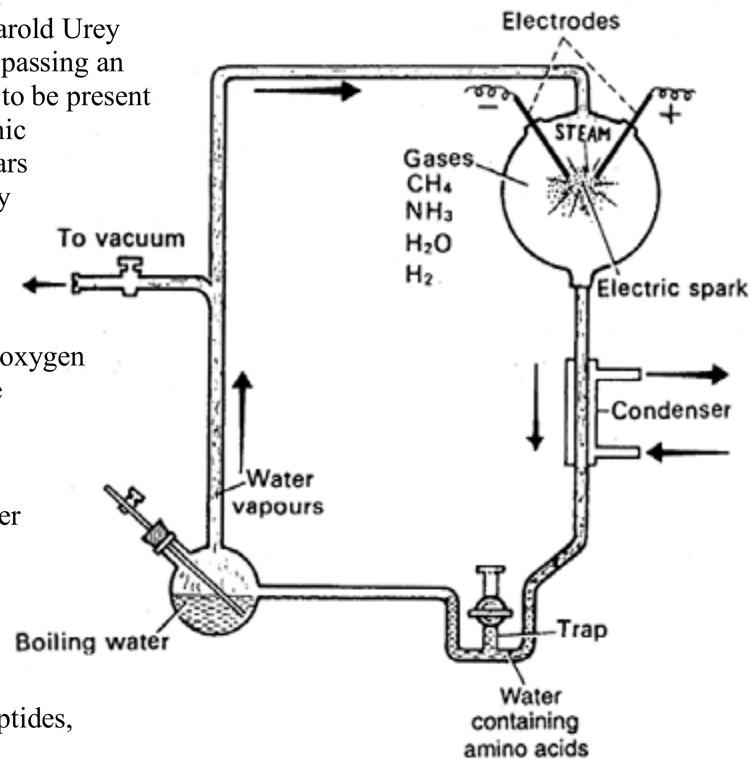
Abiogenesis Theory: From Molecules to Cells

The Earth was formed about 4.54 billion years ago and the earliest life on Earth arose at least 3.5 to 3.8 billion years ago. Conditions on Earth at that time were very different than they are today. The atmosphere was probably a mixture of gases including: H_2O, CO_2, H_2, N_2, CH_4, NH_3, H_2S and HCN. There was a great deal of energy available from volcanic activity, ultraviolet light and lightning. The oceans were very warm, about 95°C.

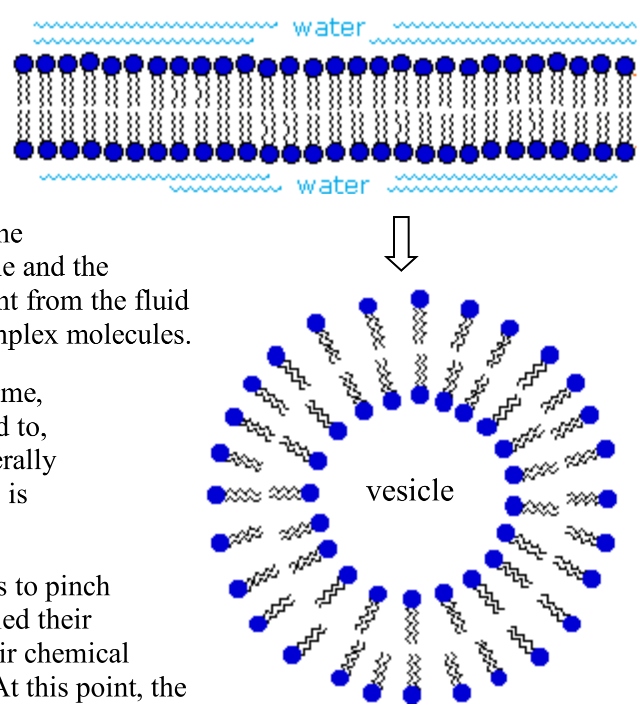
In 1953, two scientists named Stanley Miller and Harold Urey set up a simple experiment (shown to the right). By passing an electric current through a mixture of gases believed to be present in the early atmosphere, they created complex organic molecules including more than 20 amino acids, sugars and other organic molecules. Similar experiments by other researchers also produced nucleic acids and phospholipids.



Notice that there is little or no free oxygen present in these early conditions. This is important because oxygen would have quickly reacted with, and destroyed, the organic molecules.

Many of these organic molecules dissolved into the oceans, where they continued to react with each other in a "primordial soup". Along the shore of the ocean, puddles of this "soup" evapourated, concentrating the molecules and drying them on the water's surface. Molecules also stuck to layers of moist clay. These conditions have been shown to encourage the formation of simple polypeptides, RNA and phospholipid molecules.

Recall from the note on macromolecules that phospholipids have a hydrophilic (water-loving) phosphate "head" and two hydrophobic (water-fearing) fatty acid "tails". The phosphate head is attracted to water, while water repels the fatty acids. This automatically orients the phospholipid into a "bilayer".



The bilayer formed naturally into spherical vesicles, creating a membrane which separated the fluid on the inside of the vesicle from the fluid on the outside. The membrane restricted the movement of substances into and out of the vesicle and the composition of the internal fluid gradually became very different from the fluid outside. Chemical reactions inside the vesicle formed more complex molecules.

The development of this membrane was critical for life. Over time, substances such as protein, cholesterol and sugars were attached to, or imbedded in, the membrane. These substances can move laterally (from side to side) through the phospholipids, so the membrane is described as a "fluid mosaic".

The fluidity of the membrane made it possible for large vesicles to pinch apart into smaller vesicles. Eventually vesicles actually controlled their reproduction and passed on the instructions they needed for their chemical reactions using single stranded RNA as their genetic material. At this point, the vesicles are called cells, which means "little rooms" (like a prison cell) and life has begun.

NOTE: while scientists have been able to create macromolecules and vesicles in the lab, they have never been able to create "life". No one knows exactly what it is that makes molecules "come alive".

