5

The Nature of Life on Earth

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LEARNING GOALS

5.1 DEFINING LIFE
- What are the general properties of life on Earth?
- What is the role of evolution in defining life?
- What is life?

5.2 CELLS: THE BASIC UNITS OF LIFE
- What are living cells?
- What are the molecular components of cells?
- What are the major groupings of life on Earth?

5.3 METABOLISM: THE CHEMISTRY OF LIFE
- What are the basic metabolic needs of life?
- How do we classify life by its metabolic sources?

5.4 DNA AND HEREDITY
- How does the structure of DNA allow for its replication?
- How is heredity encoded in DNA?
- How does life evolve?

5.5 LIFE AT THE EXTREME
- What kinds of conditions can life survive?
- Are extremophiles really extreme?

THE PROCESS OF SCIENCE IN ACTION

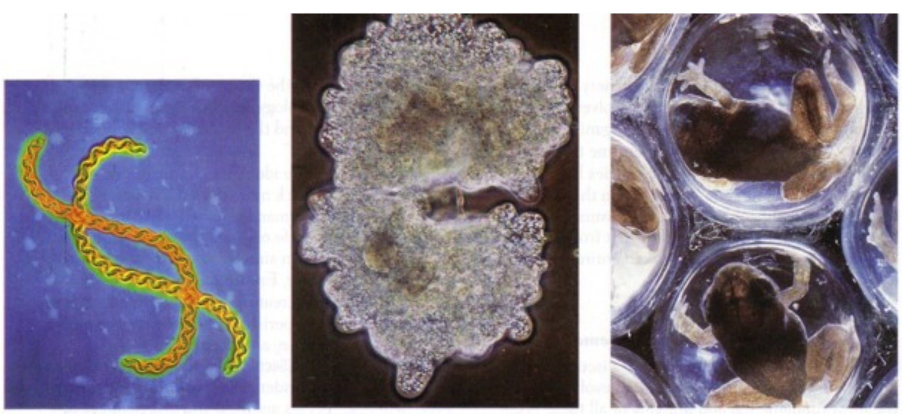
5.6 EVOLUTION AS SCIENCE
- Is evolution a fact or a theory?
- Are there scientific alternatives to evolution?

We will learn some basics definitions about "life" as we know it. It is difficult to imagine life elsewhere not functioning in a similar way.

Defining Properties of Life on Earth: What is Life?

- Order
  molecules organized in specialized patterns, not random
- Reproduction
  offspring have "genetic" material of parent(s)
- Growth and Development
  heredity – traits passed to offspring from parent(s)
- Energy Utilization
  metabolize – fuel to create/maintain ordered patterns, reproduce, grow
- Response to Environment
  actively respond to environmental changes
- Evolutionary Adaptation
  long term responses to environment and interactions between organisms affect changes in traits by survival of most adapted members of species; critical for life to survive over long time periods and across many environments

Order, Reproduction, Growth and Development



a Order: All living organisms exhibit order in their internal structure, as is apparent in this microscopic view of spiral patterns in two single-celled organisms.

b Reproduction: Organisms reproduce their own kind. Here, a single-celled organism (an amoeba) has already copied its genetic material (DNA) and is now dividing into two cells, each of which will be genetically identical to each other and to the original cell.

c Growth and development: Living organisms grow and develop in patterns determined at least in part by heredity. Here, we see growing embryos of a Costa Rican frog.

Energy Utilization, Response to Environment, Evolutionary Adaptation

d Energy utilization: Living organisms use energy to fuel their many activities. Here, we see tube worms living near a deep sea volcanic vent. These organisms obtain much of their energy from chemical reactions made possible in part by the heat released from the volcanic vent.

e Response to the environment: Life actively responds to changes in its surroundings. Here, we see a blacktail jackrabbit's ears flush with blood; the blood flow adjusts automatically to help the animal maintain a constant internal temperature by adjusting the heat loss from the ears.

f Evolutionary adaptation: Life evolves in a way that leads to organisms that are adapted to their environments. Here, the white feathers of the white-tail ptarmigan in winter plumage make it nearly invisible against the animal's snowy surroundings.

The Theory of Evolution

Darwin's Inescapable Conclusion

Facts (Premises):

1. Overproduction and Struggle for Survival

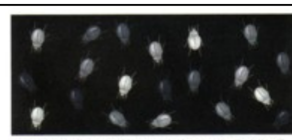
   Creates population pressure, struggle for survival among individuals in population

2. Individual Variation

   No two individuals alike, some traits "better" under population pressure for given environment

Conclusion…

Unequal reproductive success of individuals- those best adapted become progressively more common



a This imaginary beetle population has colonized a locale where the soil has been blackened by a recent brush fire. Initially, the population varies extensively in the coloration of individuals, from very light gray to charcoal.

b For hungry birds that prey on the beetles, it is easiest to spot the beetles that are lightest in color.

c The selective predation favors the survival and reproductive success of the darker beetles. Thus, genes for dark color are passed along to the next generation in greater frequency than genes for light color.

d Generation after generation, the beetle population adapts to its environment through natural selection.

