| *Biology I* | *Lecture Outline 5* | *The Cell* |
|---|---|---|

**References** (Textbook - pages 59-84, 85-102, 103-116, 117-132, 133-149, 150-168, 169-188: Lab Manual - pages 37-58)

**Introduction**

**Prokaryotic and Eukaryotic Cells**

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**References** (Textbook - pages 59-84, 85-102, 117-132, 133-149, 150-168: Lab Manual - pages 37-58)

## Introduction

1. ***Antoni van Leeuwenhoek (1632-1723)*** was probably the ***first human*** to ever ***observe*** a ***living cell***. He ***built*** his ***own microscope.***

2. Our ***textbook defines*** a ***cell*** as - the ***smallest unit*** that ***displays*** the ***properties*** of ***life***; ***composed*** of ***organelle-containing cytoplasm surrounded*** by a ***plasma membrane.***

3. The ***cell theory*** states that

   A. ***All organisms*** are ***composed*** of ***cells***

   B. ***Cells*** are the ***basic units*** of ***structure*** and ***function*** in ***organisms***, and

   C. ***Cells*** come ***only*** from ***preexisting cells*** because ***cells*** are ***self-reproducing***

4. ***Cells*** are very ***small*** - ***ranging*** in ***size*** from ***10*** to ***100 micrometers*** ***(1 micrometer is 1 thousandth of a millimeter)***. You ***cannot see*** them with the ***unaided human eye***

5. It is ***estimated*** that there are somewhere between ***50 to 100 trillion cells*** in the ***average human body***. ***(obviously a large range of estimates because it would be hard to actually count the number of cells in a human body and in a single body the number is never static).***

## Prokaryotic and Eukaryotic Cells

1. There are ***2 types*** of ***living cells***

   ***Prokaryotic cells*** - ***(pro*** means ***"before": karyote*** – means ***"nucleus")***
   ***Eukaryotic cells*** - ***(eu*** means ***"true": karyote*** – means ***nucleus")***

2. The basic or ***major difference*** is

   A. ***Prokaryotic cells*** - ***do not contain*** nuclei (nucleus = singular)
   B. ***Eukaryotic cells*** - ***do contain*** nuclei

3. Other ***characteristics*** of ***prokaryotic cells*** include

   A. Even though they ***lack*** a ***membrane bound nucleus***, they ***do have*** a ***nucleoid area*** that ***contains DNA***

   B. ***Prokaryotic cells do*** have a ***cytoplasm***. ***(Cytoplasm is the material bounded by the plasma membrane and cell wall)***

   C. ***Prokaryotic cells do not*** have the ***same organelles*** that are ***found*** in ***eukaryotic cells***.

   D. ***Organelles*** in ***prokaryotic cells*** include

      1) ***Ribosomes*** - coordinate ***synthesis*** of ***proteins***
      2) ***Thylakoids*** – ***participate*** in ***photosynthesis***

   E. ***Prokaryotic cells*** are ***structurally less complicated*** than ***eukaryotic cells***

   F. ***Bacteria*** are very ***small organisms*** that ***exist*** as a ***single prokaryotic cell***

## Animal and Plant Cell Structure – The Eukaryotic Cell

(See Handoutsof Figure 4.6, Animal Cell Anatomy and Figure 4.7, Plant Cell Anatomy, pages 68-69, Textbook, Mader, 10th Ed.)

1. The ***nucleus*** is ***bounded*** by a ***nuclear envelope*** and contains the ***nucleoplasm***

2. ***Cytoplasm*** consists of ***background fluid*** and the ***organelles*** and ***occurs between*** the ***plasma membrane*** and the ***nucleus***

3. Other ***important structures*** are as follows

   **A. Cell Wall**

      ***1) Plant cells only***

      2) ***Composition*** - contains ***cellulose fibrils*** ***(fibril = a small fiber)***

      ***3) Function*** – provides ***support*** and ***protection***

   **B. Plasma Membrane**

      ***1) Plant and animal cells***

2) ***Composition*** – a ***phospholipid bilayer*** with ***embedded proteins***

3) ***Function*** – the ***outer cell surface*** that ***regulates entrance*** and ***exit*** of ***molecules***

**C. Nucleus**

1) ***Plant and animal cells***

2) ***Composition*** - ***enclosed*** by ***nuclear envelope***
   - ***contains chromatin*** (threads of ***DA*** and ***protein***)
   - ***contains nucleolus*** which ***produces ribosomes***

3) ***Function*** – ***storage*** of ***genetic information***
   - ***synthesis*** of ***DNA*** and ***RNA***

**D. Nucleolus**

1) ***Plant and animal cells***

2) ***Composition*** – ***concentrated*** area of ***chromatin***, ***RNA***, and ***proteins***

3) ***Function*** – ***produces*** subunits of ***ribosomes***

**E. Ribosome**

1) ***Plant and animal cells***

2) ***Composition*** – ***protein*** and ***RNA*** in ***two subunits***

3) ***Function*** – carries out ***protein synthesis***

**F. Endoplasmic reticulum (ER)**

1) ***Plant and animal cells***

2) ***Composition*** – ***membranous,*** flattened ***channels*** and ***tubular canals***

3) ***Function*** – ***synthesis*** and/or ***modification*** of ***proteins*** and other ***substances***

4) There are ***2 types*** of ***ER***

   ***a) Rough ER***

   - ***Composition*** - ***studded*** with ***ribosomes***
   - ***Function – protein synthesis***

   ***b) Smooth ER***

   - ***Composition – lacks ribosomes***
   - ***Function – synthesis*** of ***lipid molecules***

**G. Golgi apparatus**

***1) Plant and animal cells***

***2) Composition – stack*** of membranous ***saccules*** ***(saccule = a little bag or sac)***

3) ***Function – processes***, ***packages***, and ***distributes proteins*** and ***lipids***

**H. Vesicle** ***(vesicle = a small membranous cavity or sac)***

***1) Plant and animal cells***

***2) Composition*** – membrane-bounded ***sac***

3) ***Function – stores*** and ***transports substances***

**I. Lysosome**

***1) Plant and animal cells***

2) ***Composition – vesicle*** containing ***hydrolytic enzymes***

***(note – hydrolytic enzymes are those that speed up and promote hydrolysis reactions like those necessary to break up large polymers like proteins, starches, and nucleic acids into their monomer subunits)***

3) ***Function – digests macromolecules*** and ***cell parts***

**J. Peroxisome**

***1) Plant and animal cells***

2) ***Composition – vesicle*** containing ***specific enzymes***

*3) **Function** – **breaks*** down ***fatty acids*** and ***converts*** resulting ***hydrogen peroxide*** to ***water:*** various ***other functions***

**K. Mitochondrion**

***1) Plant and animal cells***

2) ***Composition*** – membranous ***cristae*** bounded by an ***outer membrane***

***(note – cristae are the internal compartments of the mitchontrion)***

3) ***Function*** – carries out ***cellular respiration***, ***producing ATP*** molecules

**L. Chloroplast**

***1) Plant cells only***

2) ***Composition*** – membranous ***thylakoids*** bounded by 2 membranes

3) ***Function – carries*** out ***photosynthesis***, producing ***sugars***

**M. Cytoskeleton**

***1) Plant and animal cells***

2) ***Composition – microtubules***, intermediate ***filaments***, ***actin filaments***

***3) Function – maintains cell shape*** and ***assists movement*** of ***cell parts***

**N. Cilia and flagella**

***1) Plant and animal cells***

2) ***Composition –microtubules***

3) ***Function – movement of cell***

O. Centrioles

1) ***Animal cells only***

2) ***Composition –microtubules***

3) ***Function – unknown function***

P. Vacuoles

1) ***Animal and Plant cells***

2) ***Composition*** – membranous sac like vesicles, but larger

3) ***Function*** in ***Animal Cells***

a) only a ***few animal cells*** have ***vacuoles***

b) usually used for ***storage*** of ***substances***

4) ***Function*** in ***Plant cells***

a) ***Plant cells*** typically have a ***large central vacuole*** that may take up ***90%*** of the ***volume*** of the ***cell***

b) Normally ***filled*** with a ***watery fluid*** called ***cell sap***

c) Provides ***support*** for ***cell***

d) ***Stores*** both ***nutrients*** and ***wastes***

## Cell membrane Structure and Function

1. A ***plasma membrane encloses every cell*** including

A. A ***single cell*** of a ***unicellular organism*** like an ***amoeba***

B. ***One*** of ***many cells*** in a ***multi-cellular organism*** like ***humans***

2. ***Three important functions*** of the ***plasma membrane***

   A. ***Protection of cell*** – acts as a ***barrier*** between ***living contents*** of ***cell*** and the ***surrounding environment***

   ***B. Regulates passage*** of ***materials*** in and out of ***cell***

   C. ***Serves*** as a ***means*** of ***communication*** between ***cells***

3. **Structure of Plasma Membrane**

   (See Handout of Structure of Plasma Membrane)
   Also see Handout of Figure 5.1 Plasma Membrane of an animal cell, page 86 of Textbook, Mader, 10th Ed.)

   A. The ***plasma membrane*** is a ***phospholipid bilayer*** (***recall our discussion of lipids)***

   B. The ***phospholipid*** molecule has a ***hydrophilic*** (water-loving) ***head*** and a ***hydrophobic*** (water-fearing) ***tail*** ***(check back to handout 3.12)***

   C. This ***structure explains*** why the ***membrane*** is a ***bilayer*** with ***hydrophilic heads*** of phospholipid ***naturally facing*** the ***outside*** and ***inside*** of the ***cell*** where ***water occurs***.

   D. ***Cholesterol*** molecules are found ***scattered*** in the plasma ***membrane*** and help ***modify*** the ***fluid nature*** of the ***membrane***

   E. ***Proteins*** are ***scattered*** through- out the ***membrane*** and are of ***2 types***

      ***1) Integral proteins***

         a) Are ***embedded*** in the *plasma membrane*

         b) May ***protrude through*** on ***one surface*** of ***both surfaces*** of the ***membrane***

      ***2) Peripheral proteins***

         a) Occur ***only*** on ***cytoplasm side*** of ***plasma membrane***

F. ***Proteins*** associated with the ***plasma membrane*** and their ***functions***

(See Handout Figure 5.3, Membrane protein diversity, page 88 of Textbook, Mader, 10th Ed.)

*1)* ***Channel Proteins***

a) ***Allows*** a ***particular molecule*** or ***ion*** to ***pass thru*** the ***membrane***

b) Actually have a ***channel*** that ***allows*** a ***molecule*** to ***pass*** thru

*2)* ***Carrier Proteins***

a) Are ***involved*** with ***passage of molecules*** across ***membrane***

b) ***Combine*** with ***molecules*** and ***help*** them ***move across*** membrane

*3)* ***Cell Recognition Proteins***

a) Are called ***glycoproteins***

b) ***Help*** the ***body recognize*** invading ***pathogens*** so that ***immune system*** can ***respond***

*4)* ***Receptor Proteins***

a) Are ***shaped*** such that only a ***specific molecule*** can ***bind*** to it

***b)*** When ***bound*** to a ***specific substance*** this ***molecule triggers*** a ***cellular response***

c) ***Example*** – ***pygmies*** are ***not short*** because they ***do not produce enough growth hormone***. They are ***short because*** the ***receptor proteins*** of their cells' ***plasma membrane*** are ***faulty*** and ***cannot interact*** with the ***growth hor***mone.

