Biology 2201 Chapter 4 Notes **NAME:**____________________

Chapter 4 – Cells Up Close: Processes that Sustain Life

4.1 – Developing the Cell Theory

Cell Theory

- People have only known about the existence of cells for only the **last 300 years** or so.
- Essential scientific developments such as the invention of the **microscope** and fundamental breakthroughs regarding the theory of **biogenesis** allowed scientists to formulate the **cell theory**.

Abiogenesis

- Before people knew about the existence of cells, the leading belief was **abiogenesis**, the idea that **living things could arise from non-living or dead things (Spontaneous Generation).**
- These beliefs came from **incomplete observations** and experiments **with no controls**.

- **Some (Not So Factual) Observations**
- ***There were many "supporting" ideas for abiogenesis:***

1) Maggots suddenly appeared on uncovered meat after several days.

Fiction – Maggots were present, but only after the flies laid their eggs on the meat.

2) Frogs and salamanders suddenly appearing on or in mud.

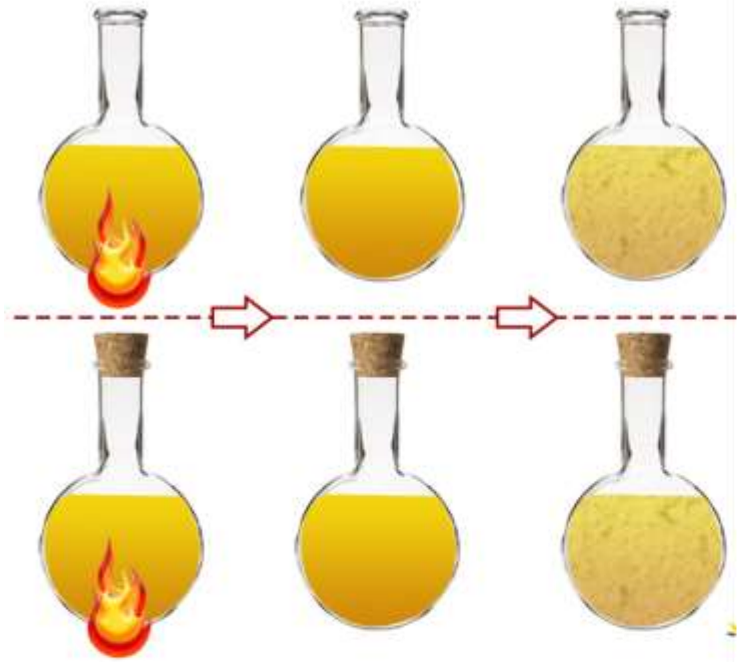
Fiction – These amphibians hibernate and burrow into the mud and come to the surface to eat.

3) ***Jan Baptista van Helmont***

Fiction – The mice found a food source and nesting material, and then mated. They possibly hid in the mixture.

4) ***John Needham***

- HIs experiment with meat broth teeming with microbes after being boiled.



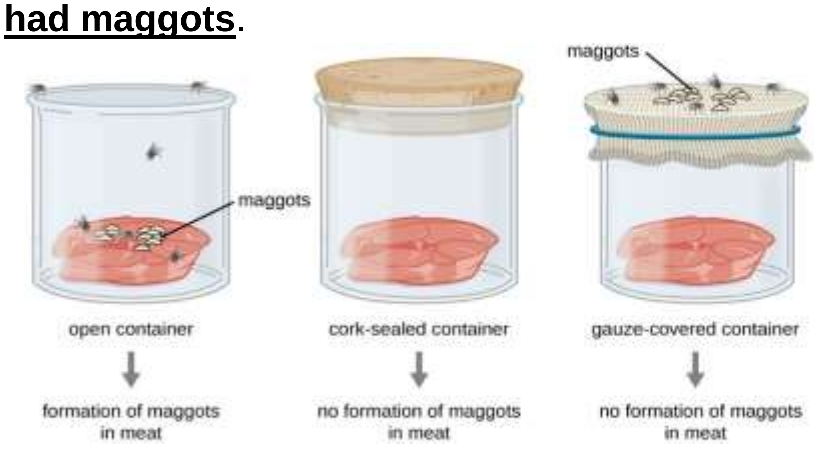
<u>Fiction – He did not boil the broth long enough to kill all the bacteria, making the broth cloudy.</u>

<u>BIOGENESIS</u>

- It is now accepted that the theory of **<u>biogenesis</u>** is correct whereby **<u>living things can only come from other living things (life from life).</u>**
- Over time, through the conduction of **<u>some key experiments</u>** using the scientific method, biogenesis was proven.
- This was an example of a major scientific **<u>paradigm shift</u>**.

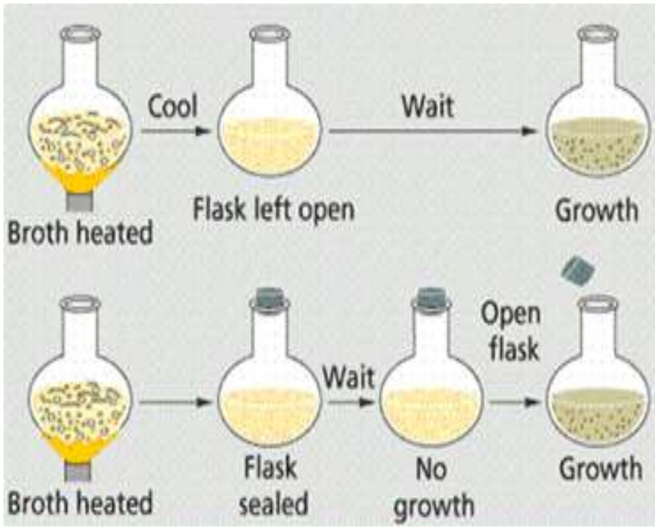
<u>Redi (1626–1697)</u>

- In the 1600's , Francesco Redi conducted one of **<u>the first controlled experiments that supported biogenesis</u>.**
- He used meat in jars, half covered with mesh and half open (**<u>mesh were controls</u>**).
- After several days he found that the mesh-covered meat had **<u>no maggots</u>**, while the open jar **<u>had maggots</u>**.



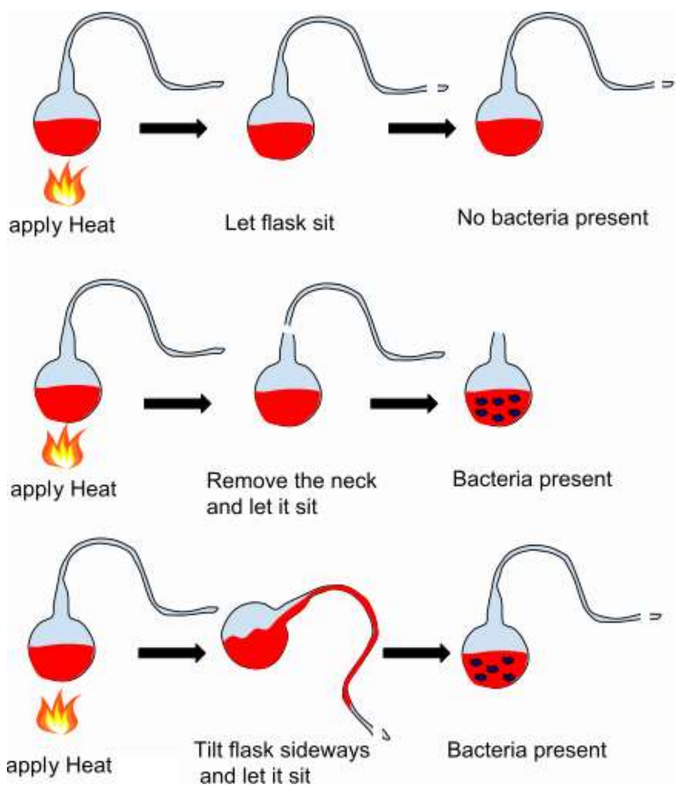
Spallanzani (1729–1799)

- Lazzaro Spallanzani repeated Needham's experiment
- This time the broth was **boiled for a longer time**.
- No life appeared in the sealed flask, while the open flask had **bacterial growth**.
- Naysayers said that boiling the broth "**killed the vital principle**" that made life arise from non-living matter like water.



Louis Pasteur (1822-1895)

- He conducted experiments that finally **disproved abiogenesis**, concluding that **organisms do NOT arise from non-living matter**.



ABIOGENESIS	BIOGENESIS
Abiogenesis refers to a theory on the origin of life, describing that the life originated from inorganic or inanimate substances	Biogenesis refers to a theory on the origin of life, describing that the life originated from pre-existing living matter
Proposed by Alexander Oparin, Stanley Miller, and Harold Urey	Proposed by Theodore Schwann, Matthias Schleiden, and Rudolf Virchow
States that the life on earth is originated from non-living compounds	Sates that the life on earth is originated from the pre-existing living forms
Not scientifically proved	Proved by scientific experiments
Based on observations and national thoughts	Based on practical experiments and material evidence

Cell Theory – 4 Key Ideas

1) All organisms are **made of one or more cells**.

2) Cells are the **basic units** of **structure and function** in all organisms.

3) All cells come from other **pre - existing cells**.

4) The activities of a multicellular organism depend on the **activities of its cells**.

Microscopes

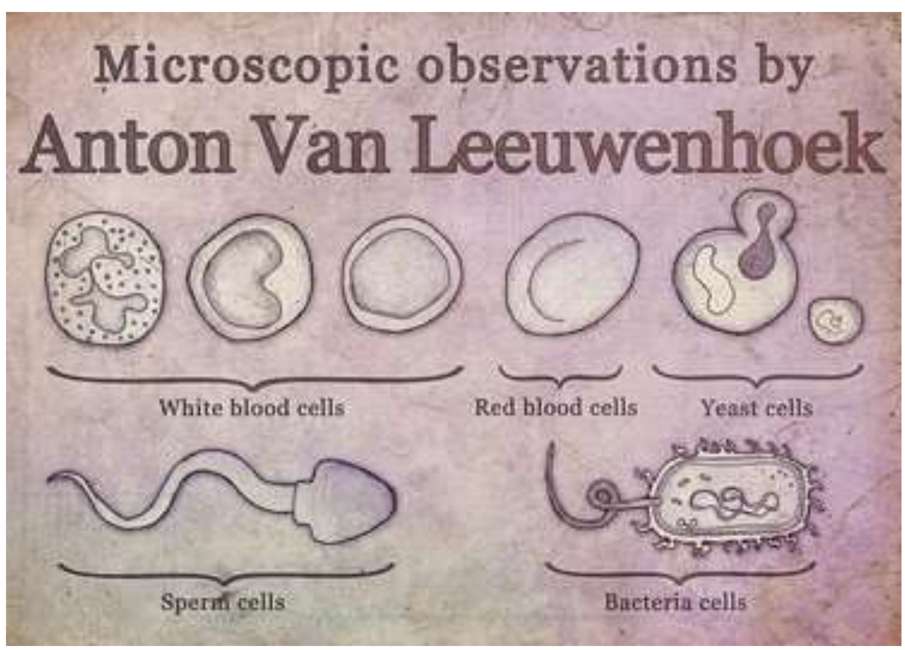
- Most cells are TOO SMALL to be seen ***macroscopically*** (**with the unaided eye**), but can be seen very effectively with **microscopes**.
- Microscopes were key to the development of **the cell theory** and the study of cells. They remain an important tool for anyone studying cells.
- With the ability to magnify objects as much as 2000 times their actual size, biologists were able to observe **cells and cell organelles**.