FIGURE 3.2 Natural selection is the primary mechanism of evolution. Here, we see how an imaginary population of beetles of mixed color evolves into one in which all the beetles are dark in color.

The Theory of Evolution
Story of Galapagos Finches

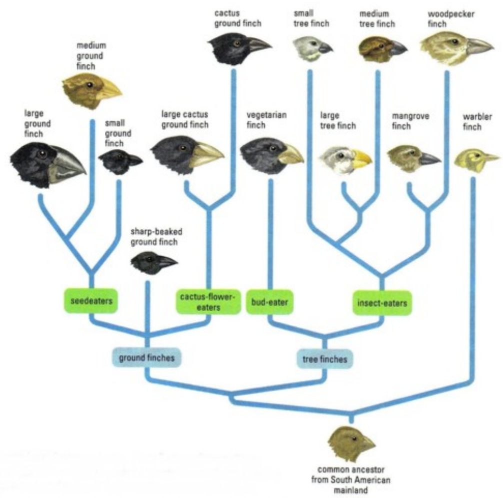
Traits in common with single ancestor from South American main land

Each island has slightly different environment and pressures for survival

Beaks are key to food intake…

With time, each island's population diverges from the ancestor according to the local environmental conditions… this is called **Natural Selection**

Eventually, some finches are seed eaters, others bud eaters, others insect eaters, depending upon isolated local environment – and the shape and functionality of their beaks reflect this



The Theory of Evolution
Story of Wild Mustard

Wild mustard was bred by humans into six different vegetables… this is called **artificial selection**

Evolution on the Molecular Level!

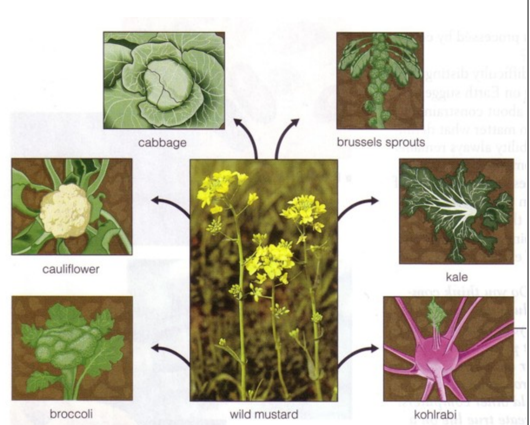
Implications: Organisms built from instructions contained in a molecule or set of molecules…

DNA = **d**eoxyribo**n**ucleic **a**cid

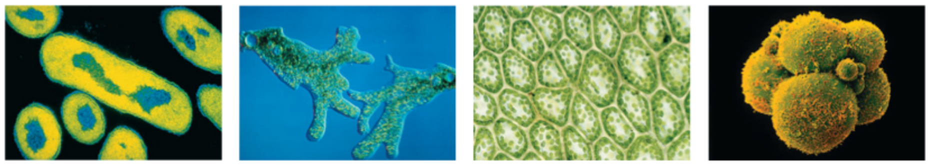
With this knowledge, we can understand the specific mechanisms that manifest natural and artificial selection

Evolution becomes a scientific model!

Evolution is critical to the survival of life across many changing environments over long time periods.



Living Cells- Basic Life Unit



a Bacteria b Amoebas c Plant cells d Animal cells

There are 4 basic cell type. Cells are a defining characteristic of life

Living matter resides inside protected by an external **membrane**- structure that protects molecules used for growth, and reproduction

Some organisms simple, single cell

Other organisms complex, trillions of cells work cooperatively for growth and reproduction

Since all life as we know it is built using cell units with some overlapping commonality in their DNA, we infer that all life originated from a single organism

Carbon Based Life

Carbon by Number, But Oxygen by Mass

Life is based upon 20 different chemical elements

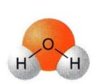
Four of these make up 96% of the mass in cells

Oxygen …… 65.0%
Carbon …… 18.5%
Hydrogen …. 9.5%
Nitrogen …… 3.3%

Why not Oxygen based life???

Most Oxygen is bound in water molecules!

FIGURE 3.7 A water molecule has a single oxygen atom bonded to two hydrogen atoms.