*5)* ***Enzymatic Proteins***

a) Are ***capabl***e of ***directly*** carrying out and fostering ***metabolic reactions***

b) These are actually ***enzymes attached*** to the ***plasma membrane*** as ***opposed*** to independently ***"floating around"*** in the ***cytoplasm***

6) ***Junction Proteins***

a) These proteins ***form*** the ***junctions*** between **animal cells**

b) ***Allows cooperation*** between ***cells*** so they can ***function*** as a ***tissue*** or an ***organ***

## G. Cell Signaling

1) The ***cells*** of multi-cellular ***organisms "talk"*** to one another by using ***signaling molecules***

2) The ***signaling molecules*** are sometimes called ***chemical messengers***

3) In ***animals***, these ***chemical messengers*** are sometimes ***produced*** in cells ***far away*** from the ***target tissues*** or ***cells***.

4) They must be ***released*** into the ***blood stream*** and via the ***circulatory system***, ***find*** their ***way*** to ***sites*** around the body where they are ***needed***.

5) ***Example***

a) ***insulin*** is ***produced*** in ***cells*** of the ***pancreas*** and is ***released*** into the ***blood stream***

b) ***insulin*** finds its ***way*** to the ***liver*** and ***interacts*** with ***liver cells***

c) the ***result*** is that ***liver cells*** conduct the ***chemical reactions*** necessary to ***store glucose*** into ***glycogen***

d) if the ***liver cells*** do ***not respond properly*** – the ***result*** is a ***disease*** called ***diabetes***

e) an ***example*** of the ***cells*** of the ***pancreas sending*** a ***signal*** to the ***cells*** of the ***liver***

## H. Fluid-Mosiac Model

1) The ***fluid nature*** of the ***plasma membrane*** means that ***cells*** are ***pliable***
***(pliable means flexible or bendable)***

2) If they were ***not flexible***, (i.e were ***brittle***), the ***long nerve fibers*** in your ***neck*** would ***crack*** and ***break*** whenever you ***nodded*** your ***head***

3) The ***fluid nature*** of the ***plasma membrane*** also ***prevents*** it from ***solidifying*** as ***temperatures*** get ***colder***

4) The ***fluidity*** of the ***plasma membrane*** is ***due*** to its ***lipid component***

5) At ***body temperature*** the ***plasma membrane*** has the ***consistency*** of ***olive oil***

6) ***Role*** of ***cholesterol*** in ***fluid nature*** of ***plasma membrane***

   a) At ***higher temperature***, ***cholesterol stiffens*** the ***membrane*** and makes it ***less fluid*** than it ***would be otherwise***

   b) At **lower temperatures**, ***cholesterol*** helps ***prevent*** membrane from ***freezing***

7) The ***mosaic nature*** of the ***membrane*** is ***due*** to the ***proteins present***

8) **Proteins** of the ***plasma membrane*** are ***bonded*** to the ***cytoskeleton*** of the ***cell*** and ***cannot move freely*** in the ***fluid phospholipid bilayer***

***There are 3 ways molecules cross the plasma membrane – Passive Transport, Active Transport, and Bulk Transport – a discussion of these three follows***

**4. Passive Transport across Plasma Membrane**

(See Handouts of Table 5.1 and Figure 5.4, page 90 of Textbook, Mader 10th Ed.)

A. ***Passive*** means that ***no energy*** expenditure required to ***cross*** the ***membrane***

B. The ***plasma membrane*** is ***differentially permeable*** - which means that ***certain substances*** can ***move across*** the ***membrane*** and ***others cannot***

***Permeable*** - means ***to penetrate***
***Differentially*** – means to ***be selective***

C. ***Table 5.1*** and ***Figure 5.4*** show which ***types*** of ***molecules*** can ***passively*** (no energy required) ***cross*** a membrane and which ***molecules require transport*** by a ***carrier protein*** and/or an ***expenditure of energy***

Note - ***water*** and ***non-charged molecules pass freely***
***charged molecules*** and ***macromolecules cannot pass freely***

D. There are ***3 ways passive transport*** is ***accomplished*** across the ***plasma membrane*** ***(Diffusion, Osmosis,*** and ***Facilitated Transport)***

***1) Diffusion***

a) ***Molecules*** that ***pass freely*** follow a ***concentration gradient*** from an ***area*** of ***high concentration*** to an area of ***low concentration***. This ***phenomena*** is called ***diffusion***

b) ***Diffusion continues*** until ***equilibrium*** is reached and the ***molecules*** are ***distributed evenly inside*** and ***outside*** the ***cell***

c) Examples

- ***Spread*** of ***aroma*** of ***strong*** perfume in a ***room*** when someone ***enters room*** with a strong odor of perfume

- ***O2*** concentration ***inside cell*** as opposed to ***outside cell***

  Question - Cell uses O2 for cellular respiration. So will the O2 concentration most likely be higher inside or outside the cell?? So which way will O2 normally be going??

- ***CO2*** concentration ***inside cell*** as opposed to ***outside cell***

  Question - Cell produces CO2 during cellular respiration. So will the CO2 concentration most likely be higher inside or outside the cell?? So which way will CO2 normally be going??

***2) Osmosis***

a) ***Definition*** – the ***diffusion*** of ***water*** across a ***differentially permeable membrane*** due to ***concentration differences inside*** and ***outside*** the ***cell***

***b) Isotonic solutions***

- are those where the ***concentration*** of ***water*** and ***solutes*** are equal both ***inside*** the ***cell*** and ***outside*** the ***cell***

- there is ***no gradient*** and therefore ***no net loss*** or ***gain*** of ***water*** by the ***cell***

- A ***0.9% solution*** of ***salt*** (NaCl) and ***water*** is known to be ***isotonic*** to ***red blood cells*** - therefore ***intravenous solutions*** given to ***patients*** are usually of this ***tonicity***

c) ***Hypotonic solutions***

- ***solutions*** where the ***concentration*** of ***water outside*** the ***cell*** is ***greater*** than ***inside*** the ***cell***

- ***conversely*** the ***concentration*** of ***solute*** (like NaCl) ***outside*** the cell is ***less*** than that ***inside*** the ***cell*** ***(hypo means" less than")***

- there is a now a ***gradien***t and ***water*** moves ***into the cell*** (***area of lower concentration***)

- if the ***gradient*** is ***great enough*** – the ***cell*** may take on so much water that it ***bursts***

d) ***Hypertonic solutions***

- ***solutions*** where the ***concentration*** of ***water outside*** the ***cell*** is ***less*** than ***inside*** the ***cell***

- ***conversely*** the ***concentration*** of ***solute*** (like NaCl) ***outside*** the cell is ***greater*** than that ***inside*** the ***cell*** ***(hyper means "more than")***

- the ***gradient*** is now the ***opposite*** of a ***hypotonic solution*** and ***water*** moves ***out*** of the ***cell*** (***area of high concentration***)

- if the ***gradient*** is ***great enough*** – the ***cell*** may shrink or shrivel

***What do you think would happen to red blood cells exposed to a hypertonic solution?***

3) ***Facilitated Transport***

a) The plasma ***membrane stops*** the ***passage*** of ***many*** useful ***molecules***

b) ***Facilitated Transport*** is the ***use*** of ***channel*** and ***carrier proteins*** of the ***cell membrane*** to ***transport molecules*** across the ***plasma membrane***

c) Like ***diffusion*** and ***osmosis***, ***Facilitated Transport*** does ***not*** require the ***expenditure of energy*** because ***molecules*** are ***moving down*** the **concentration gradient** in the ***same direction*** they would ***naturally move***

5. **Active Transport across Plasma Membrane**

   A. ***Active transport*** occurs when a ***carrier protein*** acts as a ***pump*** that ***moves*** a ***substance against*** its ***concentration gradient***

   B. The ***sodium-potassium pump*** carries ***Na+*** to the ***outside*** of the ***cell*** and ***K+*** to the ***inside*** of the ***cell***

   C. Both ***carrier proteins*** and an ***expenditure*** of ***energy*** are ***required*** to ***move molecules against*** their ***concentration gradient***

6. **Bulk Transport across Plasma Membrane**

   A. Allows ***large macromolecules*** to ***enter*** and ***exit*** the ***cell***

   B. Large ***macromolecules*** include ***polypeptides***, ***polysaccharides***, ***polynucleotides***, and ***others***

   C. These ***molecules*** are ***too large*** to be ***transported*** by ***carrier proteins***

   D. An ***expenditure*** of ***energy*** is ***required*** as ***vesicles*** must be ***formed*** to ***transport macrocromolecules*** across ***membrane***

   E. There are ***2 types*** of ***Bulk Transport***

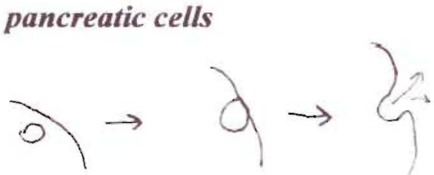
      1) **Exocytosis**

         a) Involves the ***passage*** of ***macromolecules*** from ***inside*** the ***cell*** to ***outside*** the ***cell***

         b) During ***exocytosis*** a vesicle ***forms*** around molecules and ***fuses*** with the ***plasma membrane*** and ***secretion occurs***

         c) This is the way ***insulin*** is ***released*** by ***pancreatic cells***

         ***d) See simplified diagram to right***



2) **Endocytosis**

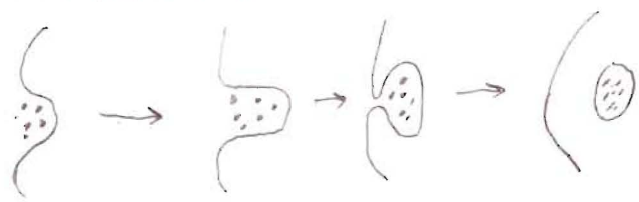
a) Involves the ***passage*** of ***macromolecules*** from ***outside*** the ***cell*** to ***inside*** the ***cell***

b) During ***endocytosis*** a portion of the ***plasma membrane*** invaginates to ***envelop*** the ***macromolecules*** just outside the cell

c) The ***plasma membrane*** then ***pinches off*** to ***form*** an ***intracellular vesicle***

d) ***Pinocytosis*** and ***phagocytosis*** ***(as noted on lab cell models and in our lab manual)*** is a ***type*** of ***endocytosis***

***e) See simplified diagram below***



## The Cell Cycle and Cell Division

1. ***Cell division*** allows a ***single cell*** to produce ***many cells*** - allowing an ***organism*** to ***grow*** and ***develop***

2. It allows a ***single cell*** human ***zygote*** to ***grow*** into a newborn multi- cellular ***baby*** with ***trillions*** of ***cells*** in just ***9 months***

3. Cell division ***allows*** the ***adult body*** to ***repair*** and ***replace worn out tissues***

4. When ***adulthood*** is reached only specific ***types*** of ***cells*** continue to ***divide***. Examples include

    ***Blood cells***
    ***Skin cells***
    ***Bone cells***

5. Other ***cells*** like ***nerve cells*** and ***brain cells no longer*** routinely ***divide***

6. Throughout life ***cell division***, allows a ***cut to heal*** or a ***broken bone*** to ***mend***

7. **Overview** of the **Cell Cycle** of an **Eukaryotic Cell**

(See Handout of Figure 9.1, page 152 of Textbook, Mader, 10th Ed.)

A. ***Definition*** – the ***cell cycle*** is an ***orderly*** set of ***stages*** that take place ***between*** the ***time*** a ***cell divides*** and the ***time*** the resulting ***daughter cells divide***

B. ***Another definition*** from textbook – the ***cell cycle*** is a ***repeating sequence*** of ***events*** in ***eukaryotic cells*** that involves ***cell growth*** and ***nuclear division***

C. There are ***2*** major ***stages*** in the ***cell cycle***

1) ***Interphase Stage***

2) ***Mitotic Stage*** which includes ***2 processes***

a) ***Mitosis*** – ***division*** of the ***nucleus***

- ***Prophase***
- ***Metaphase***
- ***Anaphase***
- ***Telophase***

b) ***Cytokinesis*** – ***division*** of the ***cytoplasm***

For following discussion - (See Handout of Figure 9.4, page 156 of Textbook, Mader 10th Ed.)