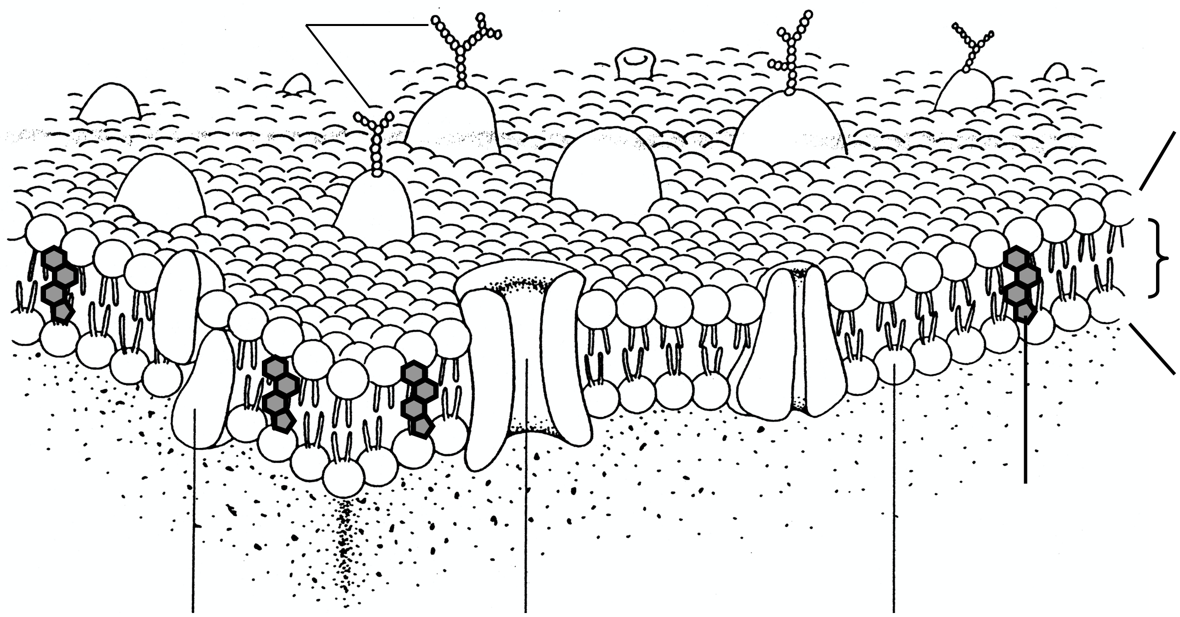
The first cells were very simple. They did not have any membrane-bound organelles such as a nucleus or mitochondria. These cells did have ribosomes made of RNA combined with proteins. Later cells developed DNA to store their genetic information. Because DNA is double stranded, it is more stable than RNA. Cells without DNA became extinct. Scientists suggest that one form of the DNA-based cell was so successful that it became the ancestor of all subsequent cells. This cell is called the Last Universal Common Ancestor (LUCA). Many chemicals and reactions are the same in all cells, which suggests that there was a single common ancestor for all living things.

The DNA in the earliest cells was a single DNA loop floating loosely in the cell's fluid. Other early cells 'clumped' their DNA in a "nucleoid" region. Neither the DNA loop nor nucleoid is surrounded by a nuclear membrane so these simple cells are called "prokaryotes" which literally means "before kernel" ('kernel' refers to the nucleus which looked like a small nut or popcorn kernel under early microscopes).

Over time, some cells became more complex and developed a membrane-bound nucleus. Cells which have a membrane-bound nucleus are called eukaryotes. "Eu" means "good or true", so these cells have a "good kernel" or "true nucleus". (FYI: Other words also use the prefix "eu": the Nazis practiced "***eu***genics" to select for "good genes" to make a master race, *eu*thanasia means "good death".)

Modern cells have a phospholipid bilayer membrane which separates the intracellular fluid (ICF, inside the cell) from the extracellular fluid (ECF, outside the cell). The cell membrane is selectively permeable, which means that it allows only some substances to move through it freely (for example, very small molecules such as H_2O, CO_2 or O_2) while it blocks the movement of other substances (larger polar molecules or ions which can not pass through the non-polar fatty acid tails). In the next lesson, we will learn how substances are moved, or transported, from one side of the membrane to the other.

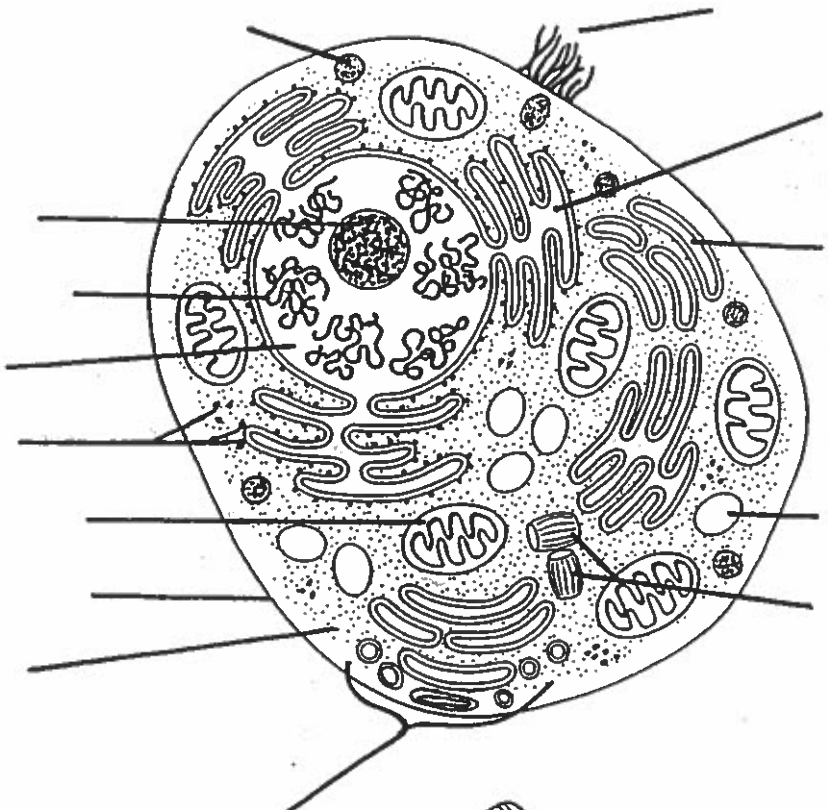
A eukaryotic cell membrane (the fluid mosaic model):

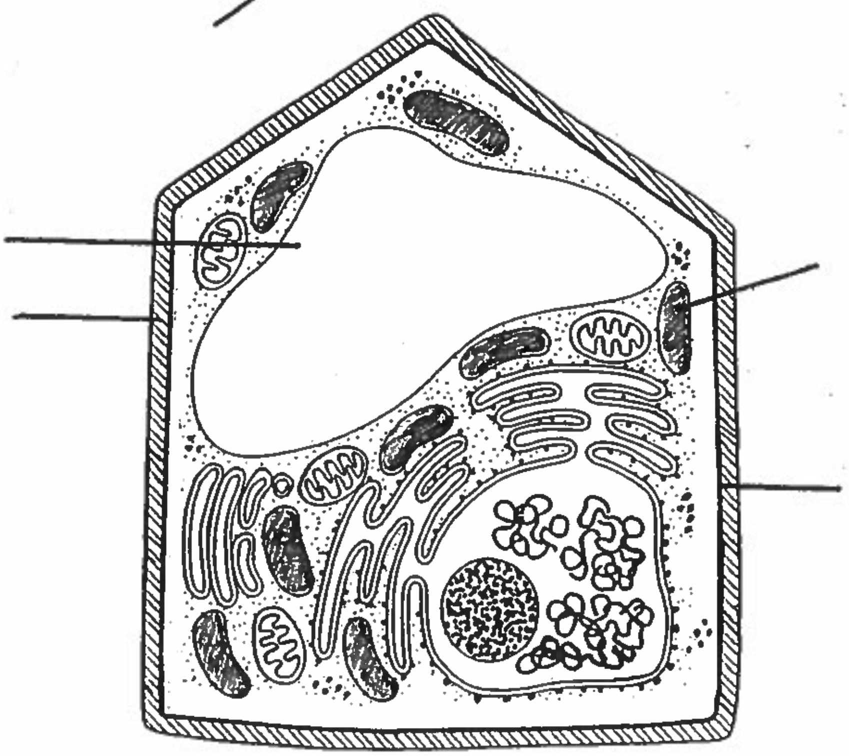


Questions: (Textbook reference pages 417 -418)

1. Describe the composition of the atmosphere when the first cells developed. What is the most significant difference between the very early atmosphere and the atmosphere today?
2. What molecules were produced in the Miller-Urey experiment?
3. Explain how the properties of phospholipids enable them to arrange themselves into a bilayer and create vesicles.
4. Why is the development of vesicles critical to the development of life?
5. Why is the development of RNA critical to the development of life?
6. How did the development of DNA affect the development of cells?
7. Why are 'modern' cell membranes described as a "fluid mosaic"? Explain the significance of both words.
8. Humans share 50% of their genetic material with bananas!! How does this fact relate to the idea of a LUCA?
9. Explain the fundamental difference between a prokaryotic and a eukaryotic cell.