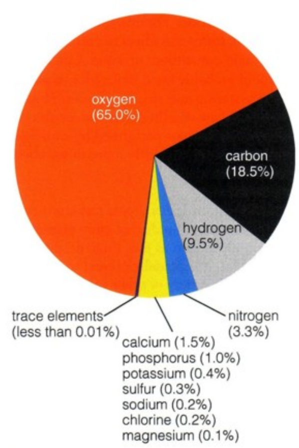
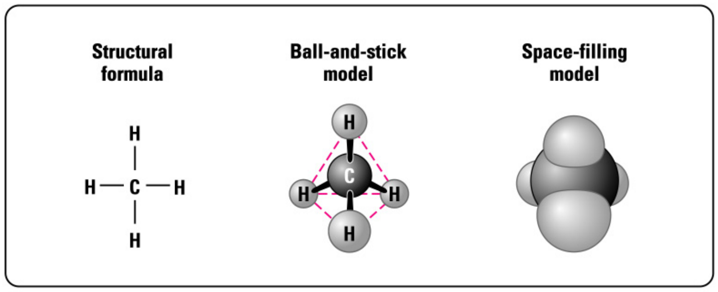


FIGURE 3.6 This pie chart shows the chemical composition of the human body by weight; this composition is fairly typical of all living matter on Earth.

Carbon has greatest diversity and strength of chemical bonds (4 bonds at a time!)

Oxygen can do 2 bonds at a time
Hydrogen can do 1 bond at a time

Molecular Structures



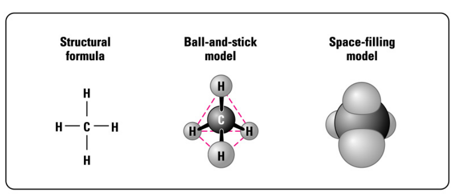
Though we will mostly view the "Structural formula" models, note the three-dimensional configuration of the more telling "Ball-and-stick" model.

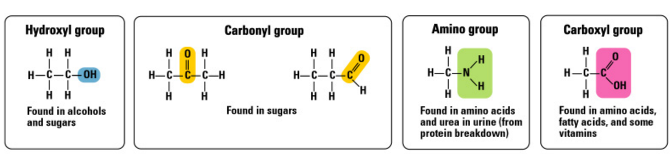
The "H" atoms are as far apart from one another as possible due to the repulsion of the positively charged nuclei.

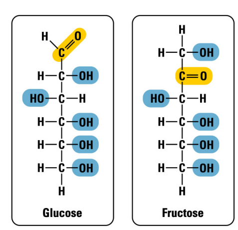
The "Space filling" model shows the "electron clouds".

Molecular Structures

Functional Groups in Biology and Metabolism







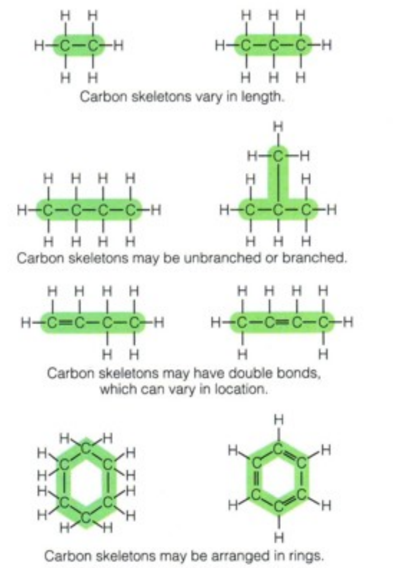


FIGURE 3.8 These diagrams represent several relatively simple hydrocarbons —organic molecules consisting of a carbon skeleton attached to hydrogen atoms. The carbon skeletons are highlighted in green. Each single line represents a single chemical bond; a double line represents a double bond. Note that every carbon atom has a total of four bonds (a double bond counts as two single bonds).

Organic Molecules

Carbon is most versatile…

Forming anywhere from 1 to 4 bonds at a time!

Carbon based molecules are called **hydrocarbons**…
carbon skeletons bonded with hydrogen atoms

Complex organic molecules are hydrocarbons with other elements bonded in them

= double bonds
- single bonds

Silicon (also abundant in the universe) is very similar to carbon, but cannot form double bonds and its single bonds are significantly weaker than carbon bonds

Chirality = "Handedness"

In nature (and in outerspace), molecules come in both "left" and "right" handed **chirality**…

ALL life on earth utilizes only "left" handed chirality.

Since molecules operate on a "lock and key" basis, it would be expected that this phenomenon of single handedness would be present in life elsewhere in the universe.

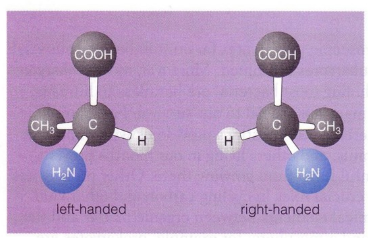


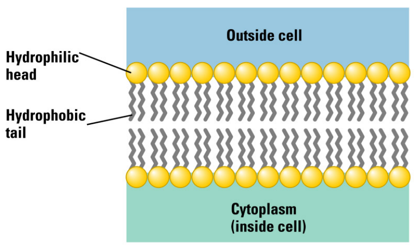
FIGURE 3.10 Any particular amino acid can come in two forms, distinguished by their handedness. These diagrams show the left- and right-handed versions of the amino acid alanine. The two versions are mirror images of each other.