Robert Hooke

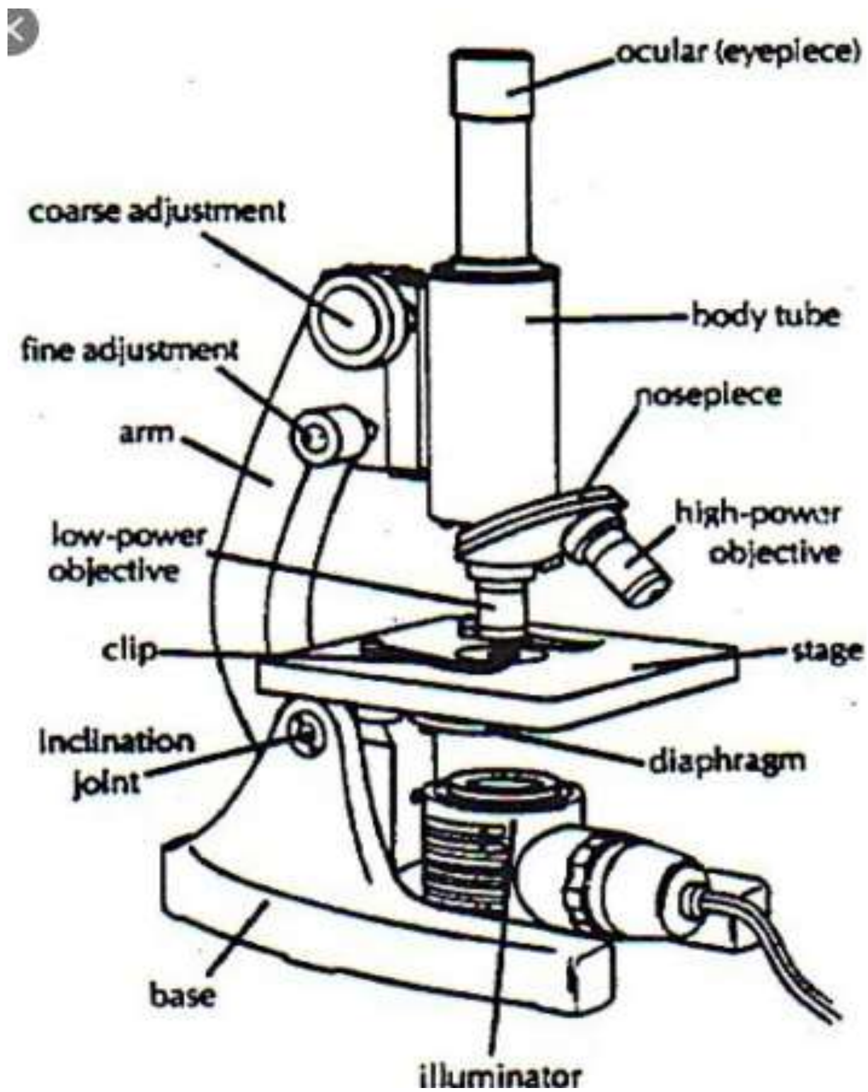


Antoni van Leeuwenhoek (1660s)

- He read Hooke's Book and designed his own **single lens** microscope – much more powerful and clearer than any existing microscopes at the time.
- He reported observing little "**animalcules**", what we now know is **bacteria**.

- ❖ Recall from junior high science the parts of a compound light microscope and how to use a microscope →



- ❖ We will also discuss ***magnification, resolution, depth of field, field of view, estimated size of objects viewed, wet mount slides, and proper biological drawings***.

Magnification

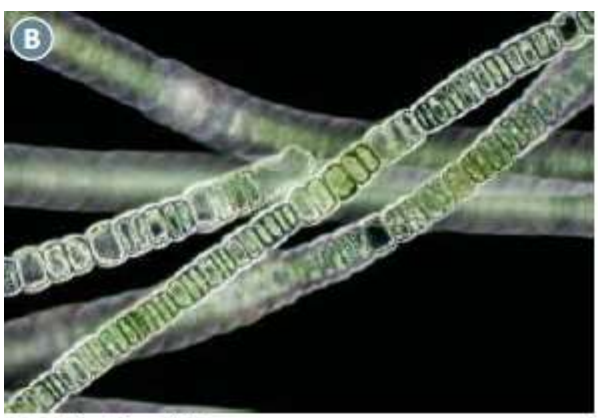
- Magnification describes **how many times larger the image is than the object**.
- The total magnification of a compound light microscope is determined by the following formula
  - **Magnification = ocular (eyepiece) lens x objective lens**
    - Example = 10 x 40 (highpower)
      = 400 x magnification

Resolution

- AKA **Resolving Power**
- Resolution is the ability to distinguish **between two points**, and thus **describes the sharpness of an image**.

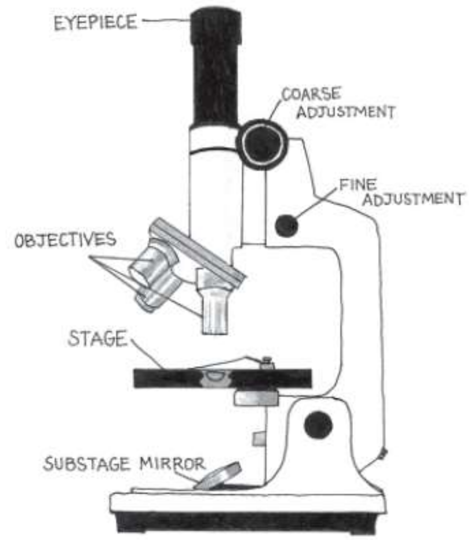
Depth of Field

- Depth of field is the **optical range that is in focus** from the **foreground to the background**.
- Microscopes have a **very short** depth of field, usually measured in micrometres (μm). If a specimen is too thick, only a portion of it will be in focus at one time.
- Note: **1 mm = 1000 μm (micrometres)**



Magnification: 200 ×

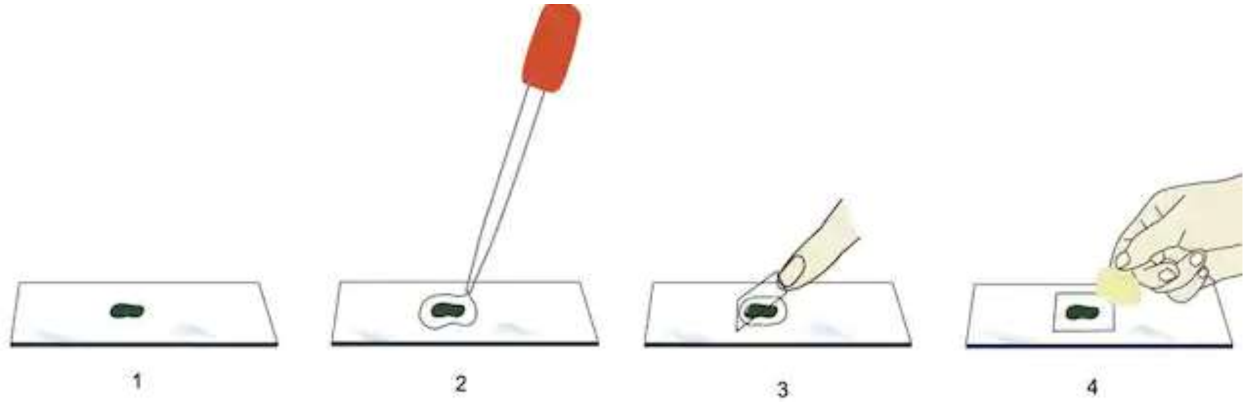
How to Use a Compound Light Microscope



1. When moving the microscope, **ALWAYS** grasp the arm with one hand and place the other hand under the base for support. Place the microscope on a level and stable surface.
2. Turning the revolving nosepiece so that the lowest power objective lens is "clicked" into position. The lowest power objective is the shortest one.
    - This objective lens is the easiest to focus and center the image in the field of view.
3. Microscope slides should always be prepared with a cover slip or cover glass over the specimen. Hold the slide on the stage by fastening it with the stage clips.
4. Turn the coarse focus knob so that the stage moves upward toward the objectives. Move it as far as it will go without touching the slide.
5. Look through the eyepiece and adjust the illuminator and diaphragm until you attain the maximum, comfortable level of light.
6. Turn the fine adjustment knob, as necessary, for perfect focus.
7. Move the microscope slide around until the sample is in the centre of the field of view.
8. Once you have attained a clear image, you should be able to change to a higher power objective lens.
    - **BE CAREFUL TO NOT LET THE LENS TOUCH THE SLIDE.**
    - You may have to move the stage down with the coarse adjustment knob.
    - **NEVER** use the coarse adjustment knob with the highest power lens in place.
9. If you lose your specimen, start from the beginning and the lowest power lens.

How to Prepare a Wet Mount Slide

1. Used for aquatic samples, living organisms and natural observations, wet mounts suspend specimens in fluids such as water, brine, glycerin and immersion oil.
2. Place a sample in the center of the slide.
3. Using a pipette/eye-dropped, place a drop of water on the specimen.
4. Place an edge of the cover slip over the sample and carefully lower the cover slip into place using a toothpick/your fingers. This method will help prevent air bubbles from being trapped under the cover slip.



How to Calculate Magnification

- The value of the objective lens traditionally go 4x, 10x, 40x, and 100x.
  - It should state the magnification on the objective lens.
- However, there is also the eyepiece to consider, which is usually 10x.
- So, we can use the following formula:

$$Total\ Magnification = (magnification\ of\ eyepiece) \cdot (magnification\ of\ objective\ lens)$$

❖ Example 1: You are looking at a cell with a 10x eyepiece and a 4x objective lens. What is your total magnification?