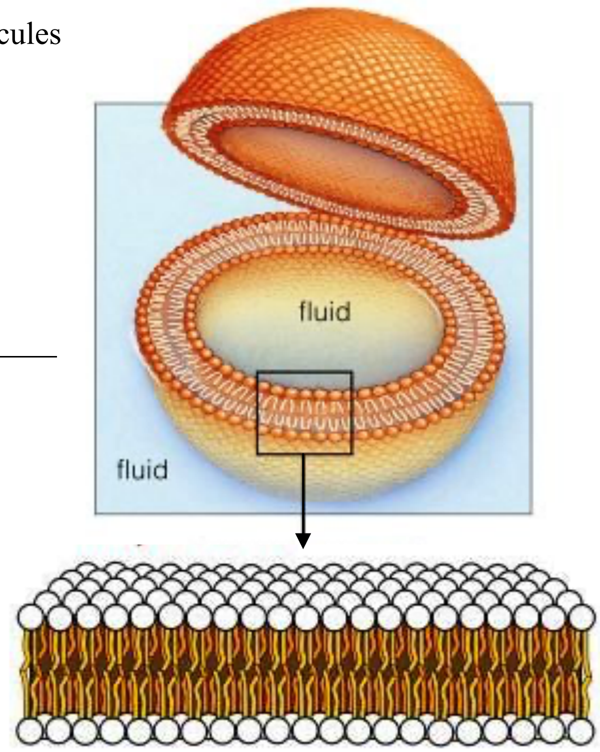
Animal and Plant Cells





Introduction to Cells

Early experiments by Stanley Miller, Harold Urey and others showed that simple molecules such as _______________ (CH_4), _________________ (NH_3), carbon dioxide (CO_2) and ________________ _________________ (H_2S) can be converted into large _________________ molecules such as ____________________, _____________, _____________________ and _______.



Also seen in Miller and Urey's experiment, large organic molecules can naturally and spontaneously form a _________________. Membranes can form ________________ and enclose a ____________ within them.

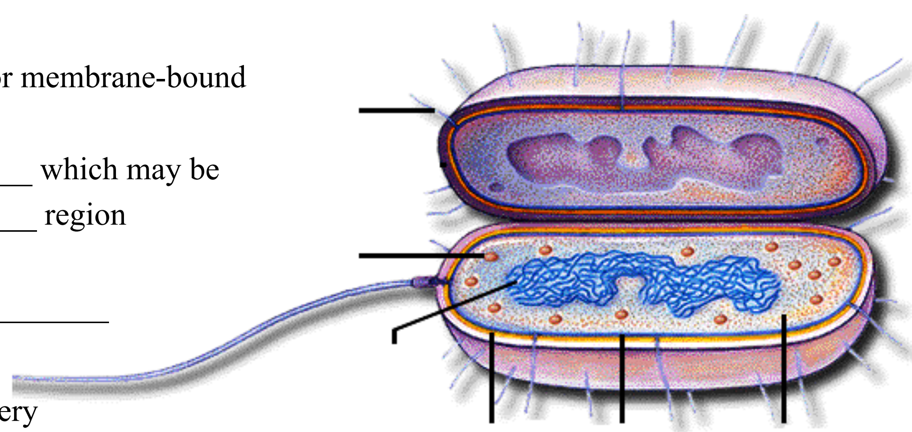
These vesicle membranes are critical for cells because they separate the ______________ fluid from the external _______________________ and control the __________________ of substances ________, and ____________, the vesicle.

Over time, these vesicles accumulated large organic molecules such as ________ and _____________ within them. Some RNA and proteins combined to make ___________________. Other RNA formed _____________________________________.

At some point, the vesicles and macro-molecules became able to ________________ themselves, becoming simple ________ which have the characteristics of ________ (see note from Day 1, Introduction to Biology and Biochemistry).

The earliest and simplest cells are called ____________________ cells

- they are very ___________, about the size of a __________________________
- they have no _______________ or membrane-bound ___________________
- they have a single loop of ________ which may be condensed in a _________________ region
- they have __________________
- ________________ and ______________ are prokaryotic cells



Over time, these early cells became very _________________. Some developed new structures such as _______________ for locomotion and __________________ for ___________________.
Some cells got quite ___________.

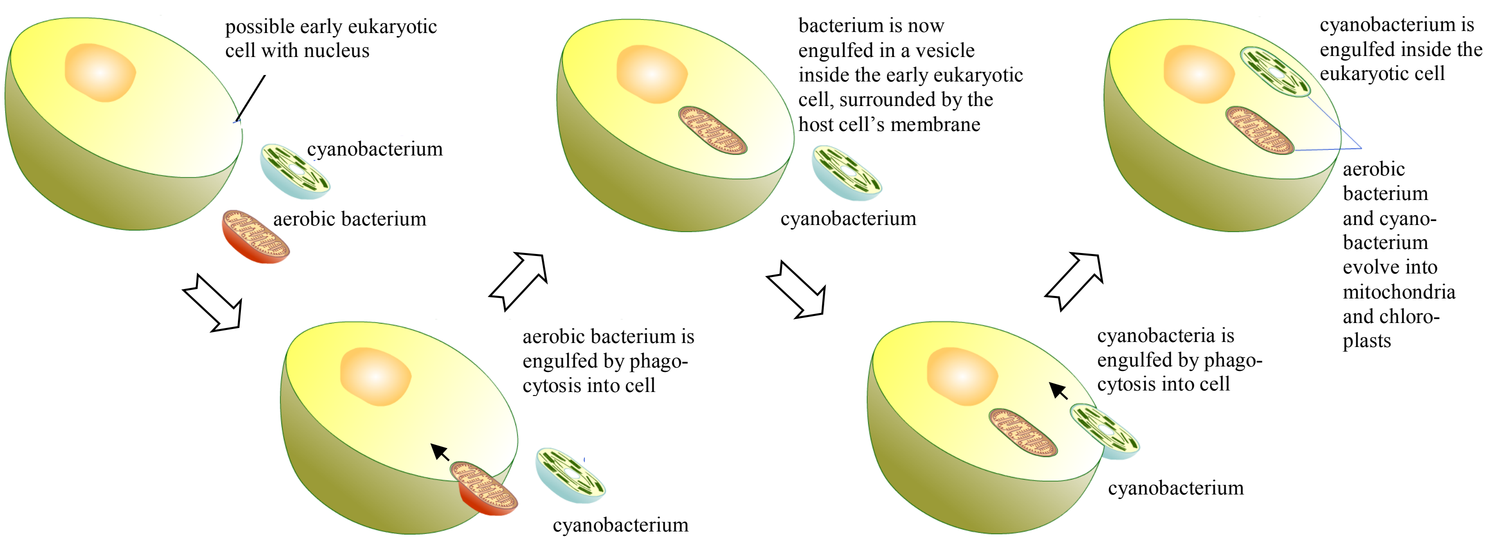
In some of the larger cells, the cell membrane ____________ in and eventually _______________ the _______ inside a __________________, creating the ______________ and giving rise to the earliest _____________________ cell.