Molecular Components of Living Cells

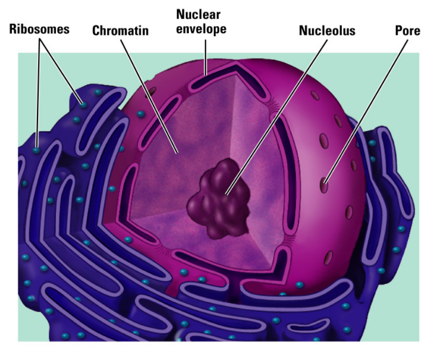
Four main classes of complex organic molecules in cells…

1. Carbohydrates - provide energy, build sturdy structures (cellulose, fiber, cell integrity)
2. Lipids - fats, store energy for future use, form cell membranes (protective barriers)
3. Proteins - work horse of cells, long carbon chains built from amino acids
4. Nucleic Acids - DNA (genetic), RNA (messenger and transfer molecules)

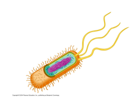
Here again, is the organization and specialization phenomenon for life's self sustenance.



(a) Phospholipid bilayer of membrane



Two Basic Cell Types



All living cells based upon same molecules and common chemistry… but two types…

Prokaryotic Cell

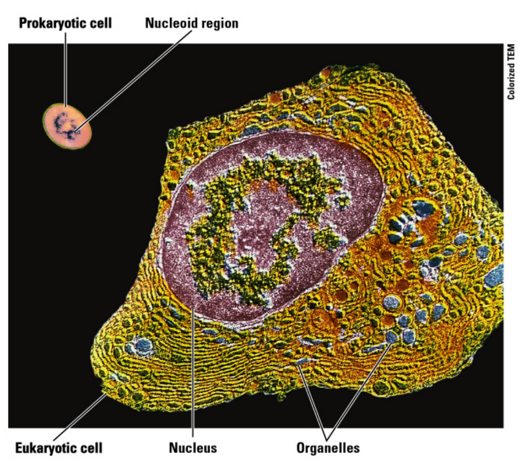
- most common
- simple, single celled only
- smaller
- have NO nucleus
- Prokaryotes: Bacteria and Archaea
- E-coli & Salmonella

Genetic material not as protected

Eukaryotic Cell

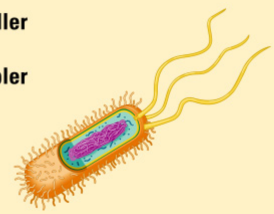
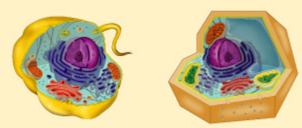
- complex, single or multicellular
- larger
- have nucleus
- Eukarea
- single celled include Amoeba

Genetic material "double" protected



Eukaryotes need Prokaryotes to survive!

Two Basic Cell Types

Prokaryotes	Eukaryotes
• Smaller	• Larger
• Simpler	• More complex
	
• Most do not have membrane-enclosed organelles	• Membrane-enclosed organelles
• Bacteria and archaea	• Protists, plants, fungi, animals

Three Domains of Life (by cell type)

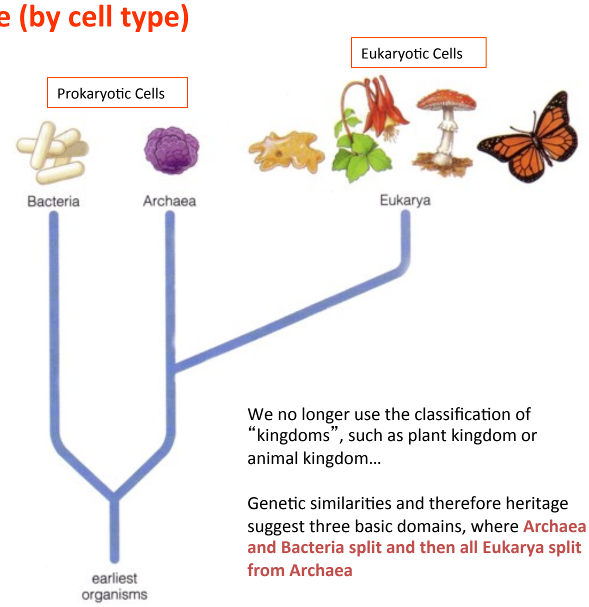
Bacteria and Archaea are both **Prokarya**…

All animals and plants are **Eukarya**…

Genetically, Archaea and Eukarya are more similar to one another than are Bacteria and Archaea

This has implication for the evolution of life on Earth…

The relative fractions of commonality of DNA between Archaea, Eukarya, and Bacteria is another reason we believe that all organisms had a common ancestor.



