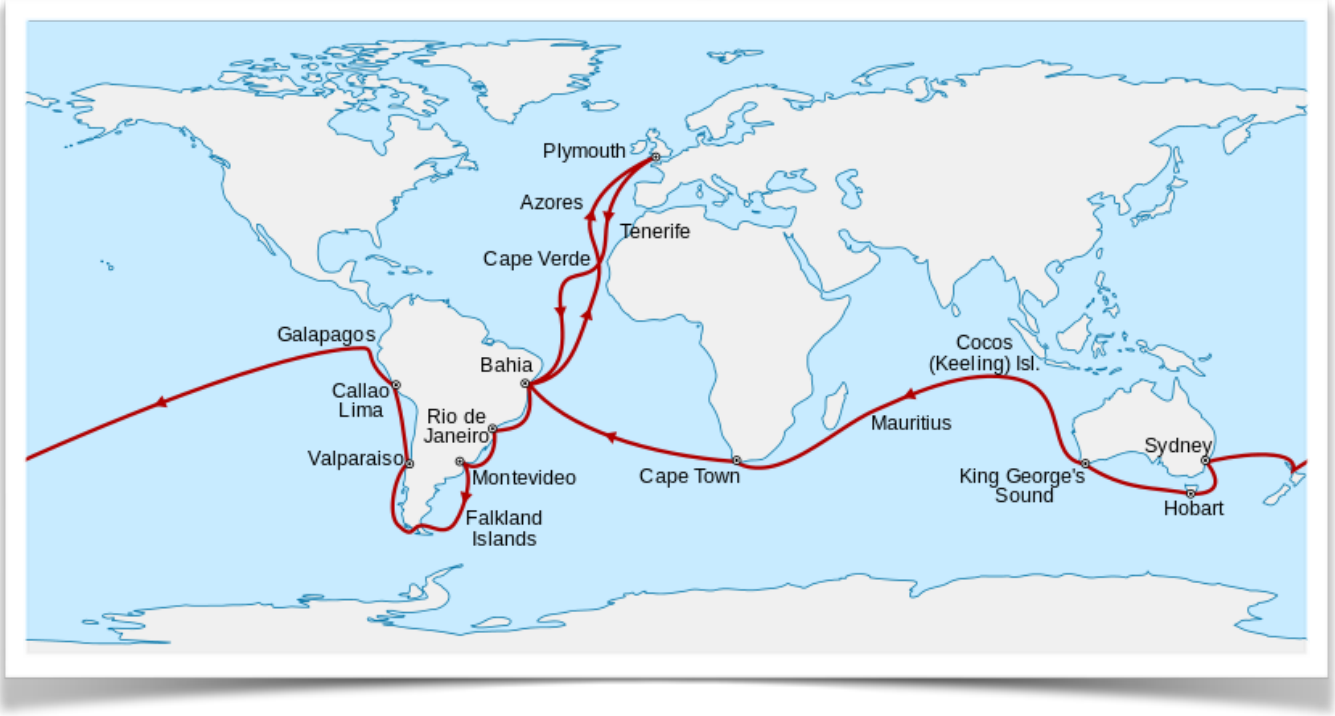
- Not all organs can change if they are constantly used.

- Acquired characteristics cannot be passed on to the offspring.