There is an interesting theory called "_________________________________" that suggests that an early eukaryotic cell _______________ a simple, aerobic _____________________ cell such as a _______________ by _____________________, possibly as a meal. However, instead of dying, the prokaryotic cell continued to ______________, _____________ the eukaryotic cell. The eukaryotic _________ cell provided _________ and a __________, protected environment for the prokaryotic cell. The prokaryotic cell used the food and provided _______________ for the eukaryotic host cell. Because _________ cells ___________________ by living together with the other, it is called a "_____________ relationship". (In contrast, if one living thing benefits at the ________________ of another, it is called a _________________ relationship.)

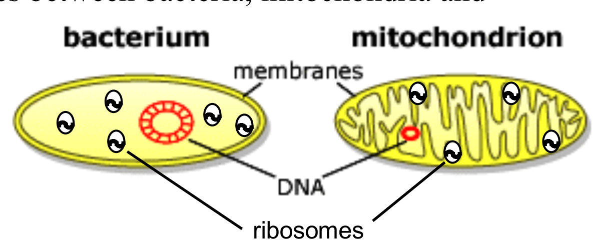
Over time, both cells became __________________ on each other and could not live ________________. At this point, the prokaryotic cell has become a _______________________ of the host cell. It has become an __________________: the _________________________.

Similarly, at a later time, a eukaryotic cell that has mitochondria engulfed another simple cell, perhaps a _______________________ that is capable of ___________________________. This cyanobacteria becomes a permanent resident inside the eukaryotic cell, producing ______________ for the host cell by __________________________. It becomes an ___________________: the ____________________.

Endosymbiosis Theory: (http://bugs.bio.usyd.edu.au/learning/resources/CAL/Microconcepts/moviePages/incorporation.html)

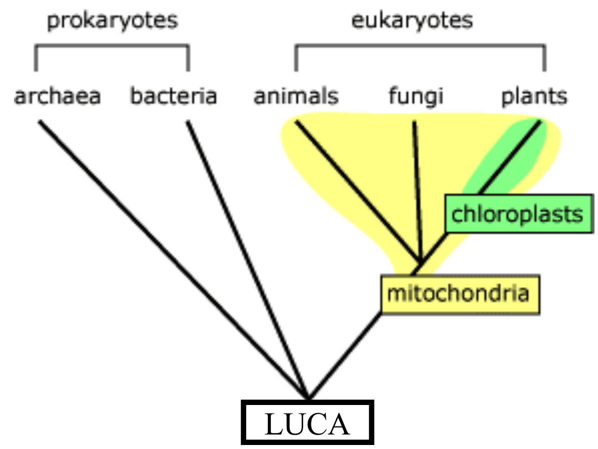


<u>**Endosymbiosis Theory**</u> is supported by the many similarities between bacteria, mitochondria and chloroplasts. Both mitochondria and chloroplasts:



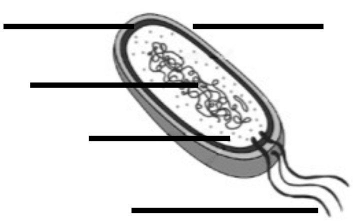
- are about the same _________ as a simple bacteria
- are surrounded by _______________________ which suggests that they were engulfed by _________________________

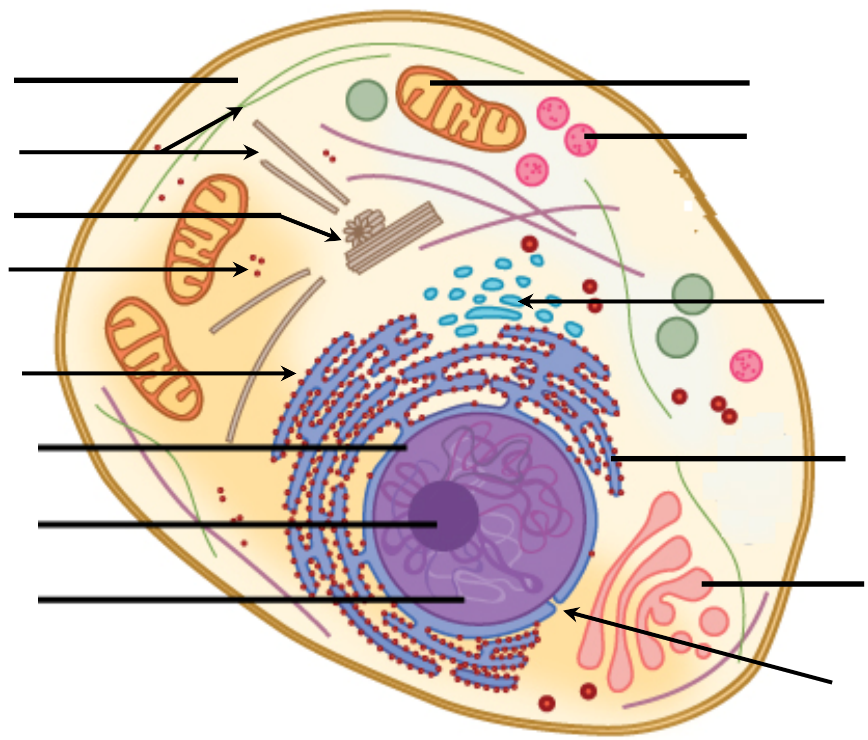
- have their own simple __________ of _________, which is similar to the DNA of early ___________
- have their own __________________, which are similar to ________________ ribosomes and significantly different from _____________________ ribosomes
- reproduce by simple ________________________ (splitting in ________) ____________________ of the host cell cycle and ________________



When you look at it this way, mitochondria and chloroplasts resemble tiny _______________ living inside eukaryotic cells! Mitochondria must have been added __________ because ________ eukaryotic cells have them. Chloroplasts must have been added __________ to only __________ cells because only ___________ cells have them.