We no longer use the classification of "kingdoms", such as plant kingdom or animal kingdom…

Genetic similarities and therefore heritage suggest three basic domains, where **Archaea and Bacteria split and then all Eukarya split from Archaea**

Classifying Life by Metabolic Sources

What are the basic metabolic needs of life?

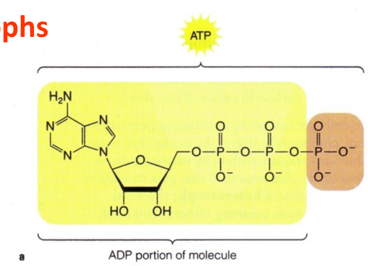
(1) a source of raw materials to build cellular structures, with carbon as the most important of these materials
(2) a source of energy to fuel metabolic processes

Table 3.1 Metabolic Classifications of Living Organisms

Metabolic Classification	Carbon Source	Energy Source	Examples
Photoautotroph	Carbon dioxide	Sunlight	Plants, photosynthetic prokaryotes
Chemoautotroph	Carbon dioxide	Inorganic chemicals (e.g., iron, sulfur, ammonia)	Certain prokaryotes, especially in extreme environments
Photoheterotroph	Organic compounds	Sunlight	Certain prokaryotes
Chemoheterotroph	Organic compounds	Organic compounds	Animals, many prokaryotes

Photo = sunlight Auto = carbon dioxide only
Chemo = chemicals Hetero = organic compounds

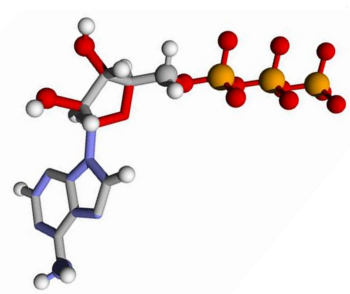
Metabolism in Chemoheterotrophs



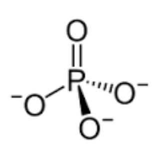
ATP Power

ADP = adenosine diphosphate

ATP = adenosine triphosphate

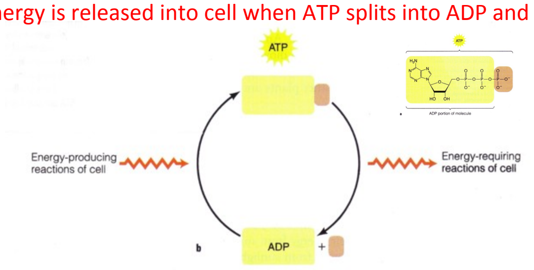


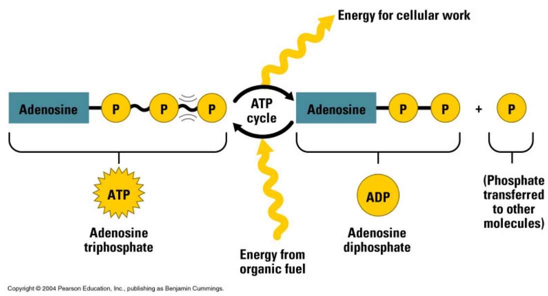
The **phosphate** group is critical in metabolism and in DNA



bonding and bond breaking of the phosphate group from the ADP molecule is the energy source in the cell

Energy from food is used to bond phosphate group to ADP to form ATP
Energy is released into cell when ATP splits into ADP and a Phosphate





https://www.youtube.com/watch?v=dDBU0lg-HYE&spfreload=10
VIDEO: carbon cycle and metabolism 5:30

DNA = Deoxyribonucleic Acid

Discovered less than 50 years ago

Spiral stranded "double helix" structure is very robust, like a skeleton.

The connecting "teeth" within the stands are called the **DNA bases**, and these bases hold the keys to heredity through DNA *replication*.

A = adenine
G = gaunine
T = thymine
C = cytosine

T links to A only
C links to G only

Four bases in different combinations along a DNA strand manifest all forms of life within and across species and plants!