How to Calculate Diameter of the Field of View

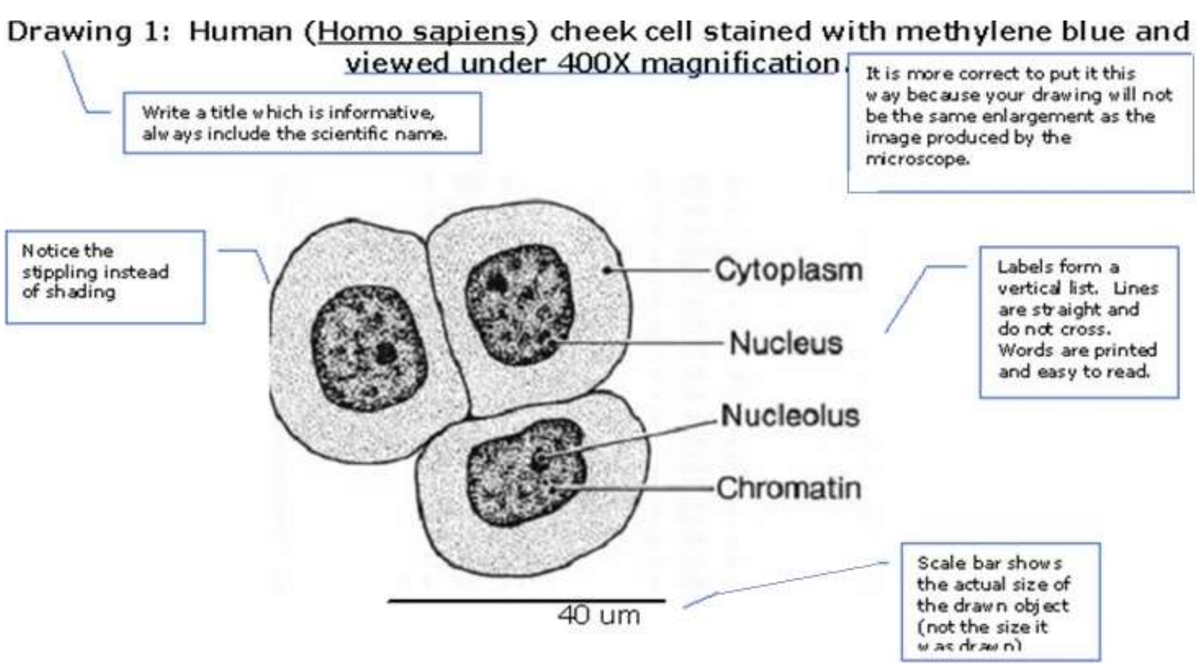
1. Place a transparent ruler under the low power objective lens of a microscope.
2. Focus the microscope on the scale of the ruler, and measure the diameter of the field of vision in millimeters.
3. This will work for the low power objective lens, but not necessarily for the higher power ones… so we can use this formula!

$$\text{field of view} = \text{diameter of low power objective} \cdot \frac{\text{magnification of low power objective}}{\text{magnification of high power objective}}$$

❖ <u>Example 2</u>: You measure your field of view diameter to be 4.0mm on the low power objective lens (4x). What would your field of view diameter be for a high power objective lens (40x)?

How to Make a Biological Lab Drawing

- Use a pencil and unlined paper when drawing a biological diagram. Draw only what you actually observe, as opposed to what you think you should be seeing.
- Represent darker areas of an object with stippling or dots. Do not shade any areas of the diagram.
- Use sharp single lines to represent an object. Do not use soft lines characteristic of sketches. Make the illustration large so that various parts of the specimen are easily distinguishable.
- Draw scale bars indicating the length and width of a specimen. A scale bar is a straight line that represents the relationship between space on your page and the actual space occupied by the specimen.
- Use a ruler to draw straight, horizontal lines in order to label different parts of the specimen. The labels should form a vertical list. All labels should be printed.
- The title should state what has been drawn and what lens power it was drawn under.

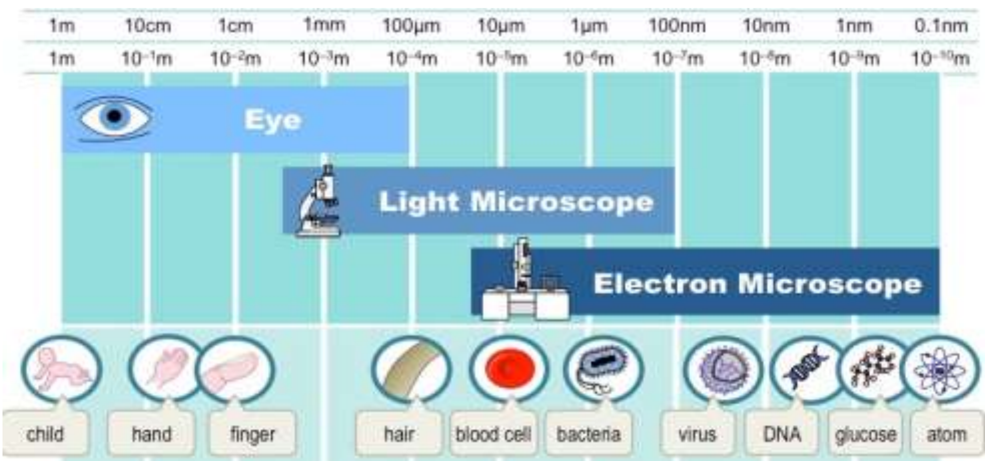


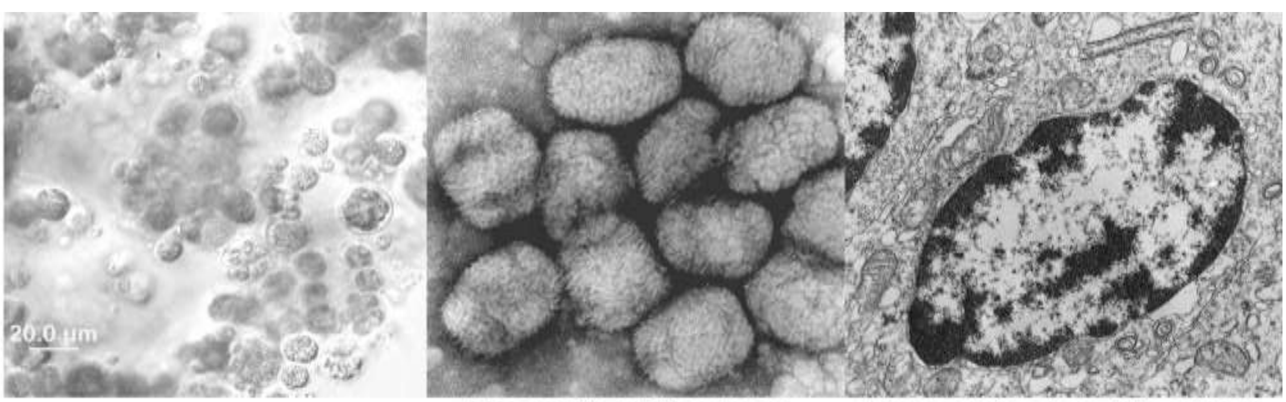
How to Estimate the Size of a Specimen

1. Objects observed with microscopes are often too small to be measured conveniently in millimeters
2. Estimate what fraction of the diameter of the field of vision that the object occupies.
    - In other words, estimate how many times your specimen can fit into the field of view.
3. Divide your field of view diameter by how many times your specimen will fit into the diameter.

- Example 3: You observe a cell under a medium power lens. You've measured the diameter of the field of view to be 2.0 mm. You estimate that the cell will fit into the diameter of the field of view about 5 times. What is the size of the cell?

TYPES OF MICROSCOPES





Light Microscope | Scanning Electron Microscope (SEM) | Transmission Electron Microscope (TEM)

Compound Light Microscope

- Compound light microscopes **direct light through a specimen** and use multiple lenses to produce a magnified image (**40 to 2000×**).
- Can see **most but not all cells**, and few cell structures.
- Resolution limited to about **0.2 µm**.

Fluorescence Microscope

- Fluorescence microscopes **detect light** given off by **naturally fluorescent** specimens or specimens stained with **fluorescent dyes**.
- Magnification range: **40× to 2000×**
- **Shines ultraviolet or near-ultraviolet radiation** on specimens to make them fluoresce

Transmission Electron Microscope (TEM)

- Electron microscopes use electromagnets to focus a narrow beam of electrons on a specimen to produce a magnified image (up to 1 000 000×).
- Specimens are embedded in plastic, **sliced into thin sections (cross-sections)**, and stained with a heavy metal or salt of a heavy metal.
- Produces a **2-D image**.
- **Excellent resolution**.

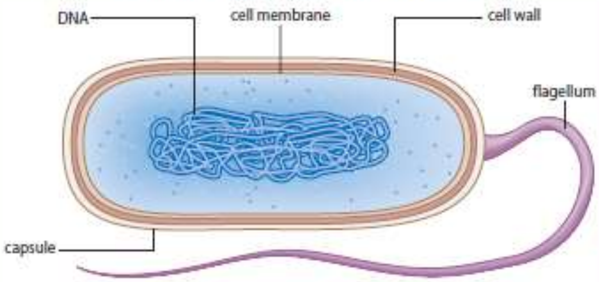
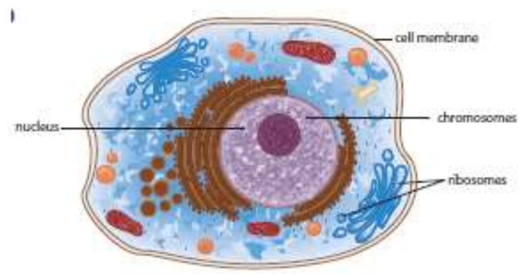
Scanning Electron Microscope (SEM)

- Magnification is over **300,000 x.**
- Resolutions **0.005 µm - lower than TEM.**
- Specimen is sprayed with **a gold coating and "scanned"** with a narrow beam of electrons.
- An electron detector produces **a 3D image** of the specimen on a TV screen.

Atomic Force Microscopy

- Magnification range: **1000× to 10 000 000×**
- **No special preparation or staining** of the specimen is needed.
- Metal-and-diamond probe scans surface of specimen; responding movements of probe are used to produce three-dimensional image in near-atomic detail

❖ 4.2 – Cell Types and Structures

Characteristic	Prokaryotes: Bacteria, Archaea	Eukaryotes: Protists, Plants, Fungi, Animals
Typical size	 2–100 µm	 100–1000 µm
Genetic material	• no nucleus; DNA not bound by a membrane • one circular chromosome	• DNA in nucleus, bounded by a membrane
Division of genetic material	• not by mitosis or meiosis	• mitosis and meiosis
Reproduction	• asexual	• asexual or sexual
Number of cells	• unicellular	• unicellular or multicellular
Organelles	• has ribosomes but membrane-bound organelles are absent	• has both ribosomes and membrane-bound organelles
Metabolism	• varies; includes cells that require oxygen to make ATP and cells that do not • some are photosynthetic	• most require oxygen to make ATP • some are photosynthetic

TYPES OF CELLS

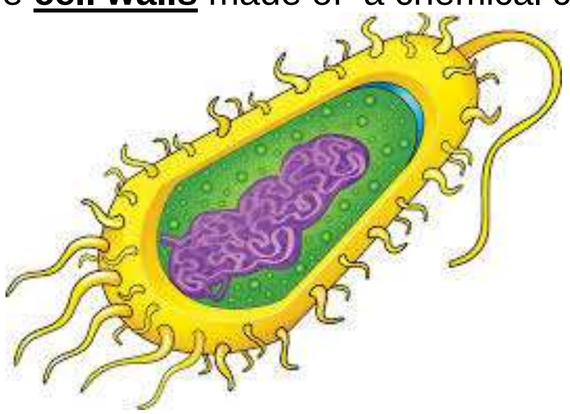
- ❖ We will explore the two main types of cells**: PROKARYOTIC and EUKARYOTIC cells**.