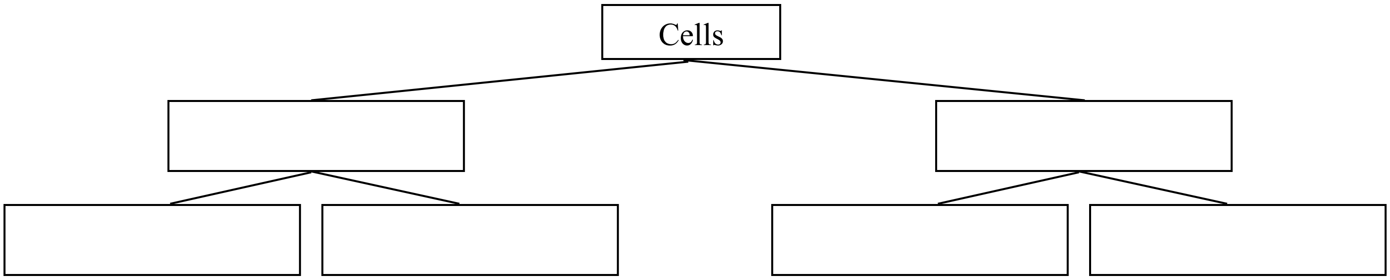
Comparing Prokaryotic & Eukaryotic Cells





	Prokaryotic Cells	Eukaryotic Cells
Relative Size		
Presence of a membrane-bound nucleus?		
Describe the genetic material		
Presence of membrane-bound organelles?		
Presence of ribosomes?		
Examples		

Notes about Some of the Cell Parts



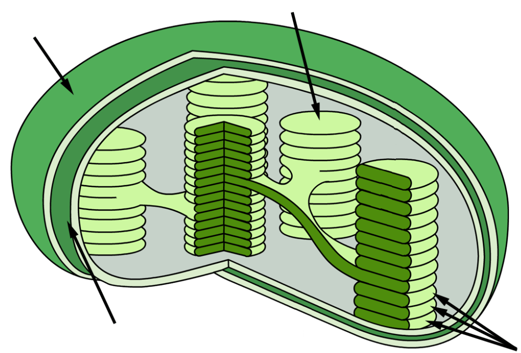
Plant cells contain __________ mitochondria and chloroplasts. Chloroplasts are one type of ____________.

Plastids:

- plastids have both an ____________ and an ___________ membrane
- they have their own _________________ and _________ which are similar to those of ______________
- plastids divide on their own, __________________________ of cell division, so it is believed that they probably originated from ___________________ by ______________________________
- there are different types of plastids found in different types of cells, depending on their function:

a) Chloroplasts

- these are _____________ plastids that contain ________________________ (a green pigment)
- they perform ______________________________ by using energy from ________________ to turn __________ and _____________ into ___________________:



- _________________ for photosynthesis are found on the ____________________ of _______________________ (stacks of thylakoids are called "grana") which provide a large ________________________ for the chemical reactions

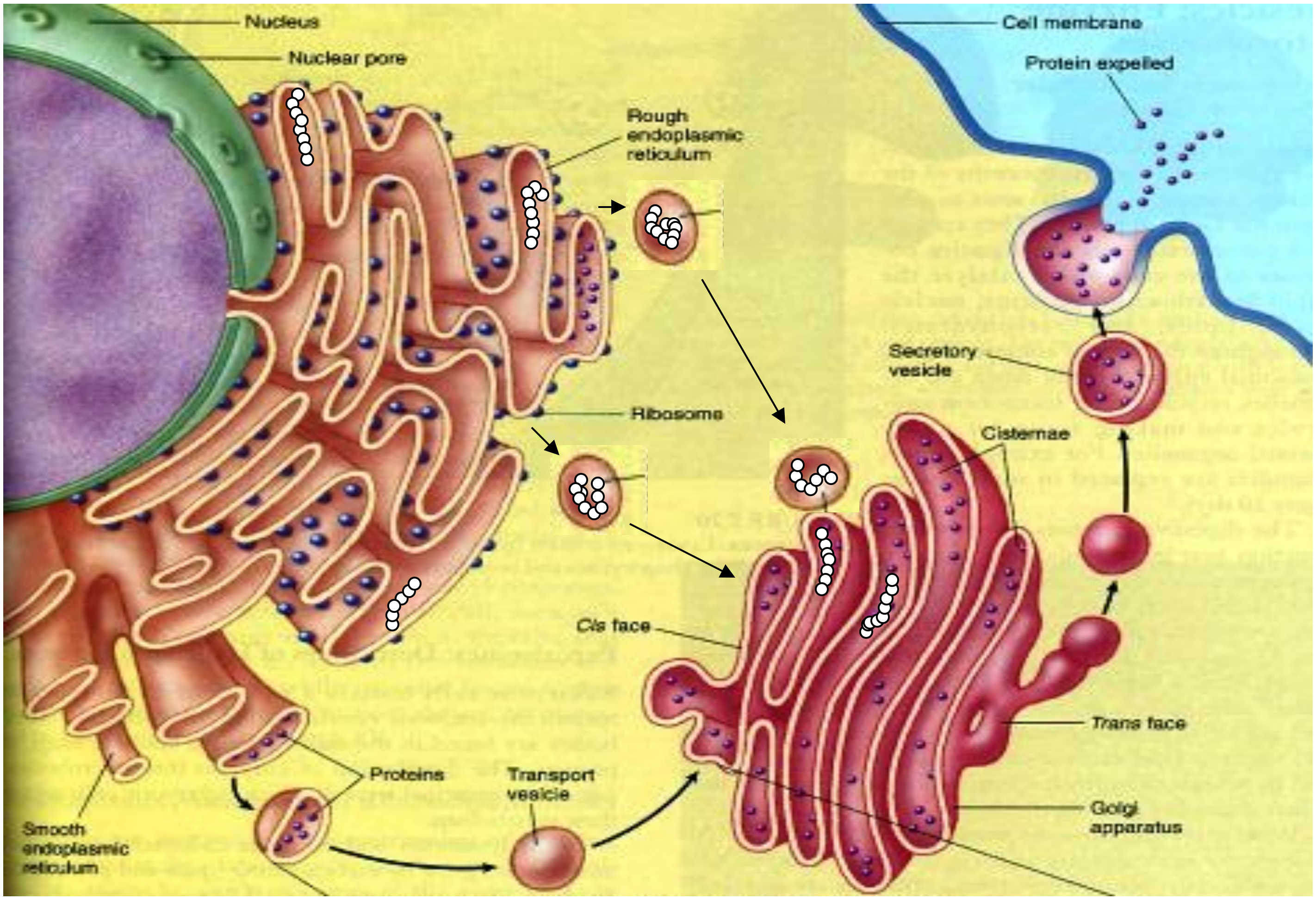
b) Chromoplasts

- these are plastids which contain pigments that can be a ________________ of colours, such as __________, ______________ and ________________
- they give specific parts of the plant a distinctive _________________
- example: the ______________ of a flower may be brightly coloured to attract ____________________, ___________ or other _______________________
- example: the ______________ of a plant may be brightly coloured to attract ________________ which eat the ______________ and then spread the _____________ in their _______________

b) Leucoplasts

- these are ______________________ or ______________ plastids that are specialized to store _____________ (when they are stained with iodine they turn ___________/_____________)
- ____________________, _____________ (such as beans and corn) and other "_______________" foods contain a large number of ____________________

Endomembrane System

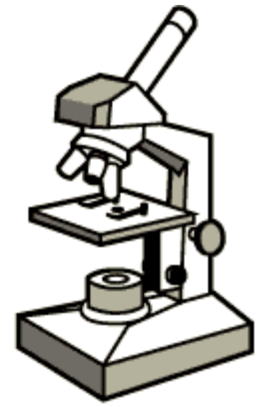


Vesicles

Vesicles are ______________________________________ that keep their contents _______________ from the _____________________. There are many types of vesicles and they are classified by their __________________ and ____________________.