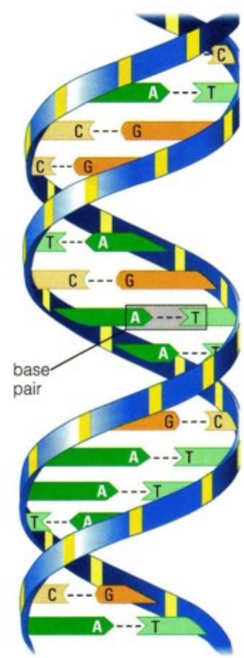
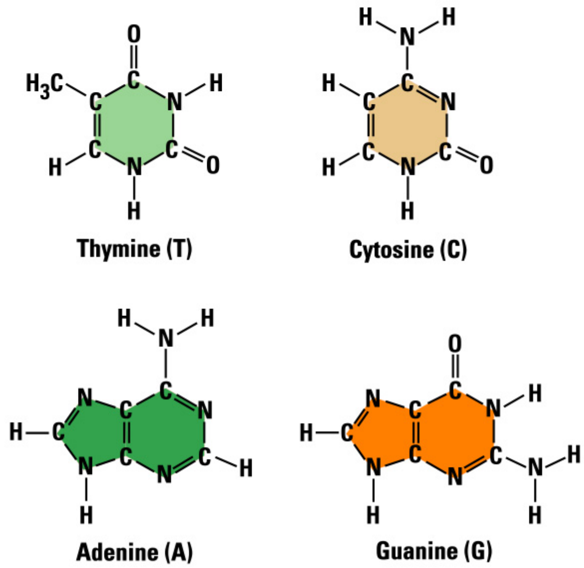
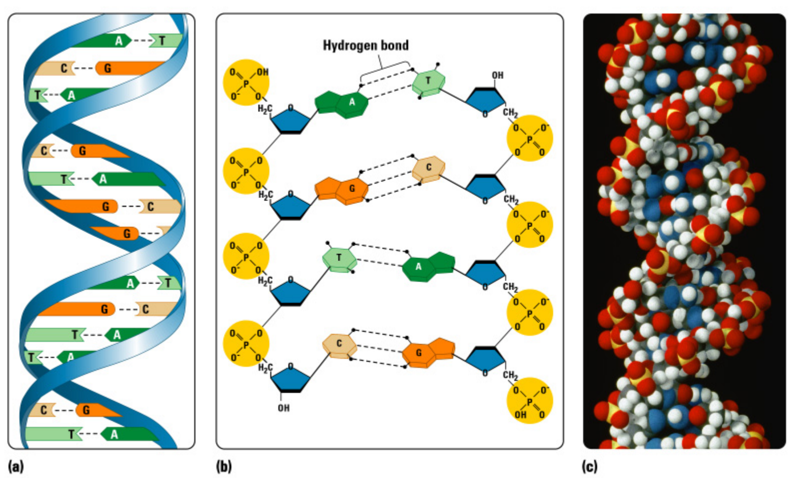


FIGURE 3.14 This diagram represents a DNA molecule, which looks much like a zipper twisted into a spiral. The important hereditary information is contained in the "teeth" linking the strands. These "teeth" are the DNA bases. Only four DNA bases are used, and they can link up between the two strands only in specific ways: T attaches only to A, and C attaches only to G. (The color coding is arbitrary and is used only to represent different types of chemical groups; in the backbone, blue and yellow represent sugar and phosphate groups, respectively.)

DNA Bases

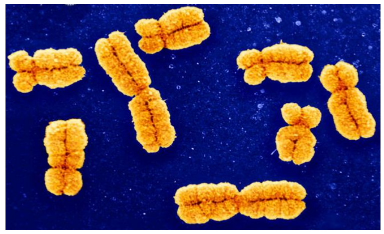


DNA Bonding Structure

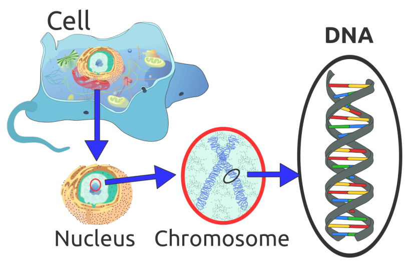


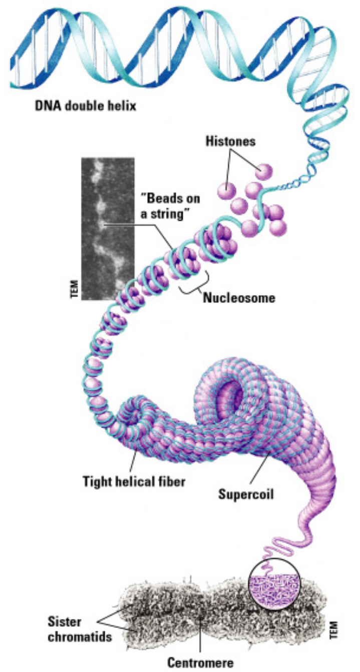
DNA Packaging

Organism	Number of chromosomes
pea plant	14
sun flower	34
cat	38
puffer fish	42
human	46
dog	78