- ❖ We will also look at similarities and differences between two types of eukaryotic cells – **PLANT and ANIMAL cells**.

Prokaryotic vs Eukaryotic

Prokaryotic:

- Have **NO nucleus**
    - *Pro* = **Before**
    - *Karyon* = **nucleus**
    - DNA in **a Nucleoid or** small ring called a **plasmid**
- **Smallest** living cells.
- **Simple** internal structure.
- Lack **membrane-bound organelles**
- **All bacteria cells are prokaryotic.**
- The only living things with prokaryotic cells are **Kingdom Bacteria and Kingdom Archaea**.
- Prokaryotic cells move using **flagella.**
- **Flagella** – **long, hair-like projections** extending from the cell membrane that propel the cell using **a whip-like motion**.
- Prokaryotic cells have **cell walls** made of a chemical called **peptidoglycan**.



Eukaryotic:

- These cells **DO have a nucleus**
- *Eu* = **True**
- *Karyon* = **Nucleus**
- Have **membrane-bound organelles**.
- i.e. **Nucleus, vesicles, mitochondria, Golgi body**
- Organelles function **as a "team"** to carry out the essential functions
- **All forms of life** other than bacteria are eukaryotic (including **plants and animals**).
- The presence of membrane –bound organelles is a major reason why eukaryotic cells **are bigger** than prokaryotic cells.

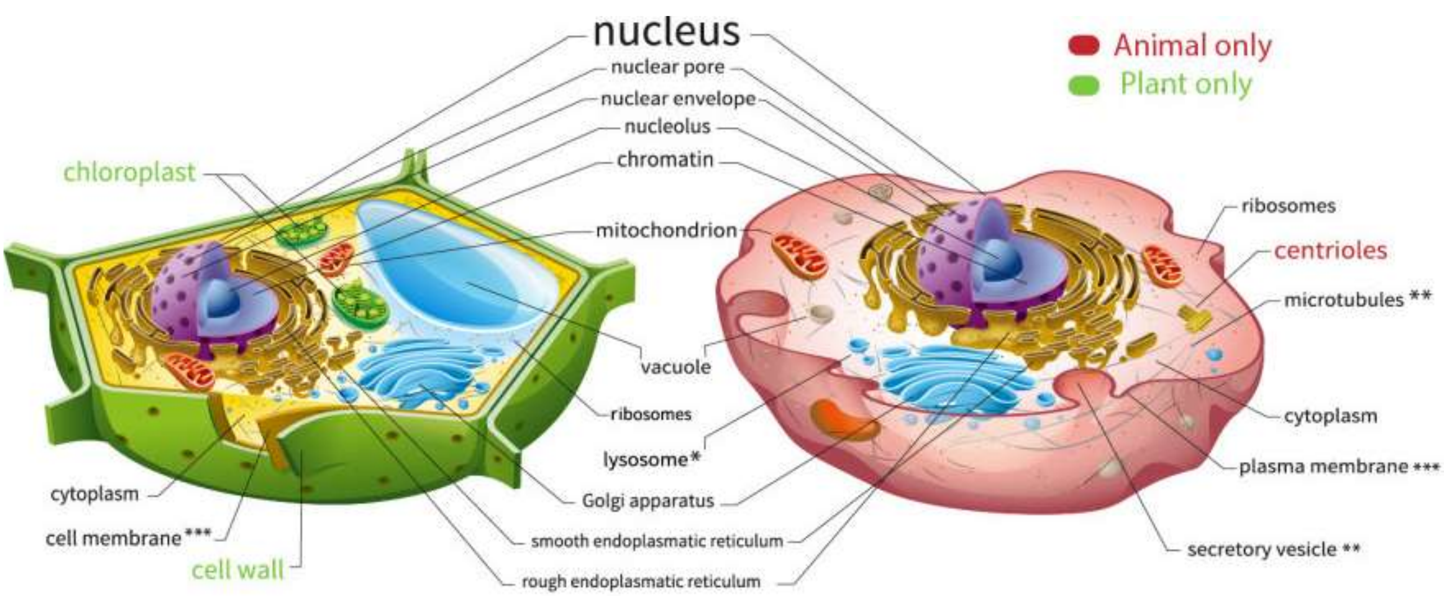
Plant Cells vs Animal Cells

❖ Plant cells contain many of the same structures as animal cells, but there are some differences:

1) Plant cells have **an outer cell wall made of cellulose**; animal cells do not. This **cell wall** provides **rigidity and protection.**

2) Plant cells have **one large central vacuole**; animal cells have **several smaller vacuoles**.**Vacuoles** **provide rigidity and stores wastes or nutrients** and is filled with water.

3) Plant cells have **chloroplasts** whereas animals do not and have **fewer lysosomes.**



* Plants may have lytic vacuoles, which act like lysosomes in animal cells.
** Although they're not labelled here, plant cells have microtubules and secretory vesicles, too.
*** Cell membrane and plasma membrane are just different names for the same structure.

Cell Organelles

What are organelles?

- **"small organs"**
- **All the functions of a cell** are carried out by organelles.
- The structure of each organelle matches its **specific function(s).**
- Organelles work together in a cell to carry out functions such as **protein production and export**.

Cell Membrane

- Structure that **separates** the cell interior from the outside world and **controls the movement of materials** into and out of the cell.
- Helps the cell **maintain homeostasis**.
- It has a **phospholipid bi-layer**.

Cell Wall

- Surrounds the cell membrane and is **strong and fairly rigid**.
- It helps to give a plant **shape and support**.
- Made up of a network of tough fibres, made mainly of **cellulose**.

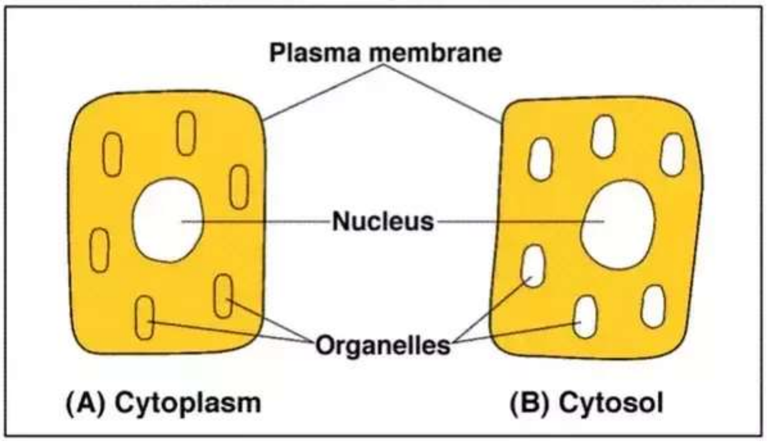
Cytoplasm

- Everything **inside the cell membrane** including the **organelles** (except the nucleus).

Cytosol

- The **fluid inside the cell** in which the organelles are suspended.

Comparison of Cytoplasm and Cytosol

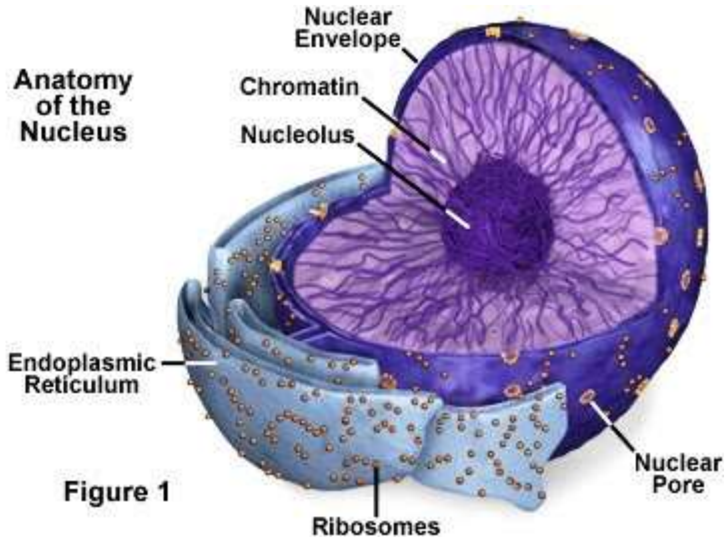


Nucleus

- Command centre of the cell that **contains the DNA blueprints for making proteins.**
- Surrounded by a **double-membrane** to protect the DNA.

Nucleolus

- A specialized area of chromatin inside the nucleus **responsible for *producing ribosomes***.



Ribosome

- Tiny two-part structure found throughout the cytoplasm that **helps *put together proteins***.

Endoplasmic Reticulum (ER)

- System of **flattened membrane-bound sacs and tubes** continuous with the outer membrane of the nuclear envelope.
    1. **Rough ER** – **Has ribosomes and synthesizes proteins**.
    2. **Smooth ER** – **Has canals which help transport the proteins** throughout the cell.

Vesicles

- Small membrane bound **transport sac**. Some special types of vesicles have different jobs in the cell.

Lysosome

- Contains **digestive enzymes** that break down **old cell parts or material brought into cells**.

Golgi Apparatus

- Stack of flattened membrane-bound sacs that **receive vesicles from the ER**.
- Package finished products into vesicles for **transport to the cell membrane** (for secretion out of the cell) and within the cell as lysosomes.

Vacuole

- Large, membrane bound fluid filled sac for the **temporary storage of food, water or waste products**.