1. **Vacuoles** are vesicles that are generally used for _______________ of materials such as ___________, ________ (salts) and ____________. In animal cells, vacuoles tend to be very _____________. Plant cells often have a very large ___________________________ that stores water, salts and sugars.
2. **Lysosomes** are vesicles that store powerful __________________ (digestive) _______________ which are needed to break down ______________________________, worn out ____________________, _______________, large food particles and other materials. This allows the molecules from these materials to be _________________ and _______________.
3. **Peroxisomes** are vesicles that store powerful ________________ which are needed to break down _____________________________________ and also some types of ___________ (_______________).
4. **Transport vesicles** __________________ from the ____________ and _______________________ _________________________________ (ER) and carry the contents to the __________________________ The transport vesicles _________ (join) with the "cis" face of the Golgi and empty their contents inside.
5. **Secretory vesicles** ___________________ from the ____________________________ and carry the contents to the _________________________. Secretory vesicles fuse with the cell membrane and empty their contents ________________ of the cell by ______________________. The vesicle membrane becomes part of the _________________________.

Microscope Calculations



It can be difficult to know the sizes of objects seen under a microscope.
How big is a human cell compared to a bacterial cell? Compared to a virus?

There are two calculations we can do:

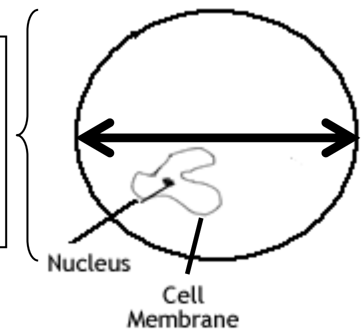
1) **Total Magnification of the Object:**

- How many times larger does the object appear than the original specimen?

Total magnification =

eg. If a specimen is viewed using a 10x ocular lens and the 40x high power lens, what is the total magnification?

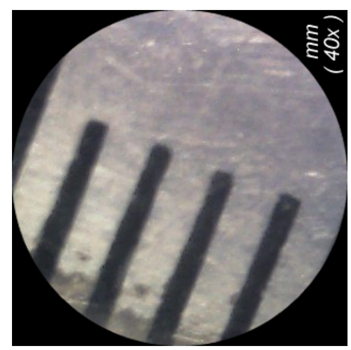
Amoeba (100x)



2) **Actual Size of the Object:**

- an object's ___________________ can be measured or calculated if the size of the _________________________ is known
- the field of view can be measured using a clear plastic __________ under ________ magnification
- place the ruler on the ___________ of the microscope and adjust to _____________
- line up the ruler so that it is measuring the field ________________ (the _____________ part of the field of view). Put one of the millimetre markings right against the ________________________ of the circle
- using the ruler markings, measure the ________ in millimetres (   )

The _________________ you see through the microscope is called the ____________________ (________).



Calculations:

- convert the FOV from mm to _______________________ (   ) using the conversion factor:

As the magnification ____________________, the amount of the object that you see ________________ in exact proportion. Mathematically, this can be written:

$$FOV_{low} \times magnification_{low} = FOV_{medium} \times magnification_{medium} = FOV_{high} \times magnification_{high}$$

Once you have measured the FOV under low power, you can use the magnification of the lenses to calculate the FOV for either _____________ or ________ power. For the above microscope under medium power (100x):

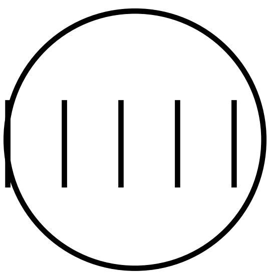
Now that you know the size of the field of view under medium or high power, you can _______________ the size of the object you are viewing.

eg. estimate the length and width of the mite in the microscope image to the right. It is viewed under medium power using the microscope from the calculations on the front of the page.

The width of the mite is about _____ of the FOV under medium power:

The length of the mite is about _____ of the FOV under medium power:

eg. A student measured the field of view under low power and then studied onion cells under low, medium and high magnification. He took pictures of the field of view under each power. Using the microscope information, estimate the actual width and length of one onion cell using the image under high power:



Ruler Under Low Power

Low Power

Medium Power

High Power

Microscope Information:

Ocular lens = 10X

Objective Lenses:

low power = 10X

med. power = 30X

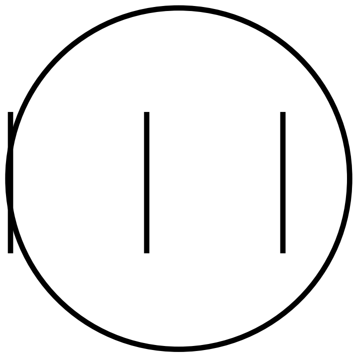
high power = 60X

Microscope Calculations Homework

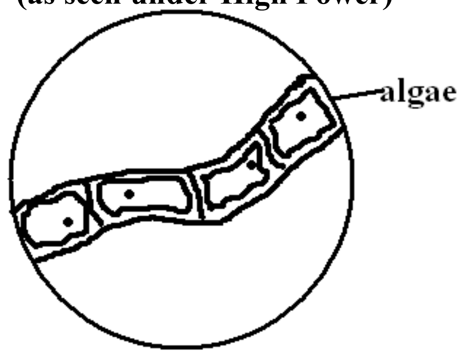
Use the diagrams and microscope information to estimate the approximate sizes of the objects in micrometers (µm) seen under the magnifications given. Show all calculations and include all units.

1. Estimate the Width of the Algae

Ruler Under Low Power



Green Algae
(as seen under High Power)



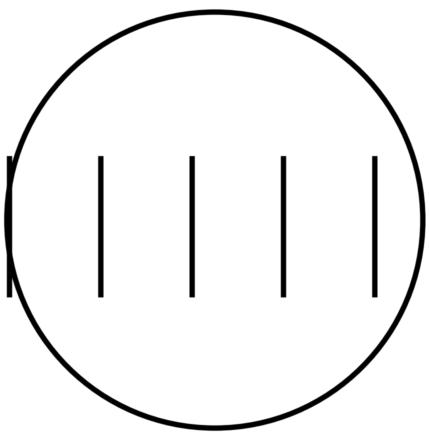
Microscope Information:

Ocular lens = 10X

Objective Lenses:
low power = 10X
med. power = 20X
high power = 40X

2. Estimate the Width of an Onion Cell

Ruler Under Low Power



Onion Cells
(as seen under Medium Power)

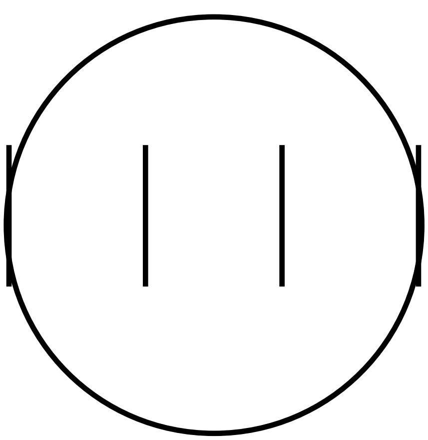
Microscope Information:

Ocular lens = 5X

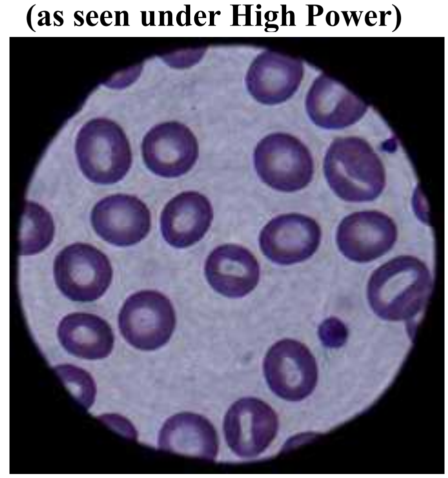
Objective Lenses:
low power = 10X
med. power = 25X
high power = 50X