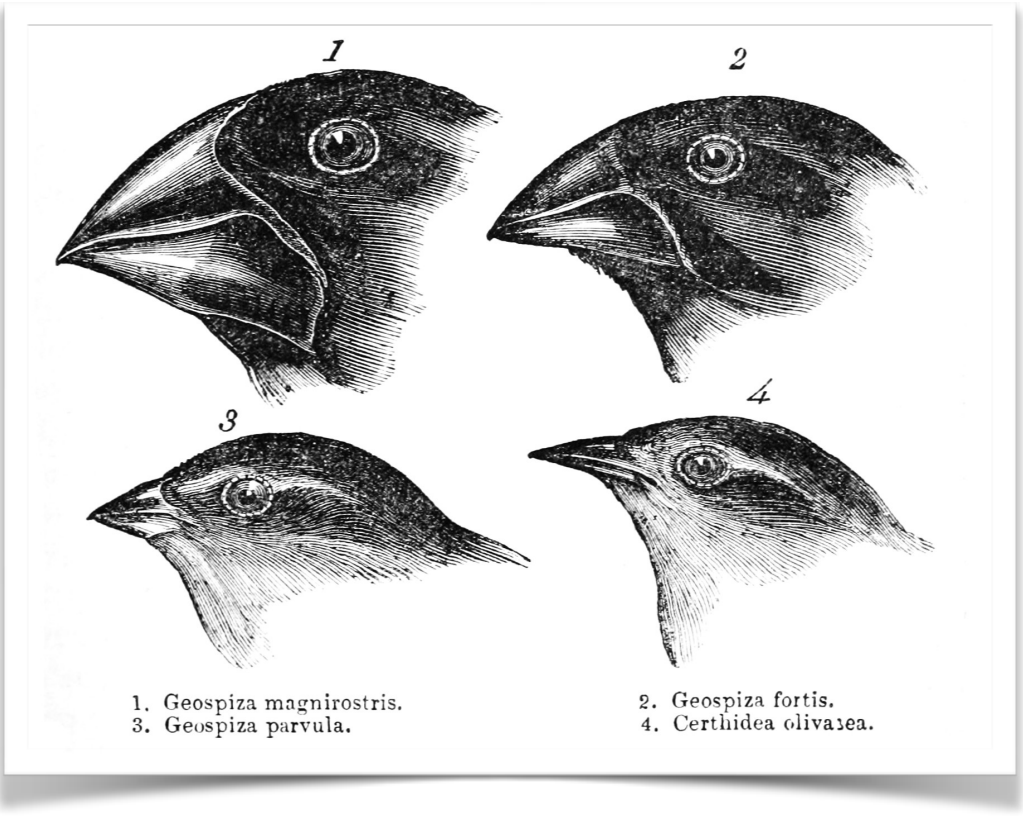
Although Lamarck ideas were disproven, his hypothesis was one of the first attempts to explain the evolution of species.

(b) Darwinism.

The British naturalist Charles Darwin participated in a scientific expedition on the Beagle. This travel started in 1931 and lasted five years. During this travel he picked a lot of samples and data about living things in a variety of places.



One of the most relevant studies was one about the animal in Galapagos islands, were he found similar species with very specific differences between them. There was a different species of mockingbird in each island with different beaks adapted to the type of food available in every particular island.