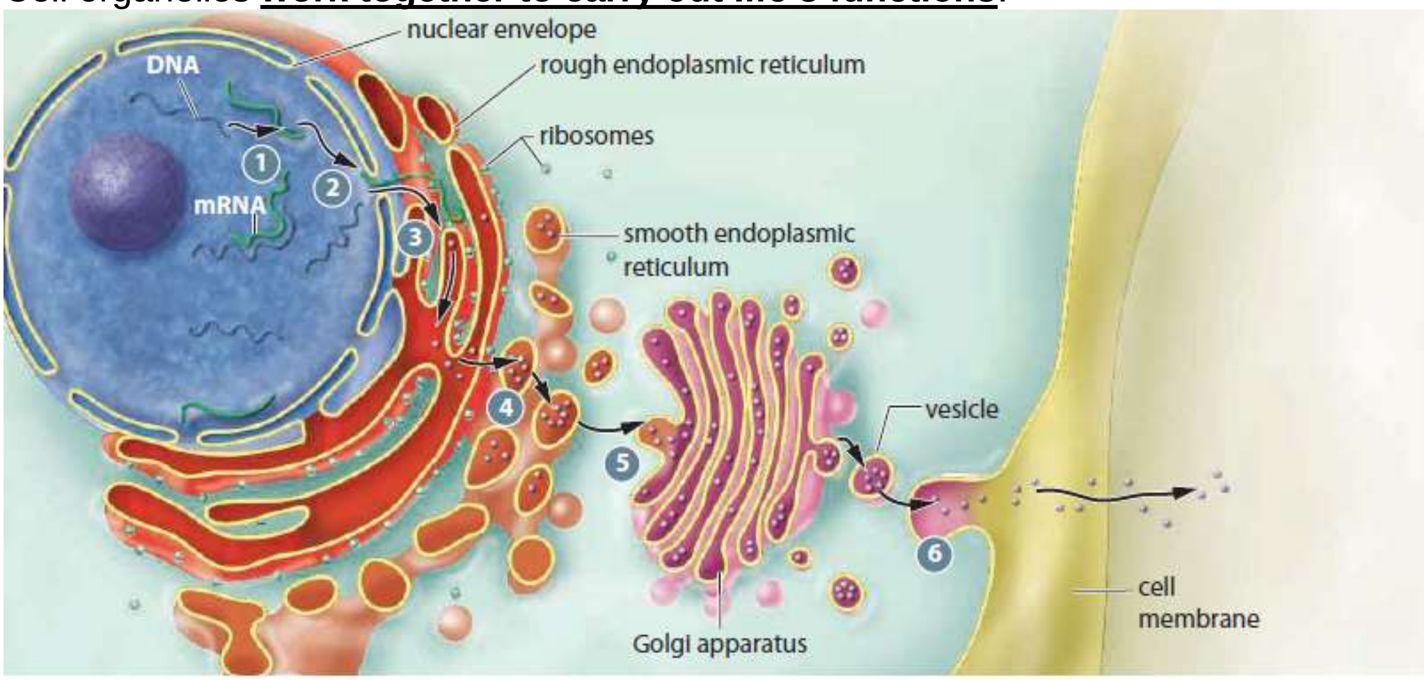
Mitochondrion

- **Powerhouse of the cell** where organic molecules (usually carbohydrates) are broken down inside a double membrane to **release and transfer energy.**

Chloroplast

- Site of **photosynthesis**
- Gives **green plants their colour** and transfers energy from sunlight into stored energy in carbohydrates during photosynthesis.
- Contains stacks of structures called **thylakoids that contain chlorophyll**.
- The thylakoids sit in a fluid called **stroma**.

Cell organelles **work together to carry out life's functions**.



1. Insulin protein information from DNA is copied to RNA.
2. RNA exits the nucleus.
3. At ribosomes on surface of rough ER, information from RNA is used to make a protein that will become insulin.
4. Vesicles from smooth ER package the protein for transport to Golgi apparatus.
5. In Golgi apparatus, the proteins are processed to form insulin protein and packaged for export out of the cell.
6. Insulin is released from the cell when vesicles fuse with the cell membrane.

4.3 – Cell Membrane Structure & Support

Cell Membranes

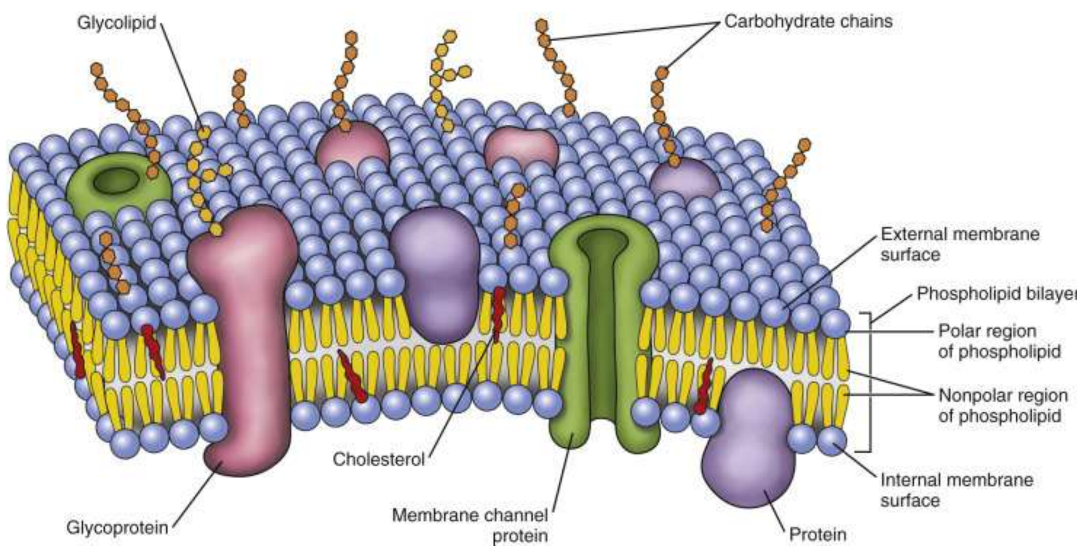
1. **Transport raw materials into** the cell.

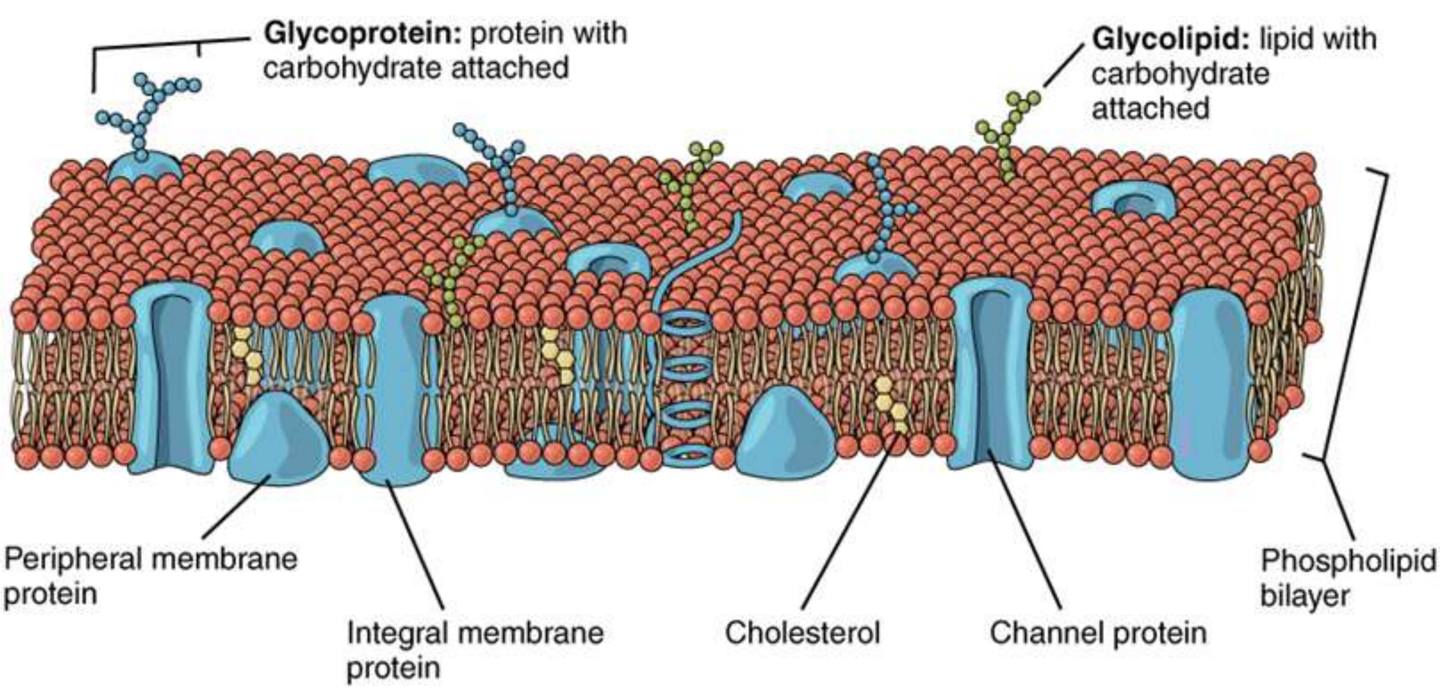
2. **Transport manufactured products and wastes out** of the cell.

3. **Prevent entry of unwanted matter into** the cell.

4. **Prevent the escape of matter needed to perform cellular functions**.

Phospholipid Bilayer - Fluid Mosaic Model





Cell Membrane Part	Structure	Functions
Phospholipids 	• Provide the overall structure for the cell membrane • Arranged in two layers	• Act as a barrier between the cell and its surroundings • Hold the other components of the cell membrane
Proteins 	• Most are embedded in the phospholipid bilayer • Some are attached to the inside or outside surface of the phospholipid bilayer	• Some proteins transport specific substances across the membrane • Some proteins are enzymes, and they control chemical reactions • Some proteins transmit signals from other cells or elsewhere in the body
Cholesterol 	• Embedded in the phospholipid bilayer	• Helps keep fluidity of membrane consistent • Reduces fluidity of membrane at high temperatures • Increases fluidity of membrane at low temperatures
Carbohydrates 	• Attach to proteins or phospholipids and protrude outside the cell	• Allow other cells to "recognize" the cell as belonging to the organism and not an intruder

Phospholipid Bilayer

➢ Phospholipids are composed of **a hydrophilic head and two hydrophobic tails**

Cholesterol

➢ A lipid that regulates the **rigidity of the membrane** over different **temperature ranges**.

Proteins

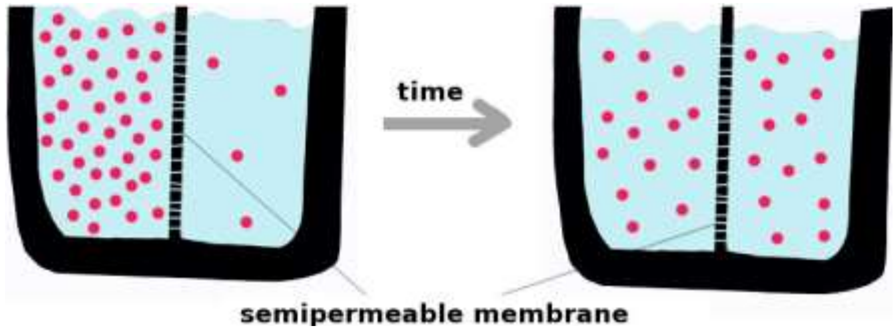
➢ **Channel or Carrier proteins**– Serve to allow materials in and out of the cell.
➢ These proteins are often **specific to certain molecules**.