8. **Interphase**

A. ***Longest stage*** of cell ***cycle*** in terms of ***time***

B. This has sometimes been ***incorrectly called*** the ***resting stage***. It is actually a ***very active time*** in the ***cell cycle***

C. Represents that ***portion*** of the ***cell cycle*** between ***nuclear divisions*** (mitosis)

D. During ***interphase,*** the ***cell*** makes ***preparations*** for ***cell division*** to include

   ***1) Duplication*** of ***most*** cellular ***contents***, including ***organelles***

   2) ***Duplication*** (replication) of ***DNA***

   3) ***Duplication*** of the ***centrosome*** that ***forms*** the ***mitotic spindle***

E. During ***interphase***, ***chromosomes*** are ***not distinct*** and are ***collectively*** called ***chromatin***

9. **Prophase**

A. Granular ***chromatin*** condenses into ***threads*** and then further into ***chromosomes***

B. ***Duplicated chromosomes*** shorten and ***thicken*** and ***each*** chromosome can be seen to consist of ***2 chromatids*** attached at a ***region*** called the ***centromere***

C. ***Nuclear membrane*** and ***nucleolus fragment*** and ***disappear***

D. ***Spindle fibers*** form ***between*** the ***centrioles*** which have moved to the ***poles*** of the ***cell***

10. **Metaphase**

A. ***Duplicated chromosomes*** line up along the ***equatorial plane*** of the ***cell***

11. **Anaphase**

A. ***Two sister chromatids*** of each duplicated chromosome ***separate*** at their ***centromeres*** giving rise to ***2 daughter chromosomes*** that ***move*** toward ***opposite poles***

B. Thus ***each pole*** receives the ***same number*** and ***kinds*** of ***chromosomes*** as the ***parent cell***

12. **Telophase** (*events* of ***prophase reversed***)

    *A.* ***Nucleus reforms***

    B. ***Nuclear membrane*** and ***nucleolus reappear***

    C. ***Chromosomes lose*** their ***identity*** and ***return*** to ***chromatin***

    *D.* ***Spindle disappears***

    *E.* ***Formation*** of a ***cell plate*** in ***plant cells*** and ***constriction*** of ***outside plasma membrane*** in ***animal cells***

13. **Cytokinesis**

    A. ***Cytokinesis*** is a ***furrowing process*** that ***divides*** the ***cytoplasm***

    B. ***Cytokinesis begins*** during ***anaphase*** and ***continues*** during ***telophase***

    C. It does not ***reach completion*** until the following ***interphase stage begins***

    ***D.*** By the ***end*** of ***mitosis***, each ***newly*** formed ***cell*** has received a ***share*** of ***cytoplasmic organelles*** that ***duplicated*** during ***interphase***

    E. ***Cytokinesis*** proceeds ***differently*** in ***plant*** and ***animal cells*** because of the ***differences*** in ***cell structure***

14. **Cancer**

    A. ***Cancer*** is a ***disease*** that is ***caused*** by a ***mutation*** to the ***genes*** that ***control*** the ***cell cycle***

    B. *Cancer* is a ***cellular growth disorder*** where there is ***uncontrolled cell division*** that results in the ***development*** of ***tumors***

    C. ***Cancer cells*** are usually ***abnormal*** and have ***abnormal nuclei***

# Meiosis and Sexual Reproduction

But ***before*** we discuss ***meiosis*** we need to ***briefly review*** a few ***facts*** about ***chromosomes***, ***chromosome pairs***, and ***chromosome numbers***.

1. **Review of Chromosomes, Chromosome Pairs, and Chromosome Numbers**

   A. ***Chromosomes*** are found in the ***nucleus*** of cell and ***consist of DNA*** and other ***proteins***. They ***transmit*** genetic ***information*** from the ***previous generation*** of ***cells*** to the ***next.***

   B. ***Each species*** of animal has a characteristic ***chromosome number***. ***Human cells*** have ***46*** and ***gorillas*** have ***48***. Insert

   C. Also, ***similar chromosomes*** normally occur in ***pairs***, called ***homologous chromosome pairs***. homologous chromosomes are: 1- similar in size 2- similar in shape 3- similar location of centromere 4- carry the genetic code for same traits.

   D. A ***cell*** or ***organism*** is called ***diploid*** if these ***homologous chromosome pairs exist*** and the ***diploid condition*** is represented by the symbol ***2N***.

   E. Thus for ***humans*** the ***diploid chromosome number*** can be written as ***2N = 46*** and ***2N = 48*** for ***gorillas***

   F. Hopefully, this is enough ***background and review*** to ***now*** look at the process of ***meiosis***

2. **Meiosis** (see ***Handout of Figure 10.2 from page 171 of Text book, Mader 10th Ed.)***.

   A. For a formal definition - ***Meiosis - is the type of nuclear division of a germ cell that reduces the chromosome number from the diploid (2N) to the haploid (N) number.***

      1) ***diplos*** - is Greek for ***two-fold***
      2) ***haplos*** - is Greek for ***single***

   B. ***Meiosis*** occurs in ***sexually reproducing*** organisms

   C. In ***animals***, like humans, ***meiosis*** only occurs in ***germ cells*** rather than ***somatic cells***. Meiosis only ***occurs*** during the ***formation of gametes*** (sperm and egg)

***(ask - if all know the difference in somatic cells vs germ cells - germ means rudimentary or precursor (Somatic cells are cells of the tissues and organs of the body)***

D. The end ***result*** of ***meiosis*** is to ***produce gametes*** (sperm and egg cells) that possess ***half*** the number of ***chromosomes*** as the typical somatic cell of the body.

   1) This ***condition*** is called the ***haploid chromosome number*** and is represented by the ***symbol N***

   2) Thus for ***humans*** the ***haploid chromosome number*** can be written as $N = 23$ and $N = 24$ for ***gorillas***

   3) **Why is it important that egg and sperm contain only half of the genetic material of the normal body cells ??.** There are two reasons.

      a) ***first reason*** has to do with ***growth*** of ***chromosome number*** with each ***generation***

      b) ***second reason*** has to do with maintaining ***normal*** biological ***functions*** and ***health***.

E. ***Meiosis*** can be divided into two steps called ***Meiosis I*** and ***Meiosis II***

   1) ***Meiosis I*** ***(homologous chromosome pairs synapse and then separate)***

      a) each ***chromosome*** in the ***primordial germ cell*** nucleus is ***replicated*** to form a ***sister chromatid***

      b) ***homologous chromosomes*** form ***pairs***

      c) ***chromosome pairs*** separate and move to ***opposite poles*** of ***germ cell***

      d) primordial germ ***cell spilts*** apart to form ***2 new*** cells called ***daughter cells*** that possess ***1 chromosome*** from ***each*** of the ***original homologous chromosome pair***. Each chromosome still consists to ***2 sister chromatids***.

      e) However, note that the ***daughter cells*** are ***haploid,*** rather than ***diploid***.

   2) ***Meiosis II*** ***(sister chromotids separate becoming daughter chromosomes)***

      a) In ***each*** new ***daughter cell***, ***chromosomes*** (each chromosome still composed to 2 sister chromatids) ***align*** near center of ***daughter*** cell

      b) ***sister chromatids split*** to form ***daughter chromosomes*** that ***migrate*** to ***opposite poles*** of the ***daughter cell***

c) Each ***daughter cell divides*** forming ***two new daughter cells*** and each ***new daughter*** cell contains ***two daughter chromosomes*** .

d) Note that ***final daughter*** cells are ***haploid***

F. The ***key result*** of ***meiosis*** is that a ***diploid*** (2N) primordial ***germ cell*** is ***converted*** into ***4 daughter cell***s that are ***haploid (N)***

3. **Comparison of Meiosis and Mitosis**

A. ***Mitosis*** - is defined as process in which a parent nucleus produces two daughter nuclei, each having the same number and kinds of chromosomes as the parent nucleus.

B. ***Mitosis*** is the kind of ***cell division*** that results in ***growth***, ***development*** and ***repair*** of ***individual organisms***.

C. ***See Handout of Table comparing Meiosis and Mitosis (see below)***

| Meiosis | Mitosis |
|---|---|
| | |
| 1. occurs only in the reproductive organs | 1. occurs throughout the body |
| 2. purpose to produce sperm and eggs | 2 purpose to allow development, growth, and maintenance of organism |
| 3. requires 2 nuclear divisions | 3. requires only 1 nuclear division |
| 4. produces 4 daughter cells | 4. produces 2 daughter cells |
| 5. produces 4 haploid daughter cells | 5. produces 2 diploid daughter cells |
| 6. daughter cells genetically different from each other and from original germ cell | 6 daughter cells are genetically identical to each other and to the original somatic cell. |
| | |
| | |

4. ***Reproduction*** - is the ***process*** by which organisms ***produce new individuals***.

**5. Sexual Reproduction**

A. ***Sexual*** reproduction ***usually requires two parents***, a ***male*** and ***female***. An ***exception*** to the ***two***-parent ***requirement*** is for organisms that are ***hermaphroditic*** and practice ***self-fertilization***.

B. ***Gametes*** (***sperm*** and ***eggs***) are ***produced***

C. The ***egg*** of one parent (***female***) is ***fertilized*** by the ***sperm*** of another parent (***male***) to form a ***zygote***.

D. ***Sexual*** reproduction is the ***general rule*** for reproduction in the ***animal kingdom***.

E. ***Examples*** are found

   a. In ***all phyla*** of ***animals***

   b. ***Common*** in ***plants***

   c. Even ***occurs*** in ***single*** cell ***eukaryotic organisms*** like ***algae***

# Cellular Metabolism and Enzymes

1. ***Definition*** of ***metabolism*** – the ***sum*** of all ***chemical reactions*** in the ***cell***.