3. Estimate the Width of a Red Blood Cell

Ruler Under Low Power



Red Blood Cells
(as seen under High Power)



Microscope Information:

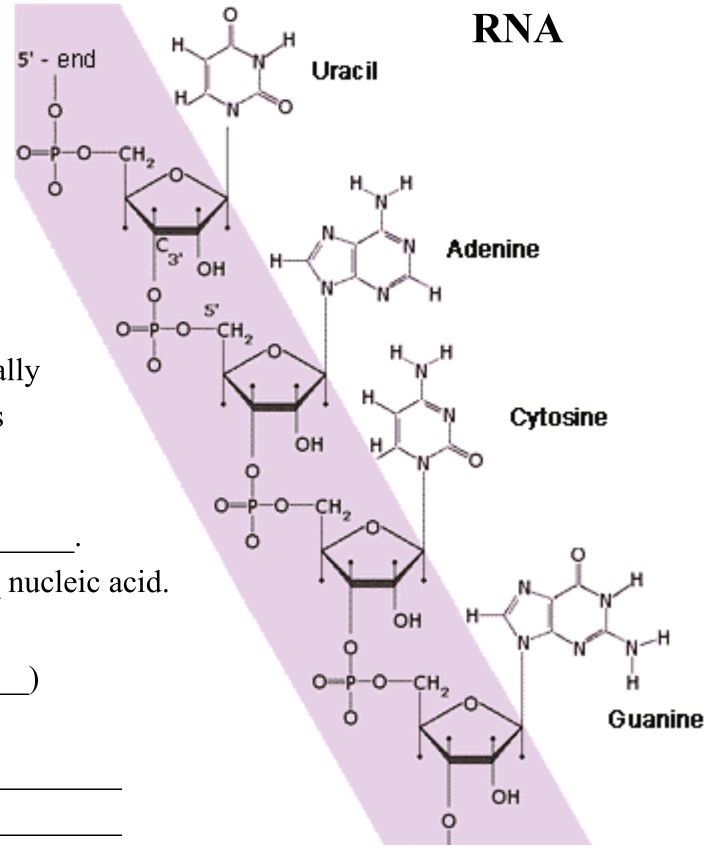
Ocular lens = 10X

Objective Lenses:
low power = 10X
med. power = 30X
high power = 60X

Answers:
1. FOV low = 2500 µm, FOV high = 625 µm, algae about 1/5 – 1/6 FOV, width = 100 – 140 µm
2. FOV low = 4500 µm, FOV med = 1800 µm, cell about 1/8 – 1/9 FOV, width = 180 – 200 µm
3. FOV low = 3000 µm, FOV high = 500 µm, red blood cell about 1/7 – 1/8 FOV, width = 55 – 72 µm

The Nucleic Acids: DNA and RNA

DNA and RNA are ______________________________ known as ________________________ because they are found primarily in the ______________ of cells. They are made of subunits called ______________________ attached together in a long chain.



Each nucleotide is made of a _____________, a ___________________ and a _______________ __________. The sugar and phosphate groups are _______________________ bonded to form a strong _______________________________ ___________________. The nitrogen base is chemically bonded to the ____________. These chemical bonds are ______________!

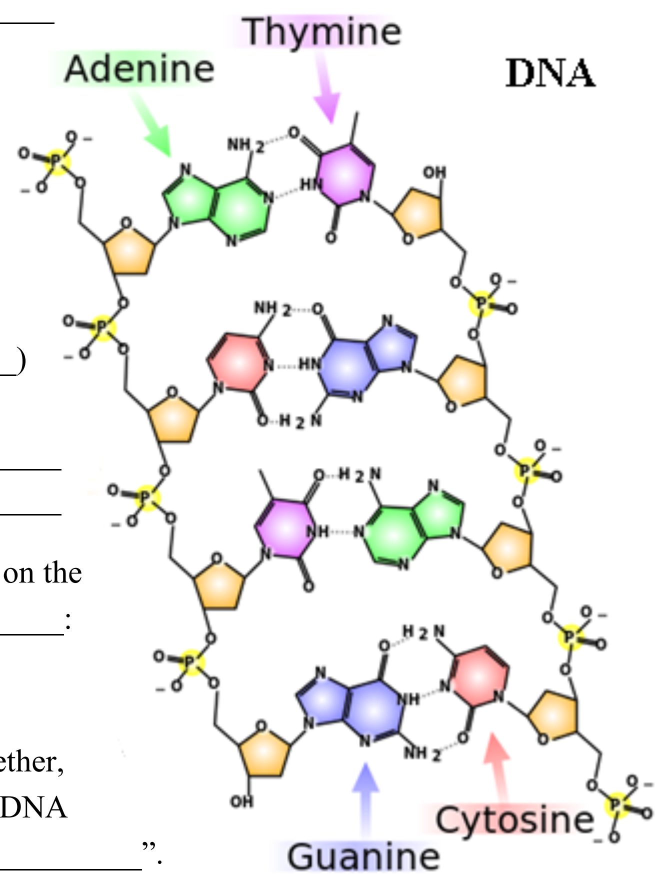
RNA stands for ___________________________________. It is the ________________ and ________________ nucleic acid.

- RNA is a ________________________________
- its sugar is _______________ (_________________)
- RNA has four nitrogen bases:

  _____________________ _____________________

  _____________________ _____________________

- RNA is primarily involved in making ________________



DNA stands for _______________________________ __________. It is _______________________________, which makes it much more ____________ than RNA. Because of its stability, DNA is ideally suited to store the cell's _________________________________.

- its sugar is ______________________ (_____________)
- DNA has four nitrogen bases:

  _____________________ _____________________

  _____________________ _____________________

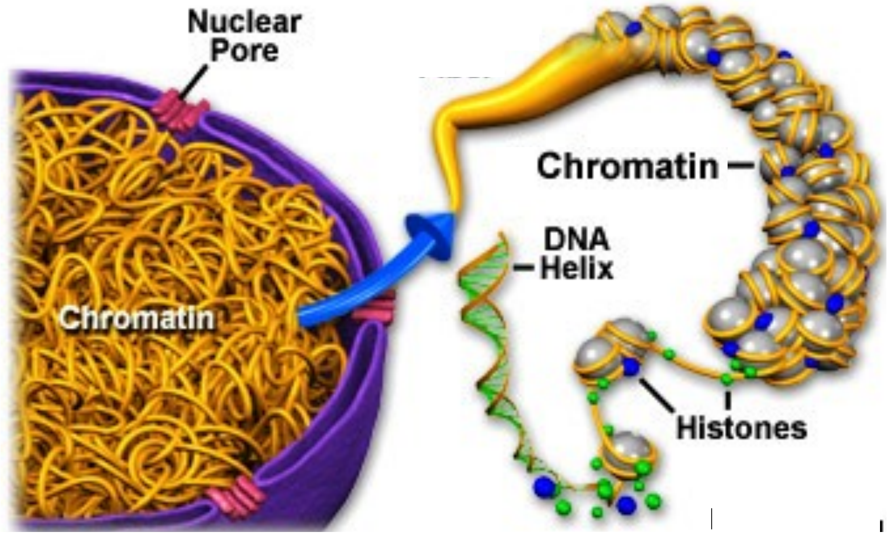
Each nitrogen base is attracted to its complementary base on the opposite strand of DNA by _____________________________:

- adenine is attracted to ___________________
- guanine is attracted to ___________________

The hydrogen bonding holds the two strands of DNA together, forming the ___________ of the _______________. The DNA molecule _____________ to form a "__________________________".