Carbohydrates

➢ Attach to proteins or phospholipids and protrude outside the cell.
➢ Often involved in **the immune response helping cells to identify one another.**

Maintaining Homeostasis

➢ The cell membrane is **selectively permeable**, **allowing some molecules to pass through, while preventing others**.



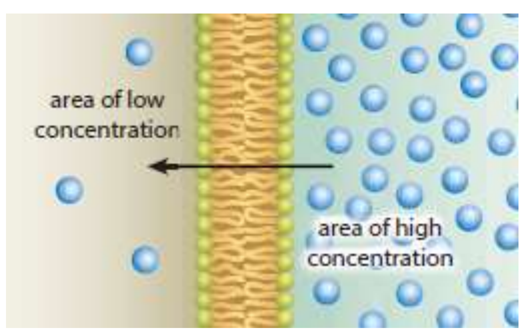
- Two Main Methods:
    - **Passive Transport**
    - **Active Transport**

Passive Transport

- The movement of any substance across a cell membrane **without the use of cellular energy (ATP)*.***
    1. **Simple Diffusion**
    2. **Osmosis**
    3. **Facilitated Diffusion**

1. Simple Diffusion

- The movement of molecules from a region of **higher concentration** to a region of **lower concentration**.
- Occurs **DOWN a concentration gradient** – **high to low**.



2. Osmosis

- The diffusion of **water molecules across a selectively-permeable membrane.**
- When the membrane does not allow the diffusion of materials, water is still able to cross the membrane from **high to low concentration.**
- *A discussion about osmosis requires us to learn about cell tonicity.*

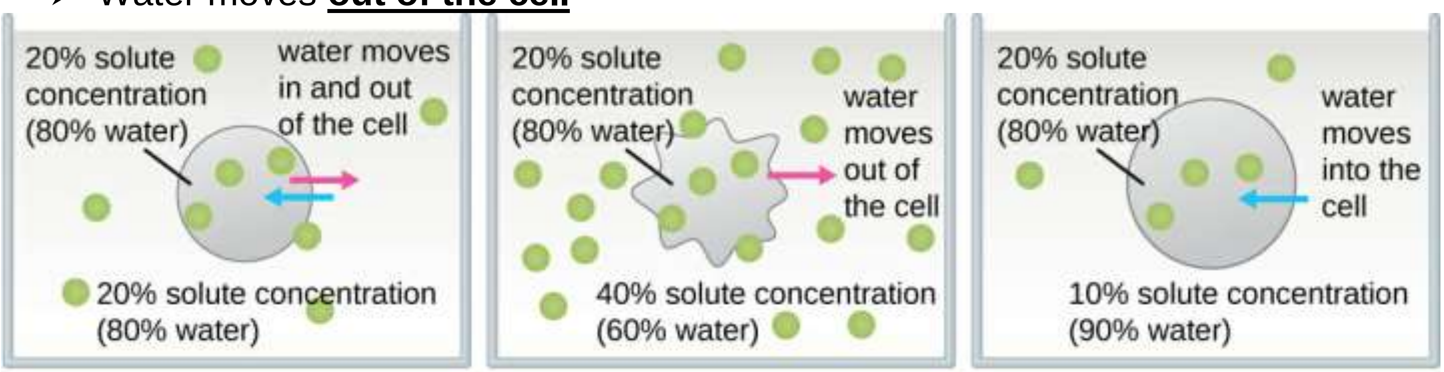
TONICITY AND CELLS

❖ Cells react differently to immersion in 3 different extracellular solutions:
- **ISOTONIC**
- **HYPOTONIC**
- **HYPERTONIC**

Isotonic Solution
- Water Concentration **outside** the cell is **equal to** the concentration **inside** the cell.
- **Equal** amounts of **solute inside and outside**.
- Water **moving in and out equally**.

Hypotonic Solution
- Water concentration **outside** the cell is **greater** than the water concentration **inside** the cell.
- **More solute inside** the cell
- Water moves **into the cell.**

Hypertonic Solution
- Water concentration **outside** the cell is **less** than the water concentration **inside** the cell.
- **More solute outside** the cell
- Water moves **out of the cell**

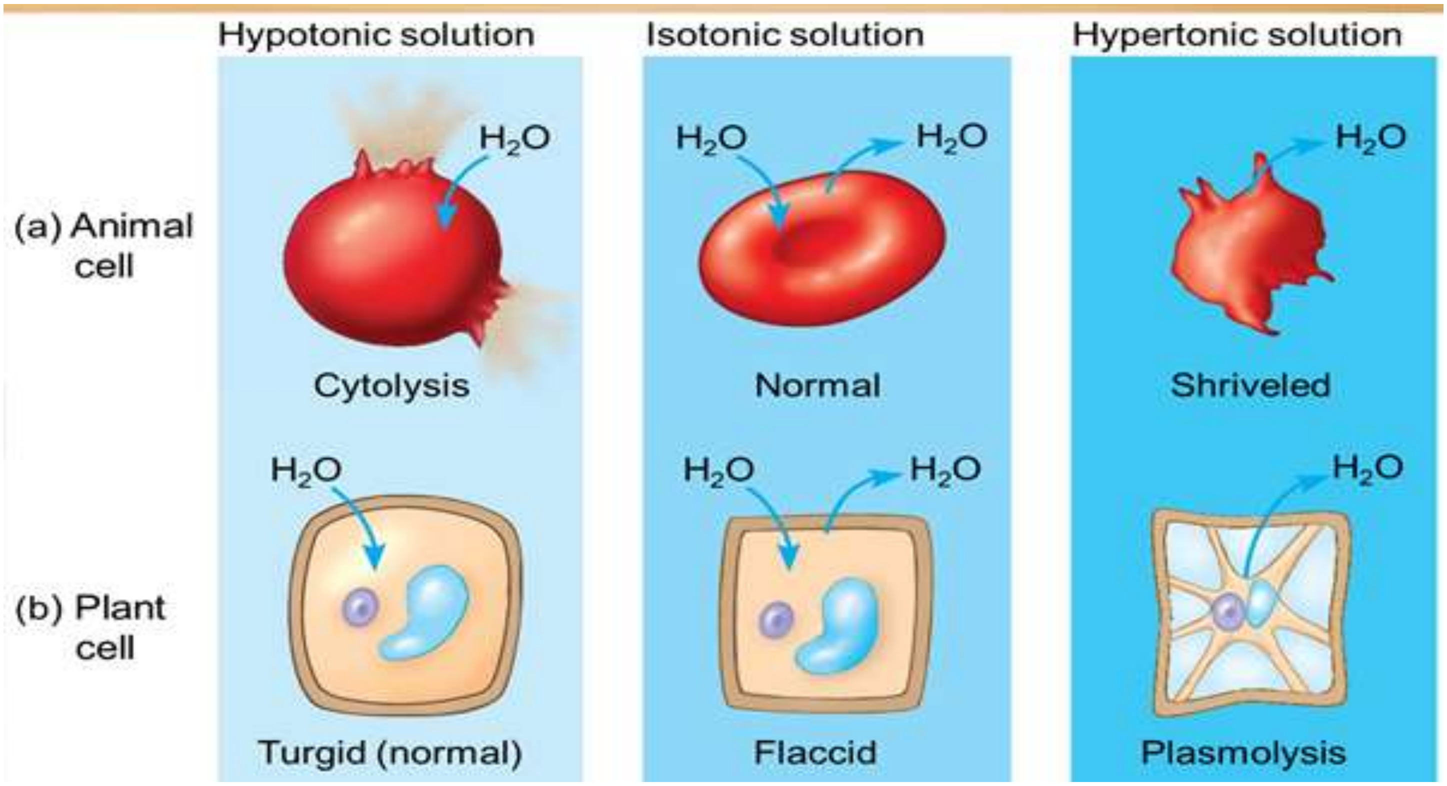


a Isotonic solution A solution that has the *same* solute concentration as another solution. There is no net movement of water particles, and the overall concentration on both sides of the cell membrane remains constant.

b Hypertonic solution A solution that has a *higher* solute concentration than another solution. Water particles will move out of the cell, causing crenation.

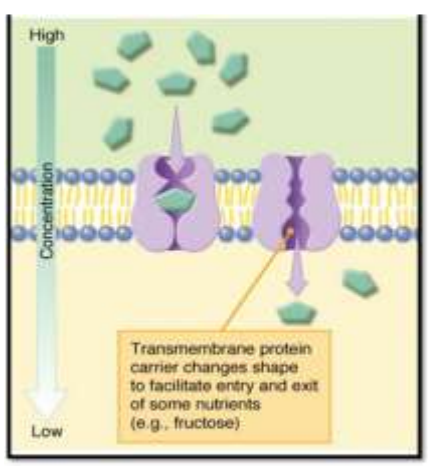
c Hypotonic solution A solution that has a *lower* solute concentration than another solution. Water particles will move into the cell, causing the cell to expand and eventually lyse.

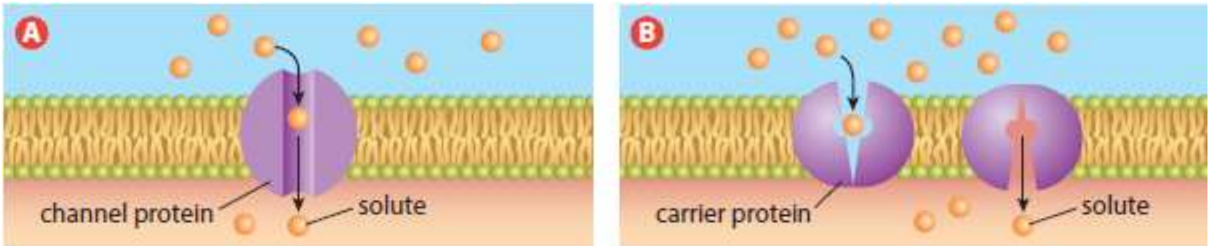
Osmosis in Animal vs Plant Cells



3.Facilitated Diffusion

- Sometimes materials are **too large or charged** to diffuse across the membrane without assistance, or **they may not be soluble in lipids**, so they cannot dissolve in the lipid bilayer.
- These materials **need help from an integral protein (*channel or carrier***).
- Movement of molecules is still **going DOWN the concentration gradient,** but now the carrier or channel protein is helping to move them**.**
- These **integral proteins (carrier or channel)** are specific to the materials that they are transporting (moving) across the membrane by **size, shape and electrical charge**.





Carrier Protein vs Channel Protein

Channel protein

- **Have a *tunnel*** that allows **specific ions** to move in or out of the cell.
- Ex. Na+ or Cl-

Carrier proteins

- ***Changes shape* to move specific molecules** in or out of the cell.
- Ex. **glucose**

Active Transport

- The movement of any substance **across a cell membrane with the use of energy from ATP**.
- In active transport, proteins move substances from areas of **lower to higher concentration (against concentration gradient)**. This is important in the process of digestion and the removal of waste.
- Example: **sodium-potassium pump, endo/exocytosis**

- **Examples of Active Transport**
  - *Kidney cells pump glucose and amino acids out of the urine and back into the blood.*
  - *Intestinal cells pump nutrients from the gut.*
  - *Plant root cells pump nutrients from the soil.*
  - *Fish gill cells pump sodium ions out of the body.*

Bulk Membrane Transport - Active Transport Example

- Sometimes molecules are **too large or too polar** to cross through the cell membrane.