2. ***2*** types of ***substances*** are ***involved*** in chemical reactions involved in metabolism

   A. ***Reactants*** – ***substances*** that ***participate*** in a ***reaction***

   B. ***Products*** – ***substances*** that ***form*** as a ***result*** of a ***reaction***

3. Can be ***written*** simply as *follows:*

   **A + B ----------→ C + D**

   **where A & B = reactants**
   **C & D = products**

4. In ***terms*** of ***energy*** required there are ***2 types*** of ***chemical reactions*** associated with ***metabolism*** ***(Exergonic reactions and Endergonic reactions)***

   A. ***Exergonic*** reactions – are ***spontaneous*** and ***release energy***

      ***1) Provides energy*** required for ***other reactions*** in the ***cell***

      2) Sometimes called ***catabolic reactions***

      3) Can be ***simply written*** as follows

      **A + B ----------→ C + D + Energy**

      4) ***Example*** is ***cellular respiration*** which includes

         a) ***glycolysis***
         b) ***fermentation***
         c) ***aerobic respiration***

   B. ***Endergonic*** reactions – require an ***input of energy*** to occur

      1) ***Depend*** on the ***energy provided*** or ***released*** by ***exergonic reactions***

      2) Sometimes called ***anabolic reactions***

3) Can be ***simply written*** as follows

$$\mathbf{A + B + Energy \longrightarrow C + D}$$

4) Examples include

a) ***protein synthesis***
b) ***nerve conduction***
c) ***muscle contraction***

5. The ***agent*** or ***carrier*** of ***energy*** generated by ***exergonic*** reactions is **ATP**

6. **ATP (Adenosine triphosphate)**

A. ***ATP*** is used to ***transfer energy*** in the ***cell*** from where it is ***produced*** to where it is ***needed***

B. Your textbook calls ***ATP*** " the ***common*** energy ***currency*** of cells - when ***cells require energy*** they ***spend ATP***

C. Most ***all organisms*** to include ***plants, animals, fungi***, and ***protists*** use ***ATP*** as the ***energy molecule***

D. ***ATP*** is a ***nucleic acid*** like ***DNA*** and ***RNA***

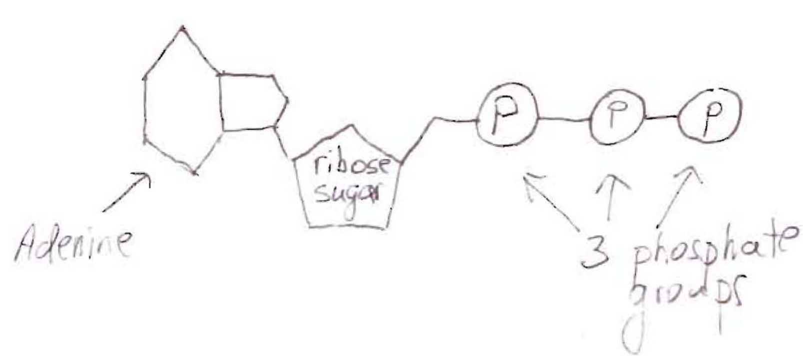
E. ***ATP*** is a ***nucleotide*** composed of

1) a 5-carbon ***ribose sugar***

2) ***adenine*** – a ***nitrogenous base***

3) ***3 phosphate groups***

F. The ***structural formula*** for ***ATP*** can be written as ***follows***



G. The ***breakdown*** of ***ATP releases*** the ***energy*** required for ***endergonic reactions***

H. The ***breakdown*** of ***ATP*** includes the ***removal*** of ***one phosphate*** group to form ADP ***(Adenosine diphosphate)***

I. This is a ***hydrolysis reaction*** and can be ***written*** simply as

**ATP + HOH ----------→ ADP + P + Energy** ***(7.3kcal/mole)***

J. Note that it ***requires energy*** to put the ***P group*** back to ***form ATP***. This is a ***dehydration reaction*** and can be ***written*** as:

**ADP + P + Energy ----------→ ATP + Water**

K. ***ATP*** and its lower energy ***partner ADP*** are the ***energy carriers*** that ***link metabolic*** energy ***exchanges*** in the ***cell***

L. ***ATP*** is very ***reactive*** and is ***not*** normally ***stored*** in the ***cell***

7. **Coupled Reactions**

A. ***Coupled reactions*** are the ***way*** that ***energy released*** by the ***hydrolysis*** of ***ATP*** can be ***transferred*** to a ***reaction*** that ***requires energy(endergonic reation)***

B. ***Textbook definition*** – ***Coupled reactions*** are ***2 reactions*** that occur in the ***same place*** at the ***same time*** in such a ***way*** that the ***energy-releasing*** reaction ***drives*** the ***energy requiring*** reaction.

C. A ***coupled reaction*** can be ***simply written*** as follows

**ATP + HOH** → **ADP + P** ***(releases energy)***

**C + D** ——————→ **A + D** ***(requires energy)***

Coupling

8. **Enzymes**

A. ***Definition*** – Enzymes are ***protein molecules*** that ***function*** as an ***organic catalyst*** to ***speed*** up a ***chemical reaction without itself*** being ***affected*** by the ***reaction***. ***(according to the dictionary - a catalyst usually hastens the results)***

B. Because it is ***usually unchanged*** by the ***reaction***, an ***enzyme*** can be used ***over and over.***

C. ***Enzymes*** are ***highly specific*** in terms of the ***types*** of ***reactions*** they ***catalyze***

D. The ***structure*** of ***enzymes*** is **governed** by ***specific genes***

E. ***Enzymes*** can be ***denatured*** ***(their nature changed)*** by the ***same agents*** that denature ***proteins***

*F.* ***Enzymes*** can be ***affected*** by both ***temperature*** and ***pH***

G. Many ***enzymes need*** other ***non-protein substances*** called ***co-enzymes*** before they are ***functional***

H. ***Enzymes*** direct ***metabolic pathways***

I. ***Enzyme inhibition*** occurs when a ***molecule*** called an ***inhibitor binds*** to the ***enzyme*** and ***inhibits*** its ***activity***

9. **Metabolic Pathways**

A. ***Chemical reactions*** do ***not*** occur ***randomly*** or in a ***haphazard*** way in cells

B. ***Reactions*** usually occur as part of a ***metabolic pathway***

C. A ***metabolic pathway*** can simply be **written** as follows

$$A \xrightarrow{E1} B \xrightarrow{E2} C \xrightarrow{E3} D \xrightarrow{E4} E \xrightarrow{E5} F \xrightarrow{E6} G$$

1) ***A thru F*** are ***reactants***

2) ***B thru G*** are ***products***

3) ***E1 thru E6*** are enzymes ***(each specific for a specific reaction)***

4) In short, the ***products*** of a ***previous reaction*** become the ***reactants*** of the ***next***

5) ***Any one*** of the letters ***A thru G*** in the above ***linear metabolic pathway*** could be a ***reactant*** in another ***metabolic pathway***

D. Some ***additional characteristics*** of ***metabolic pathways***

1) Metabolic pathways are usually ***gradual***

2) They ***occur*** in ***steps*** ***(individual reactions)*** are ***controlled*** by ***enzymes***

3) ***Individual steps*** are ***directed*** by ***enzymes*** that control ***energy transfer***

4) ***Energy exchange*** is ***linked*** by ***ADP*** and ***ATP***

10. **Enzyme-Substrate Complex**

A. The ***reactants*** in an ***enzyme*** driven ***reaction*** are called the ***substrates*** for that ***enzyme***

B. An ***enzyme*** and ***its substrate*** fit ***together*** much like a ***key*** fits in a ***lock***

C. In the ***linear metabolic pathway*** written ***above***

***1)*** ***Reactant A*** is the ***substrate*** for ***E1*** and ***B*** is the ***product***

2) ***B*** then ***becomes*** the ***substrate*** for ***E2*** and ***C*** is the ***product***

3) The ***process continues*** until the ***final product G*** is formed

D. The following ***simple equation*** summarizes how a ***enzyme forms*** a ***complex*** with its ***substrate***

| E | + | S | ----> | ES | ----> | E | + | P |
|---|---|---|---|---|---|---|---|---|
| ***enzyme*** | | ***substrate*** | | ***enzyme-substrate complex*** | | ***enzyme*** | | ***product*** |

# Cellular Respiration

1. ***Cellular respiration*** is the ***process*** by which ***cells acquire energy*** by ***breaking down glucose molecules*** ***(where do glucose molecules come from??)***

2. Cellular respiration ***requires oxygen*** ( O2) and gives off ***carbon dioxide*** (CO2)

3. It is why ***animals breath*** and why ***plants*** also ***need oxygen*** ***(yes - cellular respiration also occurs in plant cells)***

4. ***Cellular respiration*** normally involves the ***complete breakdown*** of ***glucose*** to ***carbon dioxide*** (CO2) and ***water*** (HOH)

5. ***Cellular respiration*** can be ***summarized*** by the following ***equation***

**Oxidation**

$$C_6H_{12}O_6 \quad + \quad 6O_2 \longrightarrow 6CO_2 \quad + \quad 6H_2O \quad + \quad \textbf{energy}$$

glucose

**Reduction**

   A. Is an ***oxidation-reduction reaction***

      1) ***oxidation*** is the ***loss of electrons***

      2) ***reduction*** is the ***gain of electrons***

   B. ***Electrons*** are ***not easily removed*** from ***covalent*** compounds unless an ***entire atom*** is ***removed***

   C. In ***living cells oxidation*** almost always ***involves*** the ***removal*** of a ***hydrogen*** (H) ***atom*** and its ***electron*** from a ***compound***

   D. Likewise ***reduction*** almost always ***involves*** a ***gain*** of a ***hydrogen atom*** and its ***electron***

   E. ***Glucose*** is ***oxidized*** because it ***loses electrons*** – ***when hydrogen atoms are removed so are the electrons associated with hydrogen***

F. ***Oxygen*** ($O_2$) is ***reduced*** because it ***gains electrons*** – ***when hydrogen atoms are added to oxygen so are the electrons associated with hydrogen***

6. ***Glucose*** is a ***high energy*** molecule and it ***breaks down*** into ***2 low energy molecules***, ***water*** (HOH) and ***carbon dioxide*** ($CO_2$)and therefore ***energy is released***.

7. What does the cell do with this energy? It is used to ***produce ATP***. The cell carries out ***cellular respiration*** to build ***ATP molecules*** ***(remember they are the energy currency of the cell)***

8. The ***pathways*** of ***cellular respiration*** allow the ***energy*** within a ***glucose molecule*** to be ***released slowly***. ***Cellular respiration*** is ***constantly occurring***.

9. ***Cells*** would ***lose*** a ***large amount*** of ***energy*** in the form of **heat** if the ***breakdown*** of ***glucose*** occurred ***all at once***

10. The step-by-step ***breakdown*** of ***glucose*** into ***$CO_2$*** and ***HOH*** usually results in a ***maximum yield*** of ***36 or 38 ATP molecules***, depending on conditions

11. These ***energy*** in these ***ATP molecules*** is about ***39%*** of the ***total energy*** that is ***available*** in a ***glucose molecule***

12. ***For comparison*** – only about **20% to 30%** of the ***energy*** available in ***gasoline*** is ***converted*** to the ***motion*** of a ***car***. ***(Where is a lot of the energy lost ???? -- Heat)***

13. **NAD+ and FAD**

A. As just discussed, ***cellular respiration*** is a ***series*** of ***step-by-step oxidation-reduction reactions*** where ***electrons*** are ***lost*** and ***gained***

B. A ***hydrogen atom*** with its ***energy*** is usually ***transferred*** to a ***hydrogen acceptor compound***

C. The ***2 important hydrogen acceptor compounds/enzymes*** involved in cellular respiration include

***NAD+***
***FAD***

## D. NAD+

1) A ***coenzyme*** of ***oxidation-reduction*** reactions

2) When a ***substance*** is ***oxidized*** - ***NAD+ accepts 2 electrons*** + ***a hydrogen ion*** (H+) to become ***NADH***

3) This ***reaction*** can be simply ***shown*** as:

$$NAD^{+} \quad + \quad 2e^{-} \quad + \quad H^{+} \quad \text{----------}\!\!> \quad NADH$$

4) ***NAD+*** can ***oxidize*** a substance by ***accepting electrons*** and ***reduce*** a substance by ***giving up electrons***

5) Only a ***small amount*** of ***NAD+*** is ***required*** in a **cell.** It is ***used over and over***

6) ***Electrons*** received by ***NAD+*** are ***high energy*** electrons and are usually ***carried*** to the ***electron transport chain*** ***(a phase of cellular respiration we will discuss later)***

## E. FAD

1) Another ***coenzyme*** of ***oxidation-reduction*** reactions that is ***sometimes*** used rather than ***NAD+***

2) When a ***substance*** is ***oxidized*** - ***FAD*** + ***accepts 2 electrons*** + ***2 hydrogen ions*** (H+) to become ***FADH2***

3) This ***reaction*** can be simply ***shown*** as:

$$FAD \quad + \quad 2e^{-} \quad + \quad 2H^{+} \quad \text{----------}\!\!> \quad FADH_2$$

4) ***FAD*** can ***oxidize*** a substance by ***accepting electrons*** and ***reduce*** a substance by ***giving up electrons***

5) Only a ***small amount*** of ***FAD*** is ***required*** in a **cell.** It is ***used over and over***

6) ***Electrons*** received by ***FADH2*** are ***high energy*** electrons and are usually ***carried*** to the ***electron transport chain*** ***(a phase of cellular respiration we will discuss later)***

14. **4 Phases of Cellular Respiration**

A. The ***step-by-step*** process of ***cellular respiration*** can be divided into ***4 phases*** which include

***Glycolysis***
***Preparatory Reaction***
***Citric Acid Cycle***
***Electron Transport Chain***

B. The ***complete*** breakdown of ***glucose*** requires all ***4 phases***

C. ***3*** of these ***phases (Glycolysis, Critic Acid Cycle, and Electron Transport Chain)*** are ***metabolic pathways***

D. For all 4 ***phases*** of ***cellular respiration*** the end ***products*** are

***$CO_2$***
***$H_2O$***
***ATP molecules***

E. ***Summary*** of ***phases*** in terms of the ***site*** where they occur and their ***$O_2$ requirement***

| Phase | Site | $O_2$ requirement |
|---|---|---|
| Glycolysis | Cytoplasm | No - anaerobic |
| Preparatory Reaction | Matrix of Mitochondria | Yes - aerobic |
| Citric Acid Cycle | Matrix of Mitochondria | Yes - aerobic |
| Electron Transport Chain | Cristae of Mitochondria | Yes - aerobic |

15. **Glycolysis**

(See Handout Figure 8.4, page 137 of Textbook, Mader, 10th Ed.)