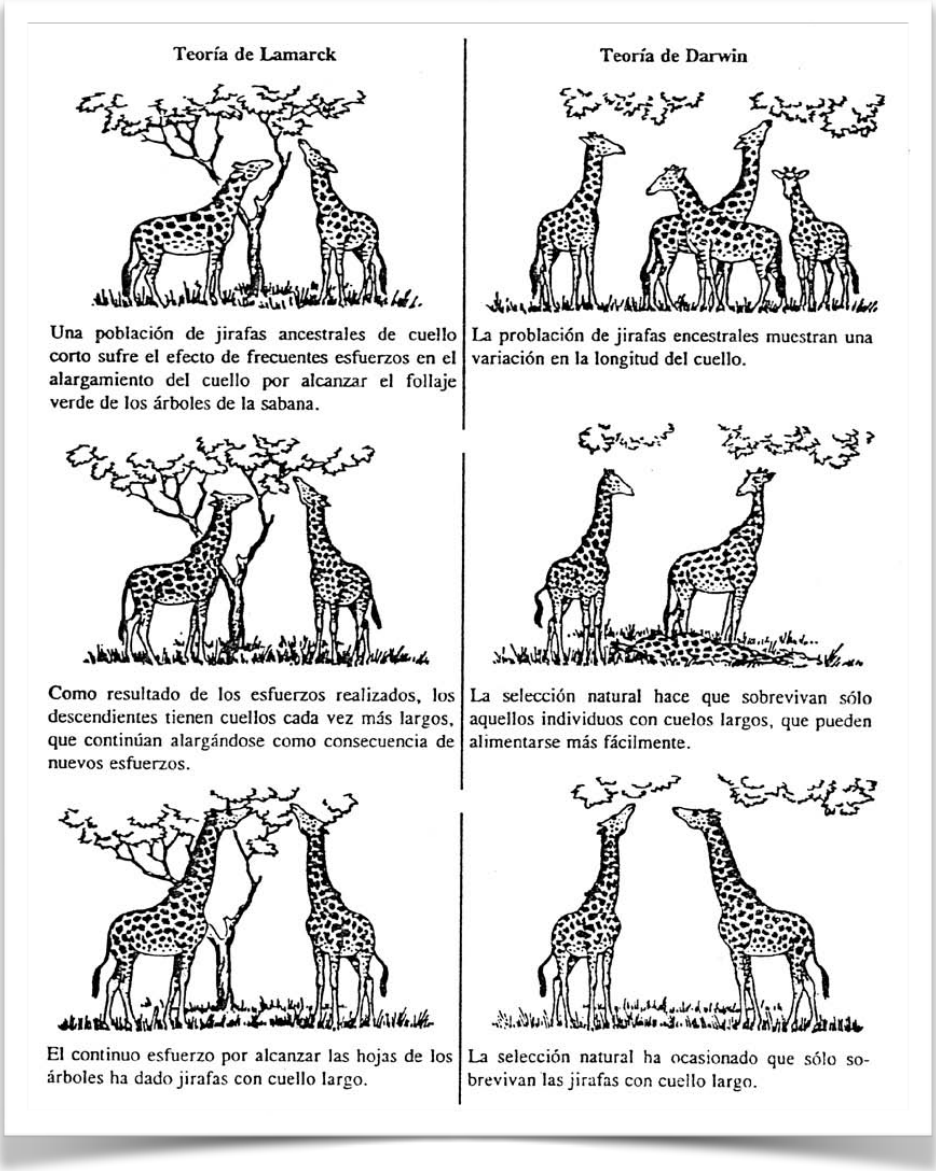
Years later, using all this data, wrote *The origin of species*. In this book, he proposed that all species come from preexistent ones, but thanks to a mechanism completely different to the one proposed by Lamarck.

Darwin proposed a new mechanism for evolution called Natural Selection:

- All living things have such fertility that their population size could increase rapidly forever.
- Actually, the size of populations does not increase to this extent. Mostly, numbers remain about the same.
- Food and other resources are limited. So, there is competition for food and other resources.
- No two individuals are alike. Therefore, they do not have the same chance to live and reproduce.
- This variation is inherited. The parents pass the traits to the children through their genes.
- The next generation comes from those that survive and reproduce. The elimination is caused by the relative fit between the individuals and the environment they live in. After many generations, the population has more helpful genetic differences, and fewer harmful ones. Natural selection is really a process of elimination.

(c) Neo-Darwinism.

The advance of science has made possible to explain some facts that Darwin couldn't. Today, we know what's the origin of diversity in the offspring (mutations and recombination during meiosis). We know the structure of DNA. We also know how characteristics can pass from one generation to the next one. Basically, Neo-Darwinism is the modern version of classical Darwinism.



3.3. Evidence for evolution.

Evolution theory is based on a series of proofs that support it. These proofs come from several disciplines: palaeontology, anatomy, biochemistry and embryology.