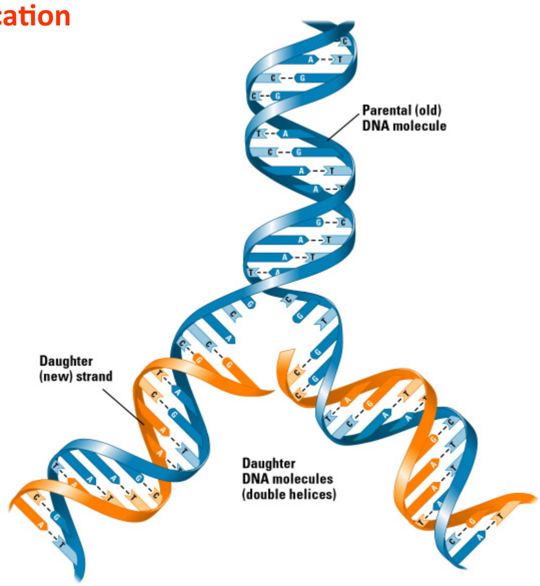


Chromosomes- where DNA is packaged

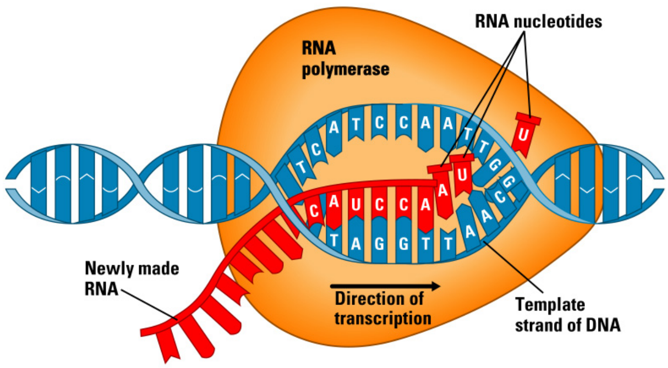




DNA Replication



DNA Replication

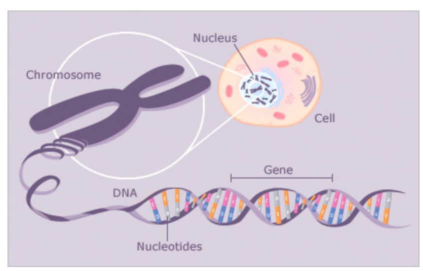


(a) A close-up view of transcription

https://www.youtube.com/watch?v=27TxKoFU2Nw&spfreload=10
DNA replication explained 5:45

https://www.youtube.com/watch?v=yqESR7E4b_8&spfreload=10
DNA replication in real time 7:47

Mutations (Accidents and Evolution)



Review the parts of DNA…

1. Gene
   Sequence of base pairs that hold instructional code to building a specialized component to the organism, i.e. hair, fingernail, etc.
2. Genome
   All the gene's of an organism, the full sequence of base pairs in all 46 chromosomes.

The human genome of 46 chromosomes consists of 3 billion DNA bases, which contain 30,000 to 120,000 genes. The Human Genome Project has mapped the entire human genome!!!

"Different cell types, such as muscle cells or brain cells, differ only because they express, or actually use, different portions of their full set of genes.

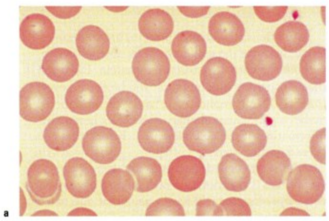
Mutations (Accidents and Evolution)

Some bacteria can copy their full genome in minutes.
A human cell can copy its full genome in a few hours!

Errors can happen…

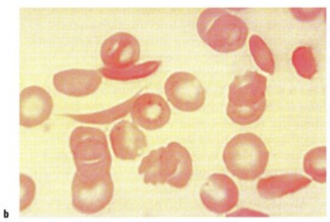
- Wrong base attached in a base pair
- A base deleted in a gene
- Extra base inserted into a gene
- Modification from radiation
- Modifications from chemicals (carcinogens)

Example: Sickle-cell blood cells resulted from genetic mutation- an A changed to a T at one location in the gene that makes hemoglobin molecules


a

These cells glob tiny blood vessels more easily and can cause a debilitating disease. Why in so many people have it in Africa and tropical areas?

It suppresses malaria! Son in these regions it is an advantage to have the mutation. Those with the mutation live longer, reproduce more offspring with the mutation. The mutation becomes the dominant genetic expression. Unequal reproductive success!!!


b

Mutations (Accidents and Evolution)

No punctuation… so insertion/deletion of a base can mess things up…

	Base Sequence of Gene	Biological "Meaning"
Common	"…thefatcatatetherat…"	"the fat cat ate the rat"
Offset +1	"…theafatcatatethera…"	"the afa tca tat eth era t"
Offset -1	"…thfatcatatetheratd…"	"thf atc ata tet her atd"

Now, the gene makes biologically nonsensical (or at least modified) proteins, amino acids, or hemoglobin, etc.

(mutations and evolution in action)

In the case of sickle cells, the mutation provided a resistance to malaria- thus, more individuals with sickle cells survived and had offspring- it proved to result in better adaptation to the environment and became more common in the gene pool.