A. ***Greek*** words ***glycos*** – means ***sugar*** - and ***lysis*** means ***splitting***

B. ***Glycolysis*** is a ***long series*** of ***reactions*** and ***each step*** has its ***own enzyme***

C. ***Gylcolysis*** can be divided into ***two steps***

1) ***Energy-investment step***
2) ***Energy-harvesting step***

**D. Energy –investment step**

1) The ***energy*** from ***2 ATP molecules*** are used to get ***things started***
2) The ***$C_6$ glucose*** molecule is ***split*** into ***two $C_3$ molecules***, each call ***G3P***
3) Each ***G3P*** has a ***phosphate group*** attached ***(where did the phosphate group come from ?)***
4) ***Each G3P*** molecule will now ***undergo*** the same ***set of reactions*** in the ***Energy-harvesting step***

**E. Energy-harvesting step**

1) ***Oxidation*** of each ***G3P*** to ***BPG*** occurs as ***NAD+*** receives high energy ***electrons*** and ***hydrogen ions***

$$NAD^+ \quad + \quad 2e^- \quad + \quad H^+ \quad \dashrightarrow \quad NADH$$

**** note that NADH will later be used in the Electron Transport Chain to produce ATP***

2) ***Each BPG*** molecule has a high energy ***phosphate group*** attached that will be used to ***synthesize 2*** more ***ATPs*** in the following ***reaction***
3) ***Substrate-level synthesis of 2 ATP molecules***
   a) involves each ***BGP molecule***, an ***enzyme*** and ***ADP***
   b) ***reaction*** results in ***two 3PG molecules***
   c) sometimes called ***substrate-level phosphorylation*** because an ***enzyme passes*** a high-energy ***phosphate*** to an ***ADP*** molecule to form ***ATP***
   d) represents an ***example*** of a ***coupling reaction*** **(energy-releasing reaction is driving a energy requiring reaction)**
4) ***Oxidation*** of ***3PG molecules*** results in ***formation*** of ***2 molecules*** of ***$H_2O$*** and 2 molecules of ***PEP***

5) **ONCE AGAIN** - ***Substrate- level synthesis of 2 ATP molecules***

a) involves each ***PEP molecule***, an ***enzyme*** and ***ADP***

b) ***reaction*** results in ***two pyruvate molecules***

c) sometimes called ***substrate-level phosphorylation*** because an ***enzyme passes*** a high-energy ***phosphate*** to an ***ADP*** molecule to form ***ATP***

d) represents an ***example*** of a ***coupling reaction*** **(energy-releasing reaction is driving a energy requiring reaction)**

6) ***End*** products of ***glycolysis*** include

***2 pyruvate molecules*** – ***breakdown of glucose molecule***
***2 NADH molecules*** – ***from oxidation reactions***
***2 ATP molecules*** - ***net gain***

F. ***Inputs*** and ***Outputs*** of ***Glycolysis***

| **Inputs** | **Outputs** |
|---|---|
| 1 Glucose | 2 pyruvate |
| 2 NAD+ | 2 NADH |
| 2 ATP | 2 ADP |
| 4 ADP + 4 P | 4 ATP |

**** Note net gain of 2 ATP***

G. When ***$O_2$*** is ***available*** - ***cellular respiration*** continues in an ***aerobic fashion*** as ***pyruvate*** enters the ***mitochondria*** where it is ***further metabolized*** with the ***end products*** being ***$CO_2$*** and ***$H_2O$***

H. When ***$O_2$*** is ***not available*** – ***cellular respiration*** continues in an ***anaerobic fashion*** in the ***cytoplasm*** where ***pyruvate*** is ***further metabolized***

16. **Fermentation**

(See Handout Figure 8.5, page 138 of Textbook, Mader, 10th Ed.)

A. ***Fermentation*** - the ***anaerobic breakdown*** of ***glucose*** that results in a ***gain*** of ***2 ATP molecules*** and ***end products*** such as **alcohol** and ***lactate***

B. ***Fermentation*** consists of ***glycolysis*** (formation of pyruvate) followed by a reduction of pyruvate

C. ***Reduction*** of ***pyruvate molecule***

1) ***NADH*** gives up its ***hydrogen ions*** and ***electrons*** to ***pyruvate***

NADH ---------------> NAD + 2e- + H+

2) In animal cells this ***results*** in the ***formation*** of either ***2 molecules*** of ***lactate*** or ***2 molecules*** of ***alcohol*** as the ***end products*** of ***fermentation***

D. ***Inputs*** and ***Outputs*** of ***Fermentation***

| Inputs | Outputs |
|---|---|
| 1 Glucose | 2 lactate |
| 2 ADP + 2 P | 2 alcohol and 2 $CO_2$ |
| | 2 ATP |

**** Note net gain of 2 ATP***

E. In ***humans***, the end ***product*** is ***lactate***, rather than an alcohol

F. ***Fermentation*** is ***beneficial*** in animal cells because it ***regenerates NAD+*** which can ***return*** to an ***earlier step*** in **glycolysis** to keep ***ATP synthesis occurring*** even though the ***Electron Transport Chain*** is ***shut down*** because of a ***lack of oxygen***

G. ***Animals*** use lactic acid ***fermentation*** for ***rapid bursts*** of energy where ***$O_2$*** in the ***cells*** is used ***up quickly*** and ***fermentation*** is the ***only pathway*** available to rapidly ***produce ATP*** to fuel muscle contractions

H. However, ***lactate*** build up in ***muscles*** can be ***toxic***

***I. Oxygen debt***

1) Usually occurs after ***strenuous exercise***

2) Refers to the ***amount*** of ***$O_2$*** needed to ***rid*** the body of ***lactate***

3) Humans ***breath heavily*** for a while ***after exercise*** to pay the ***$O_2$ debt***

4) ***Recovery*** occurs when ***most*** of the ***lactate*** is ***transported*** to the ***liver*** and ***converted*** to ***pyruvate***

J. ***Examples*** of ***products*** that are the ***result*** of the ***fermentation*** process

| | | | |
|---|---|---|---|
| bread | yogart | soy sauce | vinegar |
| wine | beer | pickles | |

17. **Preparatory Reaction**

A. The name ***preparatory reaction*** is used ***because*** it occurs ***before*** the ***Citric Acid Cycle***

B. Each ***pyruvate molecule*** (results of glycolysis) is ***oxidized*** to form ***2 molecules*** of a ***2-carbon acetyl group*** (acetyl)

1) ***Electrons*** are ***removed*** from ***pyruvate*** by ***NAD+*** and ***NADH*** is formed

2) The ***acetyl group*** is ***combined*** with a ***molecule*** called ***CoA***

3) ***CoA*** carries the ***acetyl group*** to the ***Citrus Acid Cycle***

C. ***$CO_2$*** is ***released***

D. Can be ***written*** as

$$2\ \text{pyruvate} \quad + \quad 2\ \text{CoA} \xrightarrow{2\ NAD^+ \ \longrightarrow \ 2\ NADH} 2\ \text{acetyl-CoA} \quad + \quad 2\ CO_2$$

E. ***Inputs*** and ***Outputs*** of ***Preparatory Reaction***

| Inputs | Outputs |
|---|---|
| 2 pyruvate | 2 acetyl groups |
| 2 NAD+ | 2 NADH |
| | 2 CO2 |

18. **Citric Acid Cycle**

(See Handout Figure 8.7, page 141 of Textbook, Mader, 10th Ed.)

A. The ***citric acid cycle*** is a ***cyclic metabolic pathway*** located in the ***matrix*** of the ***mitochondria***

B. It is also called the ***Krebs cycle*** after the ***chemist*** who discovered the ***pathway***

C. ***Major steps*** in the cycle – follow along with the ***numbered boxes*** in Figure 8.7 from Text

1) The cycle ***begins*** when an ***acetyl group*** carried by ***CoA combines*** with a $C_4$ ***molecule*** to form ***citrate***

2) ***Twice, substrates*** are ***oxidized*** as ***NAD+*** is ***reduced*** to ***NADH*** and $CO_2$ is ***released***

3) ***ATP*** is ***produced*** as an ***energized phosphate*** is ***transferred*** from a ***substrate*** to ***ADP***

4) Again, a ***substrate*** is ***oxidized***, but this time ***FAD*** is ***reduced*** to $FADH_2$

5) ***Once again*** a ***substrate*** is ***oxidized*** and ***NAD+*** is ***reduced*** to ***NADH***

D. As a result of ***oxidation reactions***, ***NADH*** and $FADH_2$ are ***produced***

E. $CO_2$ is ***released***

F. ***Citric acid cycle*** produces ***1 ATP per turn***

G. Because ***two acetyl groups*** enter the ***cycle*** per ***glucose molecule***, the ***cycle turns twice*** per glucose molecule

H. ***Inputs*** and ***Outputs*** of ***Citric Acid Cycle***

| Inputs | Outputs |
|---|---|
| 2 acetyl groups | 4 $CO_2$ |
| 6 NAD+ | 6 NADH |
| 2 FAD | 2 $FADH_2$ |
| 2 ADP + 2 P | 2 ATP |

19. **Electron Transport Chain**

(See Handout Figure 8.8, page 142 of Textbook, Mader, 10th Ed.)