- **Palaeontology**

Palaeontology studies fossils. Their distribution and characteristics give us lots of information:

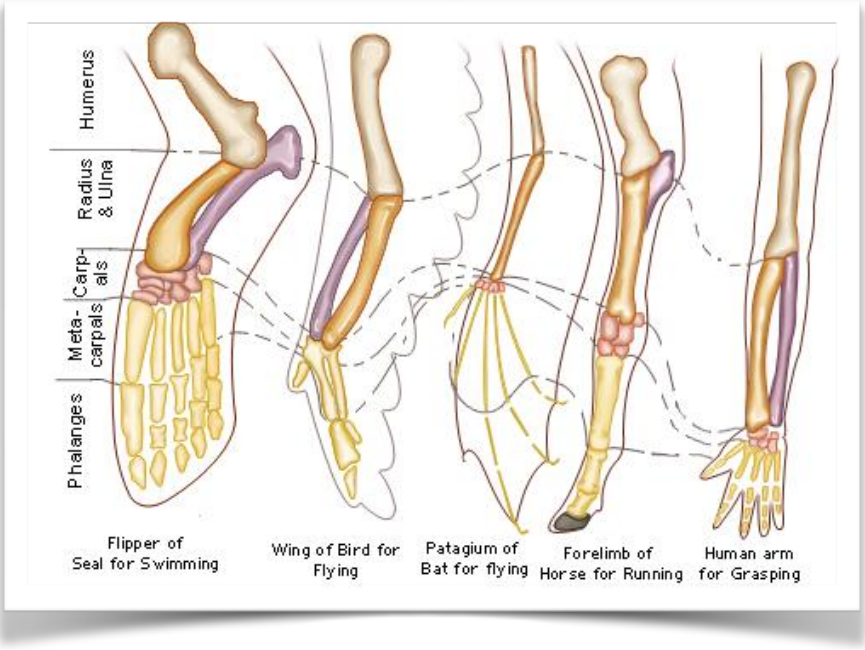
- Older fossils belong to simpler living things, newer ones belong to complex organisms
- Fossils diversity grows as time goes on. There is a low diversity among older fossils and high diversity among newer ones.
- There are fossil with mixed characteristic between two species. This make it possible to observe the evolution from one species to another.

- Fossilisation process is complex so there aren't fossils from all species that have inhabited the Earth. Although we don't have all the fossils, it's possible to establish relationships between all living things.

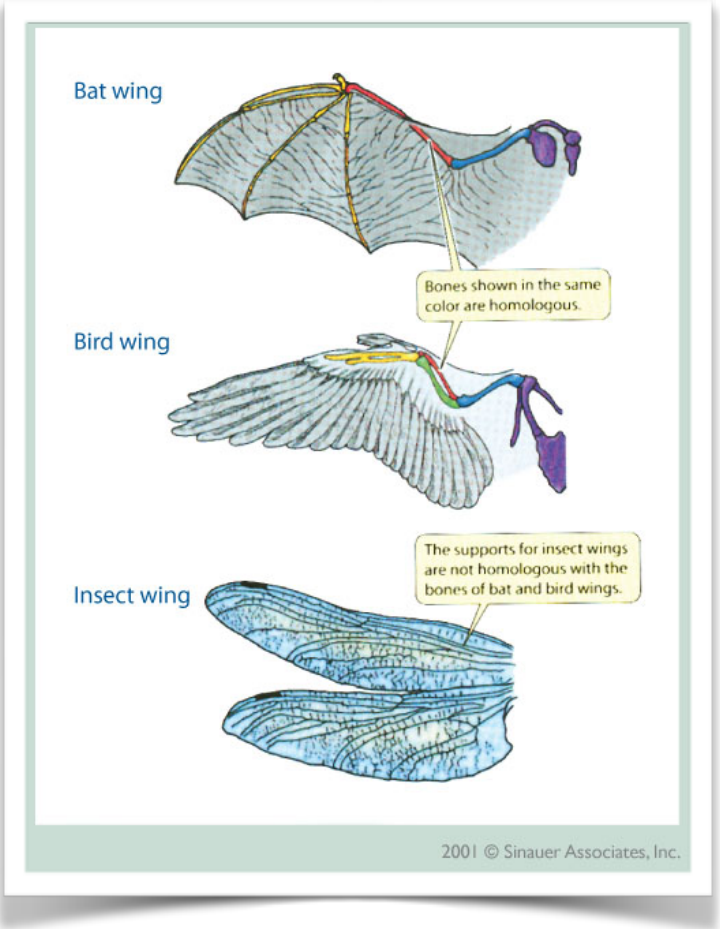
- **Anatomy**

Compared anatomy studies the similarities and differences between organs and organ systems of different living things. They study structure and function of these organs.