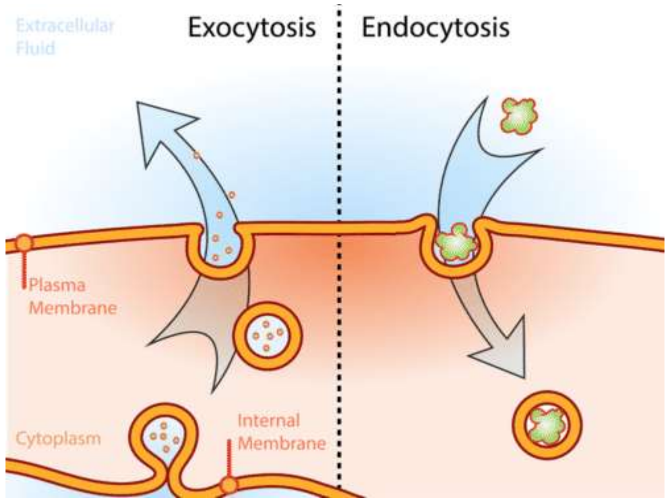
- The cell uses a specialized method of getting materials in or out of the cell using the **cell membrane** itself:
  - **Endocytosis**
  - **Exocytosis**

Endocytosis

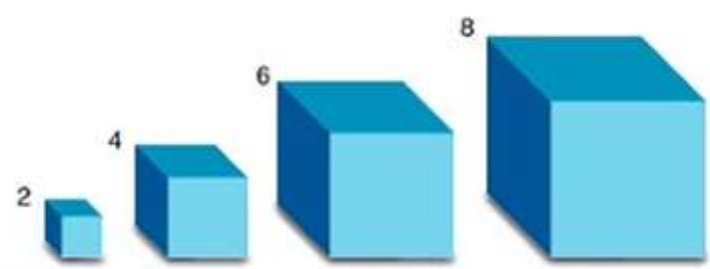
- The process by which a **cell <u>engulfs and surrounds large substances</u>**.
- The membrane **<u>folds in on itself</u>** trapping matter from the extracellular fluid within it forming a **<u>vesicle</u>**.

Exocytosis

- **<u>Reverse of endocytosis</u>.**
- A vesicle **<u>from the inside of the cell</u>** fuses with the cell membrane.
- The contents of the vesicle are **<u>excreted (expelled) into the extracellular fluid</u>**.
- Very important to the **<u>cells of organs that secrete hormones</u>**.
- Ex. The pancreas secretes insulin.
- Exocytosis is also the process by which **<u>wastes are packaged in vesicles and leave the cell</u>**.



Limits on CELL SIZE



Surface area (cm^2)	24	96	216	384
Volume (cm^3)	8	64	216	512
Surface area / Volume	3.0	1.5	1.0	0.75

- Although there are many types of cells, there is one feature that most cells share in common – **<u>their small size</u>**.
- Cells are typically **<u>less than a tenth of a mm</u>** in diameter.
- They need to be small because nutrients, water, oxygen, carbon dioxide and waste products **<u>enter or leave the cell through its surface</u>**, ***the cell membrane***.

- If a cell gets too large, it would be **inefficient** for interior substances to travel to and from the cell membrane.
- The key relationship is – **THE SMALLER the CELL, the LARGER its SURFACE AREA**.

- **LARGE CELLS**
  - **Lower Surface Area (aka Surface Area to Volume Ratio)**
  - Less surface exposed for cell membrane transport
- **SMALL CELLS**
  - **High Surface Area**
    - More **efficient** at allowing transport across the CELL MEMBRANE

4.4 – Energy Transformation in Cells

The Need for Energy

- Cells need **energy** to function and carbon to build biological molecules. **ATP is a molecule** that cells use for readily available energy.
- ATP breaks down to form another molecule **called ADP**, releasing a small "packet" of energy that the cell can use.

- Examples of processes in the body that requires ATP:
  - Active transport of materials into the cell
  - Moving chromosomes during cell division
  - The contraction of muscles
  - Synthesizing macromolecules

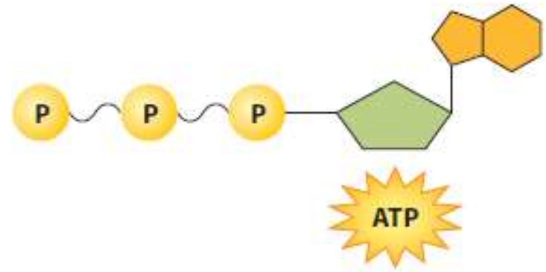
- There are two types of cellular respiration:
  1. **Aerobic Respiration** is the cellular process that uses oxygen to release energy, as ATP, from glucose.

glucose + oxygen → carbon dioxide + water + energy

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + ATP$$

  2. Cellular respiration that proceeds without oxygen is called **anaerobic respiration**.

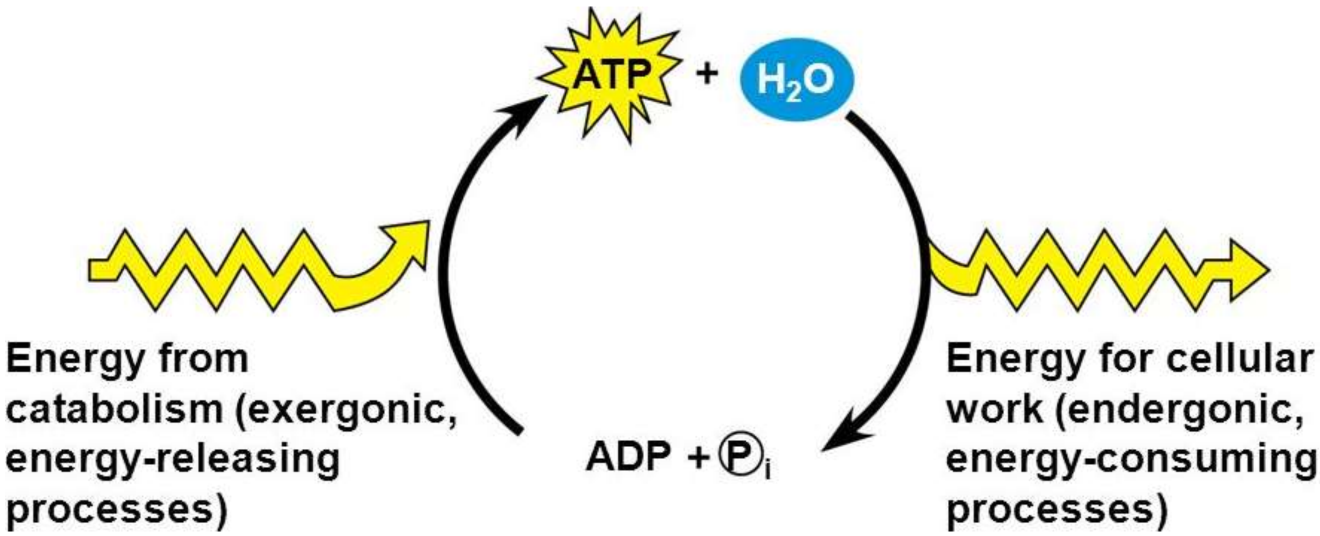
Aerobic Respiration



- ATP, short for adenosine triphosphate, is a nucleotide consisting of a group called adenosine and three phosphate groups.
- ATP undergoes a chemical reaction that results in the release of energy. This reaction produces three things:
  - a molecule called ADP (short for adenosine diphosphate)
  - a free phosphate group
  - a burst of energy that cells can use right away.
- Recall: an appreciable amount of energy is released when one of the bonds is broken in a hydrolysis (water-mediated breakdown) reaction. ATP is hydrolyzed to ADP in the following reaction:

$$\text{ATP} + \text{H}_2\text{O} \leftrightharpoons \text{ADP} + \text{P}_i + \text{energy}$$

  - Note: P_i stands for an inorganic phosphate group (PO_4^{3-})

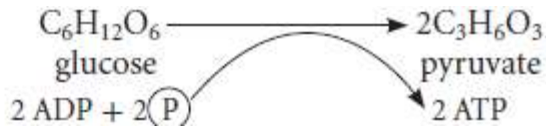


- Aerobic respiration actually consists of many, many chemical reactions
- Each reaction is catalyzed by a particular enzyme.
- These reactions take place in four stages.
  - The first stage, glycolysis, takes place in the cytosol.
  - The remaining stages take place in mitochondria.

The Stages of Aerobic Respiration

A. Glycolysis

- Through two distinct phases, the six-carbon ring of glucose is cleaved into two three-carbon sugars of pyruvate through a series of enzymatic reactions.
- The net result of the process, in addition to the splitting of glucose, is that two molecules of ATP are formed.



- Glycolysis is also the first stage anaerobic respiration that makes ATP without using oxygen.

B. Breakdown of Pyruvate

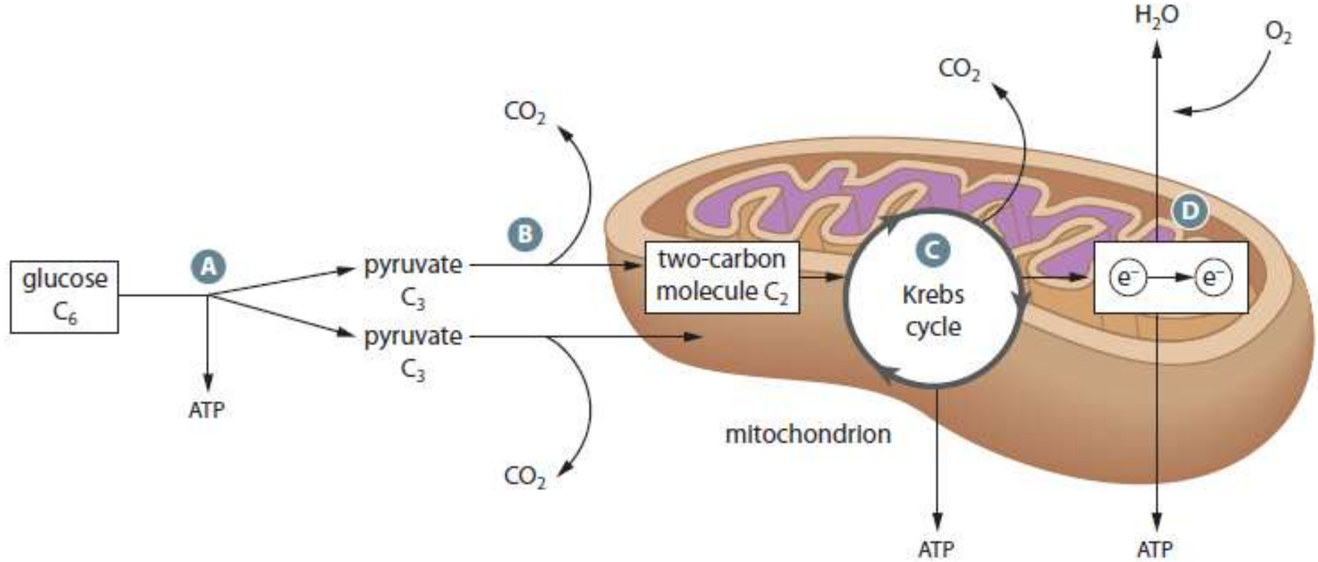
- Although glycolysis produces ATP, the more important thing is those pyruvate molecules.
- The pyruvate molecules enter the mitochondria and are converted into a two-carbon intermediate.