***A. Electronic transport chain*** is located on the ***cristae*** of the ***mitochondria***

" revise " Next time = see attached
redo this to share

B. It is a ***series*** or ***chain*** of ***5 carriers*** that ***pass electrons*** from ***one*** to the ***other.*** These include

***NADH-Q reductase*** $\rightarrow$ ***coenzyme Q*** $\rightarrow$ ***cytochrome reductase*** $\rightarrow$ ***cytrochrome C*** $\rightarrow$ ***cytochrome oxidase***

ATP ATP ATP HOH

energy NADH 100 HOH

C. The ***electrons*** that ***enter*** the ***Electron Transport Chain*** are carried by ***NADH*** and ***$FADH_2$***

D. The ***electron transport chain*** is a ***series*** of ***oxidation-reduction*** reactions.

E. ***NADH enters*** the ***chain*** at the ***beginning*** by ***giving up (***oxidation***)*** its ***electrons*** to form ***NAD+***

1) ***NADH-Q reductase*** is ***reduced*** by ***gaining electrons***

F. ***NADH-Q reductase,*** subsequently is ***oxidized*** by ***passing*** its ***electrons*** on to the next carrier ***coenzyme Q*** (which is reduced)

G. ***Energy*** is ***released*** and ***captured*** as the ***electrons*** move from ***carrier to carrier*** and from a ***higher energy*** to a ***lower energy*** state

H. This ***process*** of ***passing*** on ***electrons continues*** till the ***last carrier*** (***cyochrome oxidase***) is reached

I. ***Oxygen*** is the ***final acceptor*** of ***electrons*** in the ***Electron Transport Chain***

J. ***Oxygen*** receives the energy- spent ***electrons*** from ***cytochrome oxidase***. It then ***combines*** with H ions to form $H_2O$

K. Note that if ***$O_2$*** is ***not present***, the ***Electron Transport Chain*** will ***not function*** and an organism would ***die***

L. ***NADH enters*** the ***chain*** at the ***beginning*** and the ***result*** is that ***3 ATPs*** are ***produced*** per ***NADH molecule*** (Draw on board)

M. ***$FADH_2$ enters*** the ***chain*** at the ***second carrier*** (coenzyme Q) and the ***result*** is that only ***2 ATPs*** are ***produced*** per ***$FADH_2$ molecule*** (draw on board)

N. ***Energy*** generated by ***chain*** is used to produce ***ATP*** by a process called ***chemiosmosis***

O. ***Chemiosmosis*** - the ***process*** by which ***mitochondria*** and ***chloroplasts*** use the ***energy*** of a ***electron transport chain*** to ***create*** a ***hydrogen ion gradient*** that drives ***ATP production***

20. **Summary of ATP production**

(See Handout Figure 8.10, page 144 of Textbook, Mader, 10th Ed.)

A. ***Totals*** from ***Substrate-level ATP synthesis***

| | | |
|---|---|---|
| Glycolysis | - | 2 |
| Citric Acid Cycle | - | 2 |

B. ***Totals*** from ***NADH oxidation*** at ***Electron Transport Chain***

| | | |
|---|---|---|
| * 2 NADH from Glycolysis | - | 4 or 6 |
| 2 NADH from Preparatory Reaction | - | 6 |
| 6 NADH from Citric Acid Cycle | - | 18 |

C. ***Totals*** from ***$FADH_2$ oxidation*** at ***Electron Transport Chain***

| | | |
|---|---|---|
| 2 FADH2 from Citric Acid Cycle | - | 4 |

D. ***Grand totals*** are ***36*** or ***38*** total ***ATPs*** generated by the ***breakdown*** of ***1 glucose*** molecule by ***cellular respiration***

E. ***Note*** that the ***2 NADH*** molecules **generated** by ***glycolysis*** in the ***cytoplasm*** ***sometimes*** need to ***expend energy*** to ***get inside*** the ***mitochondria*** to take advantage of the ***Electron Transport Chain***

F. In ***some cells***, ***1 ATP*** must be ***expended*** to get ***1 NADH*** molecule from the ***cytoplasm*** into the ***mitochondria***

G. For these cells, this ***results*** in a ***net loss*** of ***2 ATPs*** to the ***grand total*** for ***ATP production*** per ***glucose molecule***

H. Some interesting ***facts*** about ***ATP***

1) Once formed, ***ATP*** molecules ***move*** about the ***cell*** to **perform** their ***work***

2) At any given time, the ***amount*** of ***ATP*** in a ***human*** would ***sustain life*** for only ***1 minute***

3) It is estimated that ***mitochondria*** produce our ***body weight*** in ***ATP*** every ***day***

add

**FIGURE 7–15** Electron transport may be compared to a stream of water (electrons) with three waterfalls. The flow of water (electrons) drives water wheels (the proton gradient). There are three sites in the electron transport system where energy-rich phosphate is produced. The electrons end up in the pond at the bottom of the waterfalls (the electron sink of oxygen), where they unite with protons and oxygen to yield $H_2O$. Electron transfer from NADH to oxygen is very exergonic, releasing about 53 kcal/mole. If released all at once, most of this energy would be lost as heat. Instead, the energy is released slowly in a series of steps, as shown here, and used to transport protons across the inner mitochondrial membrane. The membrane potential established across the membrane is the source of energy needed to synthesize ATP. For each pair of hydrogens that enters this pathway, a maximum of three ATP molecules is produced.

4) ***Muscle cells*** and ***tissues*** contain a ***high concentration*** of ***mitochondria*** and ***lots*** of ***ATP***

5) The ***dark meat*** of a ***chicken*** (legs and thighs) has a ***higher concentration*** of ***mitochondria*** than the ***light*** or ***"white" meat*** of ***chickens***. This ***suggests*** that ***chickens*** mainly ***walk*** or ***run*** rather than ***fly***.

6) ***Contrast flight habits*** of ***white breasted birds*** like ***quail*** and ***chickens*** with the ***dark meat*** breasted birds like ***ducks, geese,*** and ***doves***

## Photosynthesis

1. Textbook ***definition*** – The ***process*** occurring usually within ***choloplasts*** whereby ***chlorophyll*** containing ***organelles*** trap ***solar energy*** to ***reduce $CO_2$*** to a ***carbohydrate***

2. ***Another*** way to ***define photosynthesis*** - to ***manufacture food*** (sugars like ***glucose***) from ***$CO_2$*** and ***$H_2O$*** in the ***presence*** of ***chlorophyll***, utilizing ***light energy*** and releasing ***O2***

3. ***Photosynthesis*** is the ***food manufacturing process*** occurring ***mostly*** in the ***leaves*** of ***plants***. However ***photosynthesis occurs*** in the ***green parts*** of ***plants*** which may sometimes include ***stems***.

4. Photosynthesis ***produces organic molecules*** from ***inorganic molecules***

   A. The ***inorganic molecules*** are ***$CO_2$*** and ***$H_2O$***

   B. The ***organic molecules*** are ***carbohydrates*** like glucose – ***$C_6H_{12}O_6$***

5. ***Photosynthesis*** is the ***only significant food producing mechanism*** on ***earth***

6. ***Autotrophs*** and ***Hetertrophs***

   ***A. Autotrophs***

   1) Autotrophs are ***organisms*** that ***manufacture*** their ***own foods*** from ***simple inorganic substances***

   2) There are ***2 kinds*** or ***autotrophs***

      **a) Photosynthetic autotrophs**

      - Depend on ***light energy*** to ***produce food***
      - ***Examples*** are ***green plants***, ***algae***, and ***cyanobacteria***

      ***b) Chemosynthetic autotrophs***

      - Depend on ***energy*** from ***chemical reactions*** from the ***breakdown*** of ***inorganic molecules***
      - Can occur ***without light energy***

- ***Examples*** are many ***bacteria***, especially those found in the ***dark depths*** of the ***ocean***

3) ***Autotrophs*** are the ***producers*** on ***earth***

***B. Heterotrophs***

1) Heterotrophs are ***organisms*** that ***cannot manufacture*** their own ***food***

2) To ***survive***, they ***must eat*** an ***autotroph*** or ***another hetertroph***

3) Different ***types*** of ***heterotrophs*** include

   **a)** ***Carnivores*** - consumers in a food chain that eat animals

   ***b)*** ***Saprophytes*** – consumers in a food chain that live and gain their nutrition from a dead host

   ***c)*** ***Parasites*** – consumers in a food chain that live and gain their nutrition on a living host

4) ***Heterotrophs*** are the ***earth's consumers***

7. ***Photosynthesis*** is the ***source*** of ***$O_2$*** for ***animals*** to ***breath*** in and to ***deliver*** to their ***cells*** to ***complete cellular respiration***

8. ***Raw Materials*** (inputs) for ***photoshythesis***

(See Handout of Figure 7.2, page 119 of Textbook, Mader, 10th Ed)

A. $H_2O$

1) ***Source*** is ***$H_2O$*** in the ***soil***

2) ***$H_2O$*** is ***absorbed*** by the ***roots*** and ***dispersed*** throughout the ***plant***

3) ***$H_2O$*** is found in the ***cell walls*** and ***mesophyll cells*** of the ***leaves***

**B. CO2**

1) ***Source*** is ***$CO_2$*** in the ***atmosphere***

2) ***$CO_2$ diffuses*** through the ***stomata*** into the ***intercellular spaces*** of the ***leaf***

3) Here it ***dissolves*** into the ***$H_2O$*** that ***saturates*** the ***walls*** of the ***mesophyll cells*** of the ***leaf***

9. The ***5 essential factors*** needed for ***photosynthesis*** are

***A. $CO_2$***

***B. $H_2O$***

***C. Light energy***

***D. Chloroplasts***

***E. Suitable temperature*** – normally 5 C to 40 C (41 F to 104 F)
- rates increase up to about 35 C (95 F)

10. ***Site*** of ***Photosynthesis***

(See Handout of Figure 7.2, page 119 of Textbook, Mader, 10th Ed) and

(See Handout of Figure 7.4, page 121 of Textbook, Mader, 10th Ed)

A. ***Photosynthesis*** occurs in the ***green portions*** of ***cells***

B. ***Leaves*** contain ***mesophyll cells*** that are ***specialized*** for ***photosynthesis***

C. Once ***inside*** a ***mesophyll cell, $H_2O$*** and ***$CO_2$ diffuse*** into a cellular ***organelle*** called a ***chloroplast***.

***(Greek word chloros - means green)***
***(Greek word plastos - means formed, molded)***

D. A ***double membrane*** surrounds the ***chloroplast*** and its ***semi-fluid interior*** is called the ***stroma***

***E.*** The ***stroma*** is the ***site*** where ***$CO_2$*** is ***reduced*** to a ***carbohydrate***. This is where the ***Calvin cycle reactions*** occur and ***sugar*** (glucose) is ***made***

F. ***Inside*** the ***chloroplasts*** are ***structures*** called ***thylakoids***

G. The ***thylakoid membrane*** contains ***chlorophyll*** and other pigments capable of ***absorbing solar energy*** – the ***energy that drives photosynthesis***

H. The ***thylakoid membrane*** is the site of the ***light reactions*** of ***photosynthesis***

11. Overall ***summary equation*** for ***photosynthesis*** can be ***written*** as ***follows***

**Reduction**

$$6CO_2 \quad + \quad 12H_2O \quad \xrightarrow[\textit{Chlorophyll}]{\textit{Solar energy}} \quad C_6H_{12}O_6 \quad + \quad 6O_2 \quad + \quad 6H_2O$$

**Oxidation**

A. ***Photosynthesis*** is an ***oxidation-reduction*** reaction and is much ***like cellular respiration*** in ***reverse***

B. ***Recall*** that

1) ***oxidation*** is the ***loss of electrons*** - ***in living cells this usually means the loss of an H atom and its electrons***

2) ***reduction*** is the ***gain of electrons***- ***in living cells this usually means the gain of an H atom and its electrons***

C. ***$CO_2$*** is ***reduced*** to form a ***carbohydrate*** like ***glucose*** – the ***fuel*** for ***cellular respiration***

D. ***$H_2O$*** is ***oxidized*** to form ***$O_2$*** – the ***gas*** so important for the ***survival*** of ***animals***

12. There are ***2*** major ***sets*** of ***reactions*** involved in ***photosynthesis***

***A. Light Reactions – occur*** in ***thylakoid membranes*** of ***chloroplasts***

***B. Calvin Cycle Reactions*** – occur in ***stroma*** of ***chloroplasts***

## 13. Light Reactions

(See Handout of Figure 7.4, page 121 of Textbook, Mader, $10^{th}$ Ed)