Extremophiles

"lovers of the extreme"
life at the extreme

Black Smokers

Temperatures of 750 degree F.
Water boils at 212 F, but pressures so high that the water does not boil.

Prokaryotes (Archaea), metabolize sulfuric acid and they get their carbon from carbon dioxide

These are Chemoautotrophs

These "thermophiles" would die in in the sunlight and in an oxygen atmosphere

Some "extremophiles" can survive in our environment, while others would not (more versatile than eukaryotes like ourselves!

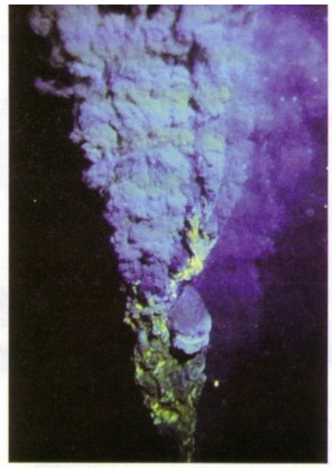


FIGURE 3.17 This photograph shows a black smoker—a volcanic vent on the ocean floor that spews out extremely hot, mineral-rich water.

Tubeworms (yum!) live off the Archaea around black smokers!

In the outskirts of those ecosystems white crabs and clams thrive

Outside a certain radius, the back bottom deep ocean is pretty devoid of these "higher" life forms.

Extremophiles

Thermophiles are adapted to different temperature ranges.

In this hot spring, the different colors are the reflected light from thermophiles living at different temperatures in the sulfur rich water

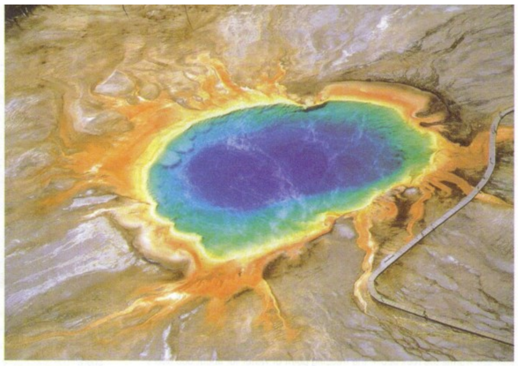


FIGURE 3.18 A hot spring in Yellowstone National Park. The different colors in the water are from different microbes that survive in water of different temperatures. To get a sense of scale, note the walkway winding along the lower right.

Extremophiles

<u>Endospores</u> are prokaryotic "resting" cells

<u>Lithophiles</u> have been discovered most recently, and as far south as Washington and Oregon!

These organisms obtain nutrients from chemical in the rocks and get their carbon from carbon dioxide (chemoautotrophs).

This is the type of life we might expect to exist on Mars!

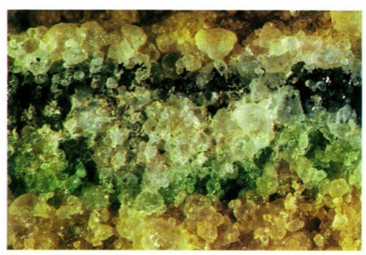


FIGURE 3.20 This photograph shows a slice of rock from a dry valley in Antarctica. The colored zones contain microbes that live inside the rock. Microscopic algae, fungi, and bacteria live in the airspaces between tiny mineral grains. During most of each year, the organisms are frozen, but sunlight warms the rock above the freezing point of water for about 500 hours each year. The piece of rock shown is 1.8 centimeters across.

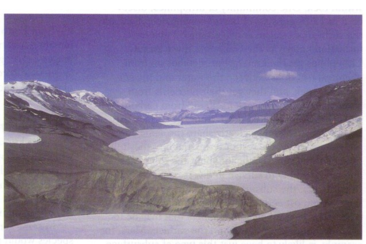


FIGURE 3.19 A dry valley in Antarctica. The valleys are deserts with extremely little rain or snowfall. The ice in the valley comes from runoff from surrounding regions.

Extremophiles

Consider *Bacillus anthracis* (causes deadly disease of “anthrax”)

This **endospores** can survive with *NO water*, in *extreme heat* or *extreme cold*, and even in the *vacuum of space*!!!

They could easily travel from one plant to another in the solar system and possibly even persist between the stars (we do not know how long they can survive in space, but we think they can persist at least for several centuries).

We now believe that extremophiles may be more numerous than organisms that survive in our “normal” environment!

So… when searching for life in the universe, perhaps we will first find it in environments hostile to humans. So, which is the extreme?

“if you could play Russian roulette with a time machine capable of sending you to any point in Earth’s history, you would have a 1 in 10 chance of being able to breathe the air.”

(yet life has persisted for almost all of the earth’s history)