C. Krebs Cycle

- This is the breaking down of the molecules from stage two into CO_2 molecules, H_2O molecules, and generating additional ATP.

D. Oxidative Phosphorylation

- The energy-carrying molecules produced in the previous stages are used to make ATP.



A Glycolysis is the breakdown of one glucose molecule to form two pyruvate molecules and a small amount of ATP.

B The conversion of pyruvate into a 2-carbon molecule connects glycolysis in the cytosol to the Krebs cycle in the mitochondrion. During pyruvate conversion, carbon dioxide is released.

C The Krebs cycle is a circular series of reactions that produce a small amount of ATP along with energy-carrying molecules that move on to the next stage of cellular respiration. Carbon dioxide is also released during the Krebs cycle.

D In oxidative phosphorylation energy-carrying molecules pass electrons to an electron transport chain in the mitochondrial membrane. Oxygen is the last electron acceptor in the chain. As electrons are passed from one carrier in the chain to the next, energy is released. This energy is harnessed to make ATP. More ATP is produced during this stage of cellular respiration than any other.

- For every one molecule of glucose that undergoes aerobic cellular respiration, a maximum of 36 to 38 ATP molecules can form.
- Six oxygen molecules are consumed in the reaction, and six molecules each of carbon dioxide and water are produced.

$$\underset{\text{glucose}}{C_6H_{12}O_6} + \underset{\text{oxygen}}{6O_2} \longrightarrow \underset{\text{carbon dioxide}}{6CO_2} + \underset{\text{water}}{6H_2O}$$

$$38\ ADP + 38\ (P) \longrightarrow 38\ ATP$$

The Stages of Photosynthesis

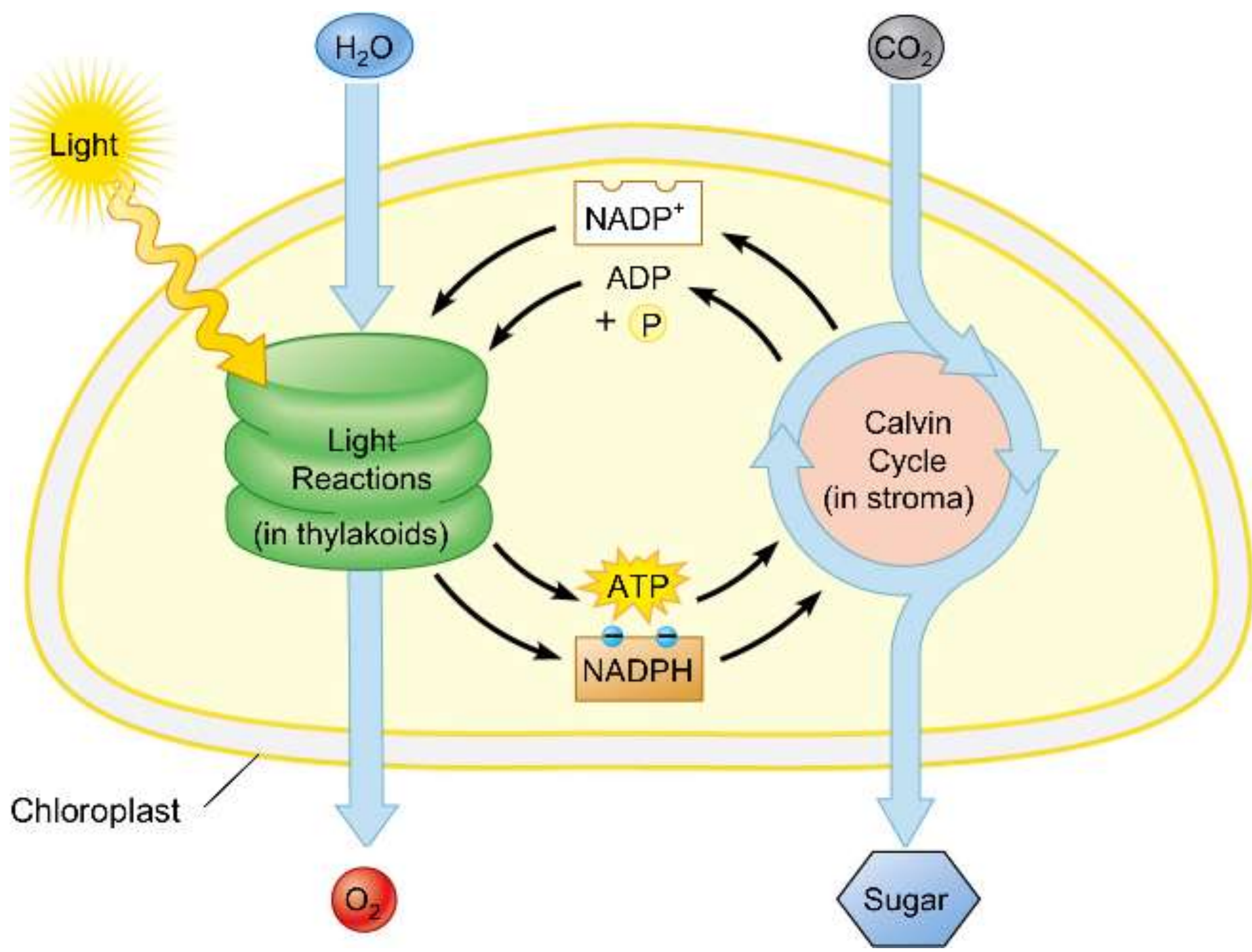
A. Light Dependent Reactions

- Chlorophyll pigments absorb light energy.
- Light energy is used to make two molecules needed for the next stage of photosynthesis: the energy storage molecule ATP and the reduced electron carrier NADPH.
- This stage of photosynthesis uses a molecule of water and produces a molecule of oxygen.

B. Calvin Cycle

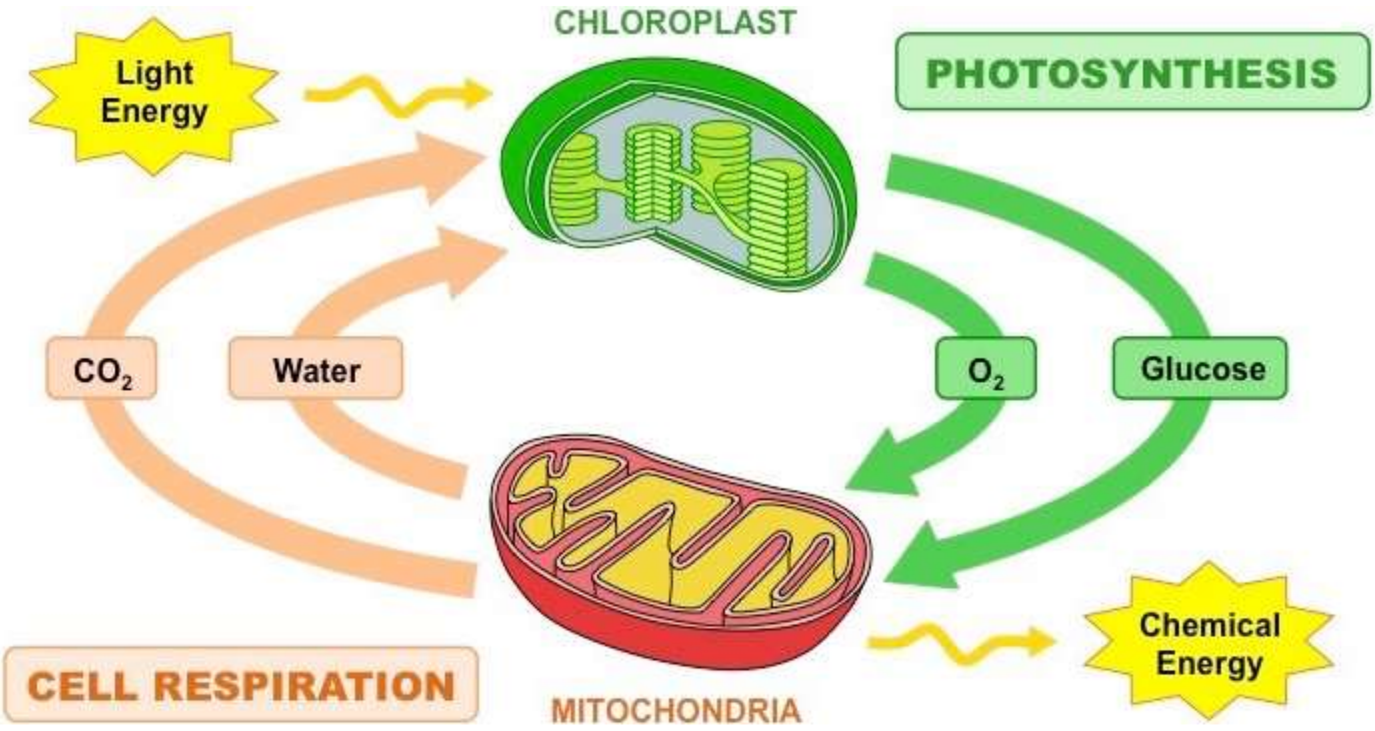
- Uses the products of the light dependent reactions to convert carbon dioxide into glucose.
- These reactions occur in the stroma of the chloroplast.

$$\underset{\text{carbon dioxide}}{6CO_2} + \underset{\text{water}}{6H_2O} \longrightarrow \underset{\text{glucose}}{C_6H_{12}O_6} + \underset{\text{oxygen}}{6O_2}$$



Complementary Processes

- In photosynthesis, plants use energy from sunlight to convert carbon dioxide and water into glucose and oxygen.
    - This overall reaction is the reverse of the overall reaction for aerobic respiration.
- Photosynthesis not only supplies our atmosphere with oxygen, but also removes carbon dioxide from the atmosphere.



Complementary Reactions

- In fact, photosynthesis and cellular respiration are **<u>the opposite of each other in terms of reactants and products</u>**.