A. The ***light reactions*** are ***non-cyclic reactions***

B. ***Light reactions*** only occur during ***daylight*** when ***solar energy*** is ***available***

C. ***Occur prior*** to ***Calvin Cycle reactions*** and ***provide*** needed ***inputs*** to ***Calvin Cycle reactions***

D. Are normally ***not sensitive*** to the ***effects*** of ***temperature***

E. The ***green pigment chlorophyll*** is responsible for ***absorbing*** the ***solar energy*** and ***exciting electrons*** to provide the ***energy*** needed to ***drive*** the ***light reactions***

F. This ***energy*** is used to

1) *split* ***$H_2O$*** into ***H ions*** and ***$O_2$***

2) ***H ions*** are used to make ***NAPDPH*** – which ***stay*** in the ***chloroplast*** to be used in the ***Calvin Cycle reactions***

$NADP^+$ + 2 $e^-$ + $H^+$ ---------> NADPH

3) ***$O_2$*** is ***released*** into the ***atmosphere*** – note that the ***$O_2$ released*** into the ***atmosphere*** comes from the ***original $H_2O$*** molecule and not ***$CO_2$***

4) ***Energy*** also used in ***formation*** of ***ATP***

G. ***Summary of inputs*** and ***outputs*** of ***light reactions***

| Inputs | Outputs |
|---|---|
| Solar energy | O2 |
| H2O | ATP |
| | NADPH |
| | |

H. During the light reactions, solar energy is converted to chemical energy and can be summarized as follows

***Solar energy*** ⟶ ***Chemical energy***
***(ATP, NADPH)***

I. ***2 products*** from the ***light reactions*** that are ***essential*** to ***functioning*** of ***Calvin Cycle reactions*** are

*1) ATP*
*2) NADPH*

**14. Calvin Cycle Reactions**

(See Handout of Figure 7.4, page 121 of Textbook, Mader, 10th Ed)

A. The ***Calvin cycle reactions*** are a ***cyclic reaction***

B. These ***reactions*** are sometimes called the ***dark reactions***, because they ***do not require light***. However, they ***can occur*** in ***daylight*** as ***well*** as during ***darkness***

***C. Occur after light reactions***

D. ***Calvin cycle reactions*** are ***driven*** by ***enzymes*** in the ***stroma*** of the ***chloroplast***

E. Recall that the ***action*** of ***enzymes*** is ***affected by temperature*** – therefore the ***Calvin cycle reactions*** are usually ***sensitive*** to the ***effects*** of ***temperature***

F. During ***Calvin Cycle reactions***, ***atmospheric $CO_2$*** is taken up and then ***reduced*** to ***a molecule called*** G3P that can be ***converted*** to ***glucose ad(recall how did $CO_2$ got inside chloroplast)***

G. The ***ATP*** and ***NADPH formed*** during the ***light reactions*** are used to ***reduce $CO_2$***

H. ***Summary of inputs*** and ***outputs*** of ***Calvin cycle reactions***

| Inputs | Outputs |
|---|---|
| CO2 | G3P |
| NADPH | |
| ATP | |
| | |

I. G3P – called ***glyceraldehydes-3-phosphate*** is the ***actual product*** of the ***Calvin Cycle reactions***

J. ***G3P*** can be ***converted*** to

1) ***glucose*** and other ***carbohydrates*** like ***cellulose*** and ***starch***
2) ***lipids*** and ***oils***
3) ***amino acids and proteins***

J. During the ***Calvin Cycle reactions***, the ***ATP*** and ***NADPH*** formed during the ***light reactions*** are used to ***reduce*** $CO_2$. This can be ***summarized*** as follows

$$\underset{\textit{(ATP, NADPH)}}{\textbf{\textit{Chemical energy}}} \longrightarrow \underset{\textit{(carbohydrate)}}{\textbf{\textit{Chemical energy}}}$$

**Figure 4.** **Animal cell structure.**

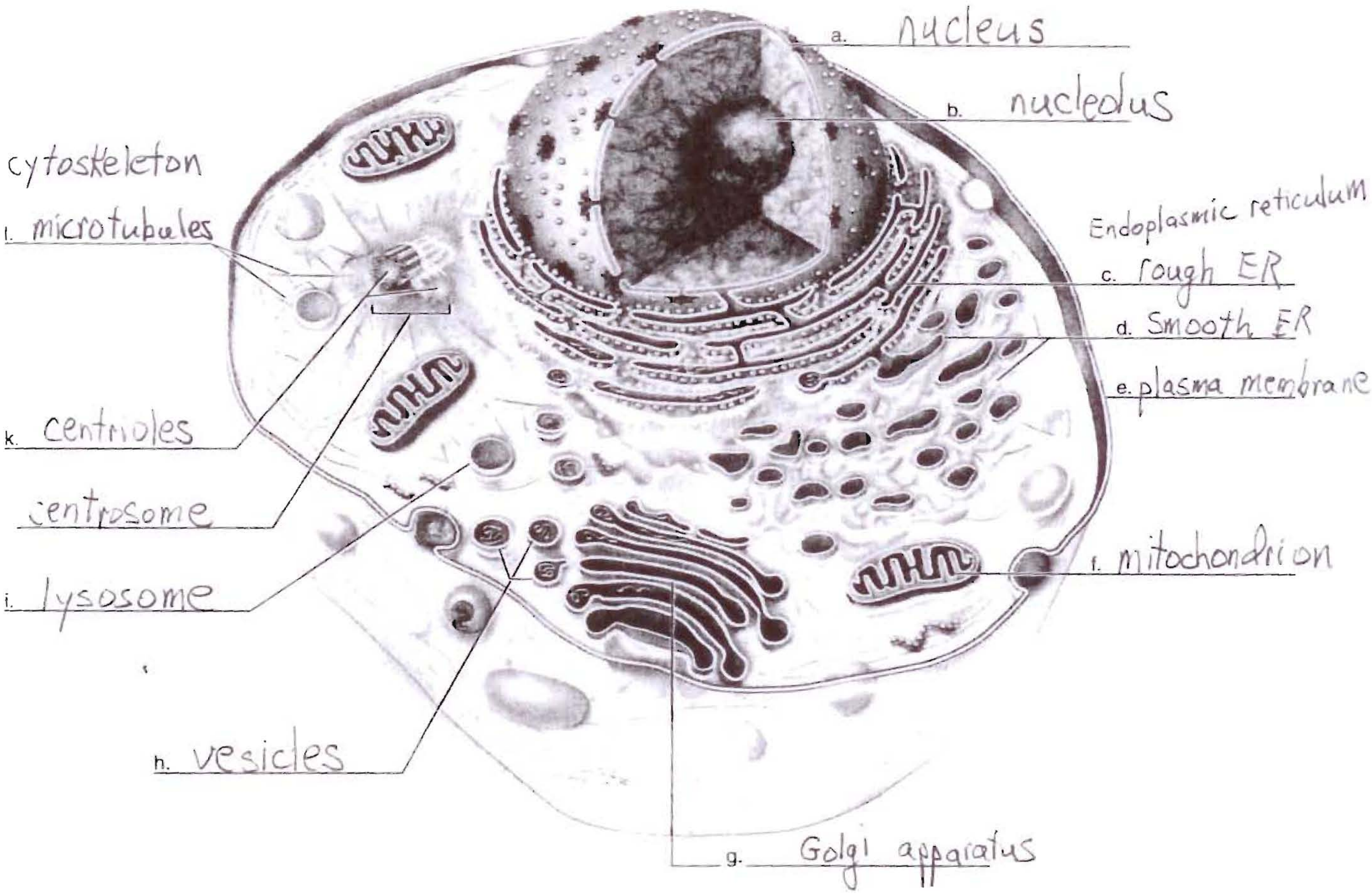
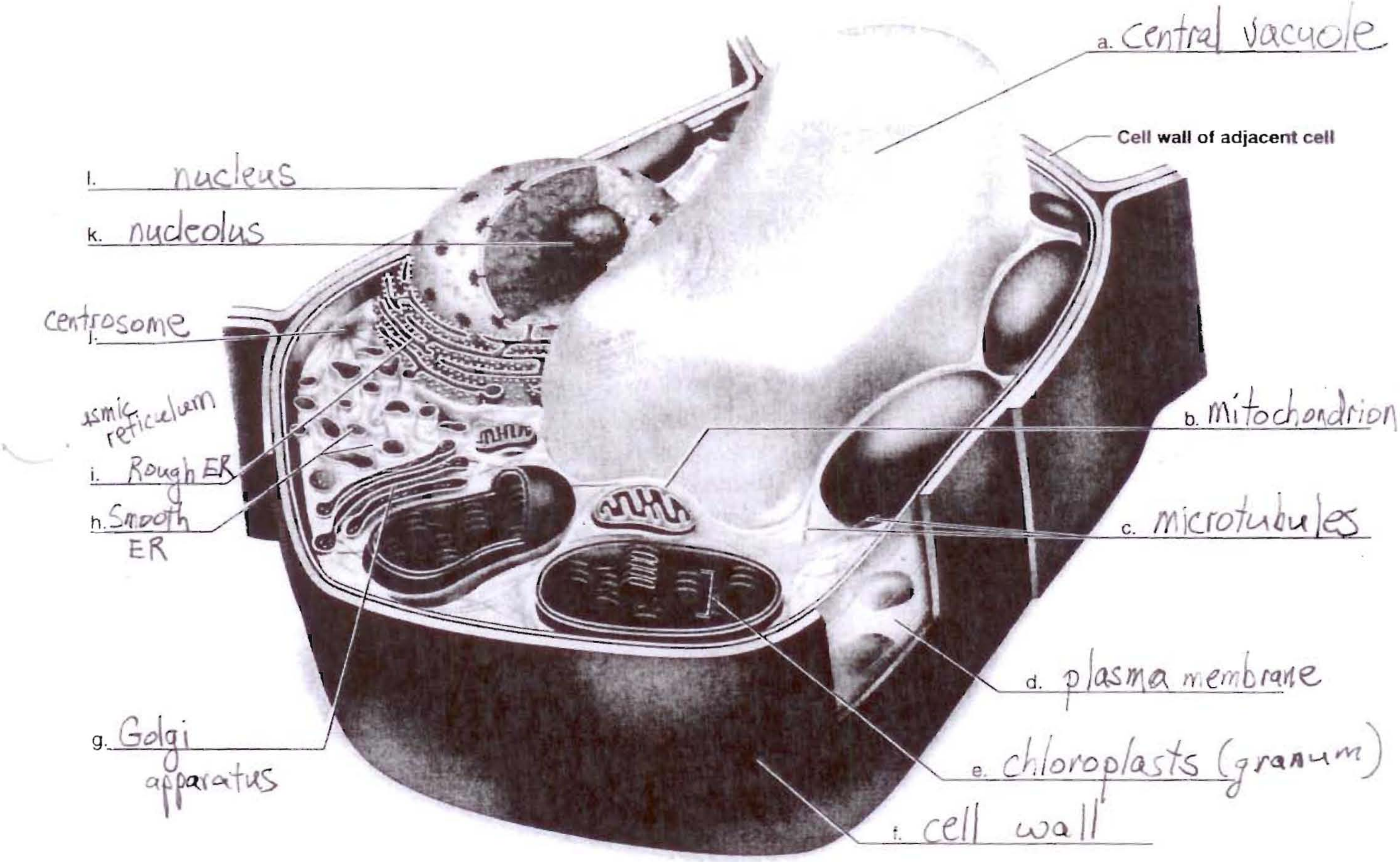
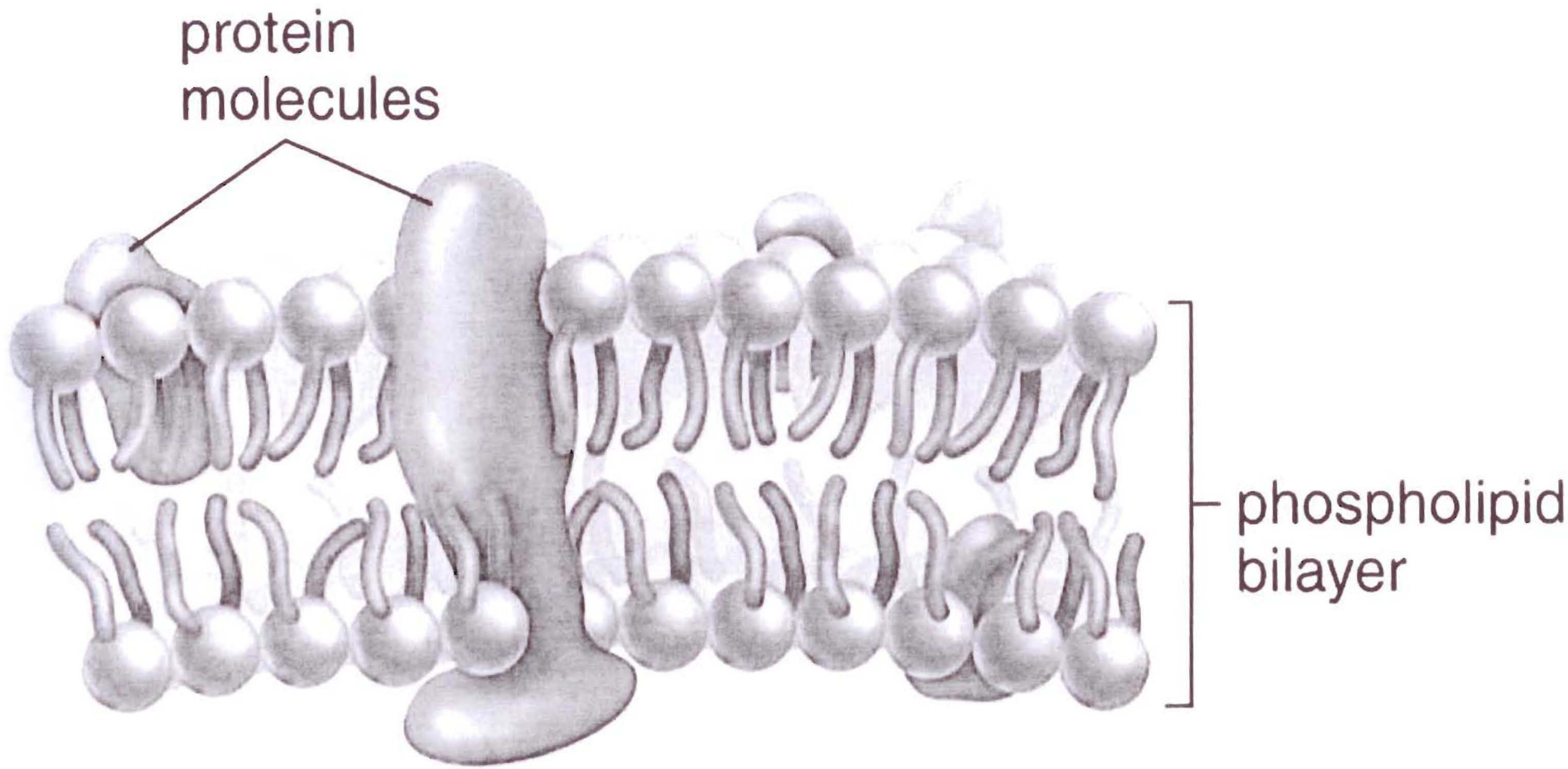