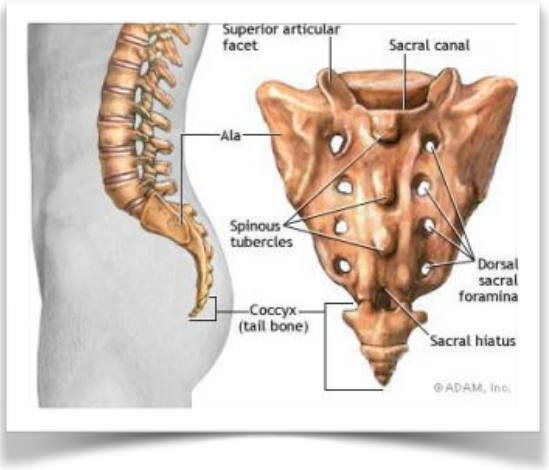
- Homologous organs are those with the same structure but different functions. Their presence is an evidence of divergent evolution. Species with homologous organs share a common predecessor but they have adapted the function of the organ or system to the environment they have been living in.



- Analogous organs are those with different inner structure but similar function. Their presence is an evidence of convergent evolution. Species with analogous organs don't share a common predecessor, but they show the importance of adaptation to the environment.



- Vestigial organs are organs with no clear function in the organisms. Their presence shows similarities between species. Some of them still use the organ/s meanwhile some of them have stopped using it/them. Species with vestigial organs are related to those that still use the organ/s.

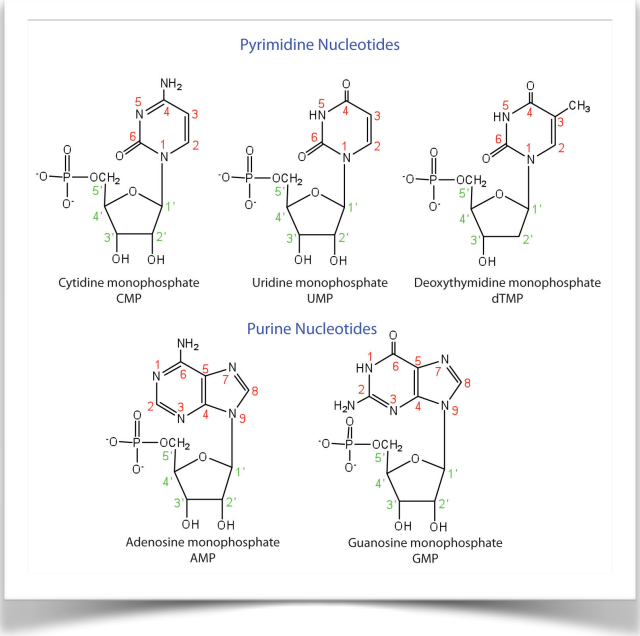


- **Biochemistry**

Biochemistry studies the chemical compounds that living thing are made of and how they react with each other. All living things show some common biochemical characteristics.

- Cell membranes of all cells are made of similar lipids.

- In all living things, genetic material is made of a chain of nucleotides. There are only five different nucleotides and they are present in all types of living things.



- All proteins are made of the same 20 different amino acids. The only difference between proteins is the order and number of them.

- The way all living things translate the information contained in the genetic material is basically the same for all species. Comparative studies about DNA composition of different species prove that the highest the relationship between species, the highest the similarities between their DNA composition.

This group of biochemical evidence for evolution can only be explained if we assume the existence of a common predecessor for all types of living things, as evolution theory states.

• **Embryology**

Embryology studies the process of development of living things. Similar developments between species show high relationship.