It is the _____________ of the ___________________________ (A, T, C and G) in DNA that stores the genetic information. A "____________" is a section of DNA which has the information to make one _______________. Humans have ___________________________ protein-coding genes but this makes up only ________ of the total DNA. The rest of the DNA used to be called "_________________" but now we suspect that it is important in making ________ and _____________________ cell activities.

If you take all of the ___________ ______________________ from a single human cell and lay it out, end to end, it measures about ______________. But the average human cell is only ___________ (_________________) in diameter and the ________________ is even smaller. How does all of the DNA _______ into the nucleus?

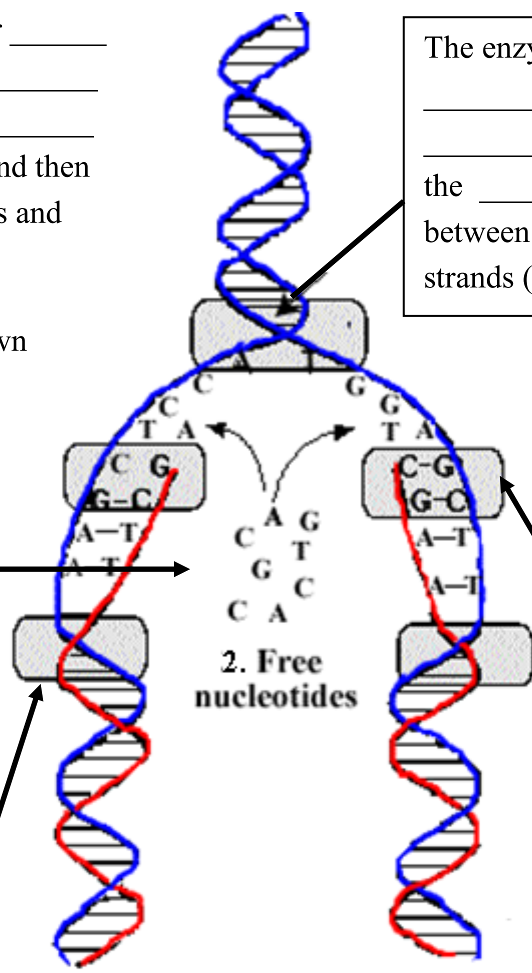


When a cell is not dividing, the DNA is found in the nucleus as ___________________. Chromatin is made of DNA wrapped around _________________ called __________________, as shown in the diagram above. While the length of the DNA is 2 meters, the length of the __________________ chromatin is only ______________.

When the DNA needs to be copied for ______ _________________ or ___________________ __________________, it is ________________ from the histones, ________________ and then wrapped back up again. This preserves and protects the valuable DNA.

The steps of DNA replication are shown in the diagram to the right:

The enzyme ________________ ________________and ____________ the DNA, breaking the _________________________ between the complementary strands (like unzipping a zipper).



The exposed __________________ attract their complementary ___________________ (_________, (__________________________ and __________________) that are free in the ________________.

An enzyme called ___________________ chemically bonds the ____________ and _______________ on adjacent _________________ together to form the ______________- ________________ backbone.

The two new strands of DNA are _________________ into _____________ by another enzyme.

Mutations

Sometimes there is a __________________ when the DNA molecule is being _____________ and this changes the ___________ of the _______________________ (A,T,C or G). A change in the order of the nucleotides is called a __________________. Mutations may change the order of the _____________ ___________ in the _______________________ chain and this changes the shape of the ____________.

Two common types of mutations caused by DNA replication (copying) errors are:

1. A _______________________________________ (also called a ___________________________) which replaces a __________________________________ with another nucleotide.

eg. The sequence is AATCGCTTAGAG could become: ______________________________________

2. A _________________________ mutation which ________________ (adds in) or _____________ (leaves out) one or more nucleotides.

eg. The sequence AATCGCTTAGAG could become: ______________________________________

The DNA sequence is read in groups of ____________ nucleotides. Each set of three nucleotides is called a _____________ and it is the code for a single _________________________.

As an analogy, the DNA sequence (a ____________) is like a ____________________ written with only __________ letter words (_______________). A mutation is similar to changing one ______________ in a word, or changing the ____________ of the letters, and this changes the ___________________ of the sentence.

eg. Read this sentence: Thedaywashotbuttheoldmandidnotgethishat.

If we group the letters into three letter words we get:

____

If we replace the “d” in day with an “e” (a base-pair substitution), we get:

____

If we change the “d” in day with an “r” (a base-pair substitution), we get:

____

If we insert an “r” after the d in “day” (a frameshift mutation), we have:

____

A mutation may be a:

1. ________________ (helpful) mutation that makes a protein or cell function _________________
2. _______________ (harmful) mutation that makes a protein or cell function _________________ , the cell may even _________
3. ______________ mutation that does not __________________ or ____________ the cell

Summary:
The structure of the DNA molecule has three properties which are critical to how it functions:

1. **Because A always pairs with T and C always pairs with G, DNA can make copies of itself**. If you pull the two strands apart, each can be used as a pattern to make the matching (complementary) strand (and a new DNA molecule).
2. **DNA can carry information**. The order of the bases along a strand is a code - a code for making proteins and these control all cell functions.
3. **DNA can be greatly condensed**:
   - the total length of the completely uncoiled DNA in a single cell is about 6 meters
   - the total length of the chromatin (partially coiled DNA) is 28 cm
   - the total length of the chromosomes (completely coiled DNA during mitosis) is approximately 0.060 cm or just 0.6 millimeters

Homework:

1. Re-read the above note very carefully.

a) What molecules make up a nucleotide?
b) What are three significant differences between DNA and RNA?
c) What is a gene?
d) What are the TWO components (parts) of chromatin?
e) What is a codon?
f) What three properties make DNA an excellent molecule to carry the genetic code?

2. For the genetic code (gene): TATAGCGTGAAATTCACGG
   a) write it in codons: ____
   a) write one possible point mutation: ____
   b) write one possible frameshift mutation: _____________________________________

3. Read pages 199 – 203. (up to but not including Cloning)
4. Write a brief outline of the steps of DNA replication. Include the information from our class note and the diagram on the top of pages 200 – 201.
5. What is one way that cells protect themselves against copying errors during replication?
6. Give an example of a "condition" caused by a genetic mutation.
7. What is a mutagen? Give examples of two different types of mutagens.
8. Explain how some mutations may cause cancer.
9. A common form of cystic fibrosis is caused by a single point mutation. Read the BioFact on page 30 about cystic fibrosis (you read this earlier when we were discussing cell transport). How does the point mutation (a genetic disorder) cause cystic fibrosis? How does cystic fibrosis affect cells and then people?