**Figure 4.7 Plant cell structure.**

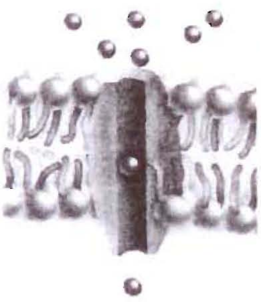


Plasma Membrane



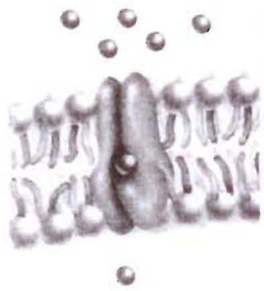


# Figure 5.3 Membrane Protein Diversity



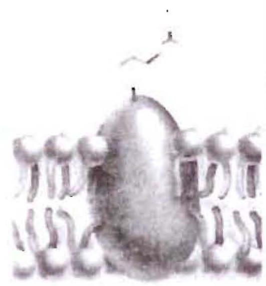
**Channel Protein:** Allows a particular molecule or ion to cross the plasma membrane freely. Cystic fibrosis, an inherited disorder, is caused by a faulty chloride ($Cl^-$) channel; a thick mucus collects in airways and in pancreatic and liver ducts.

a.



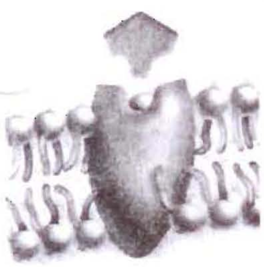
**Carrier Protein:** Selectively interacts with a specific molecule or ion so that it can cross the plasma membrane. The inability of some persons to use energy for sodium-potassium ($Na^+$–$K^+$) transport has been suggested as the cause of their obesity.

b.



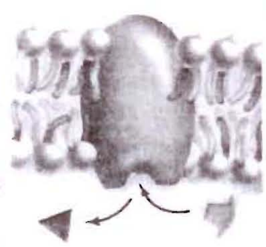
**Cell Recognition Protein:** The MHC (major histocompatibility complex) glycoproteins are different for each person, so organ transplants are difficult to achieve. Cells with foreign MHC glycoproteins are attacked by white blood cells responsible for immunity.

c.



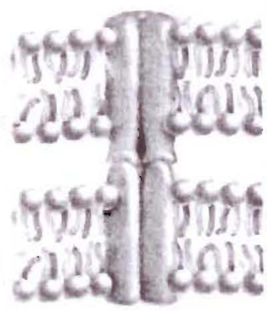
**Receptor Protein:** Is shaped in such a way that a specific molecule can bind to it. Pygmies are short, not because they do not produce enough growth hormone, but because their plasma membrane growth hormone receptors are faulty and cannot interact with growth hormone.

d.



**Enzymatic Protein:** Catalyzes a specific reaction. The membrane protein, adenylate cyclase, is involved in ATP metabolism. Cholera bacteria release a toxin that interferes with the proper functioning of adenylate cyclase; sodium ($Na^+$) and water leave intestinal cells, and the individual may die from severe diarrhea.

e.



**Junction Proteins:** Tight junctions join cells so that a tissue can fulfill a function, as when a tissue pinches off the neural tube during development. Without this cooperation between cells, an animal embryo would have no nervous system.

f.

**FIGURE 5.3 Membrane protein diversity.**

These are some of the functions performed by proteins found in the plasma membrane.

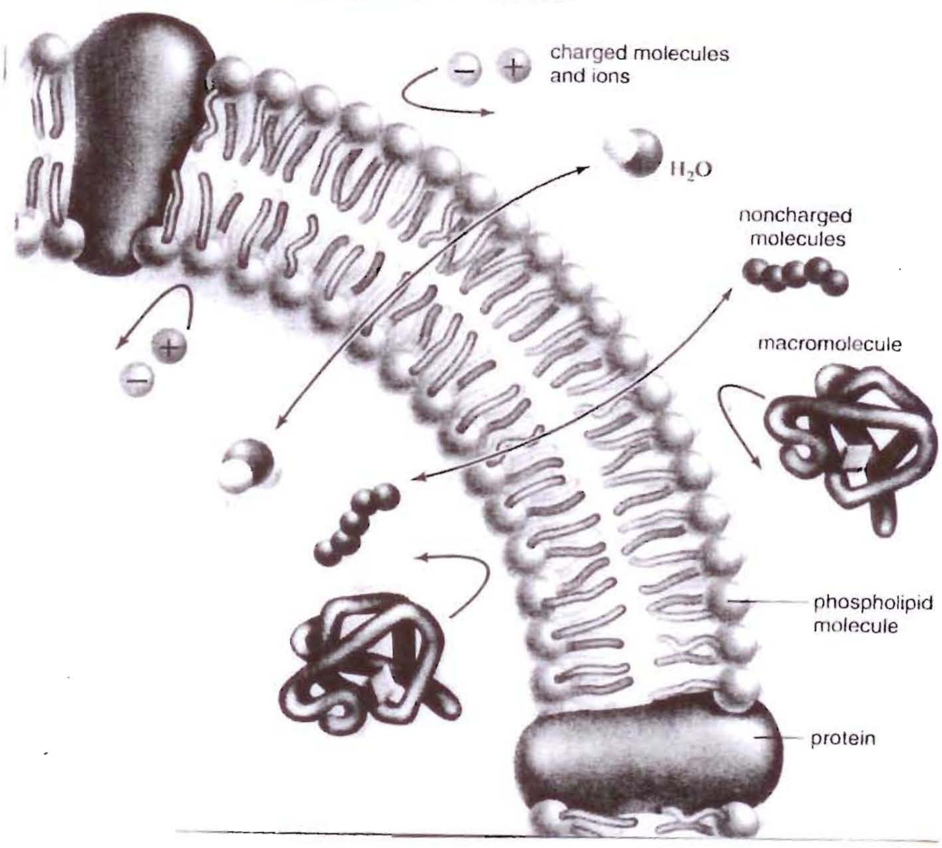
## TABLE 5.1

**Passage of Molecules into and out of the Cell**

| | Name | Direction | Requirement | Examples |
|---|---|---|---|---|
| Energy Not Required | Diffusion | Toward lower concentration | Concentration gradient | Lipid-soluble molecules, and gases |
| | Facilitated transport | Toward lower concentration | Channels or carrier and concentration gradient | Some sugars, and amino acids |
| Energy Required | Active transport | Toward higher concentration | Carrier plus energy | Sugars, amino acids, and ions |
| | Bulk transport | Toward outside or inside | Vesicle utilization | Macromolecules |

**FIGURE 5.4 How molecules cross the plasma membrane.**

The curved arrows indicate that these substances cannot passively cross the plasma membrane, and the long back-and-forth arrows indicate that these substances can diffuse across the plasma membrane.



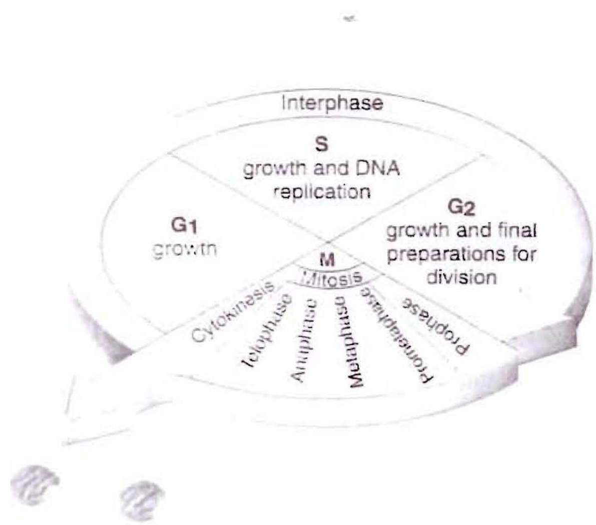
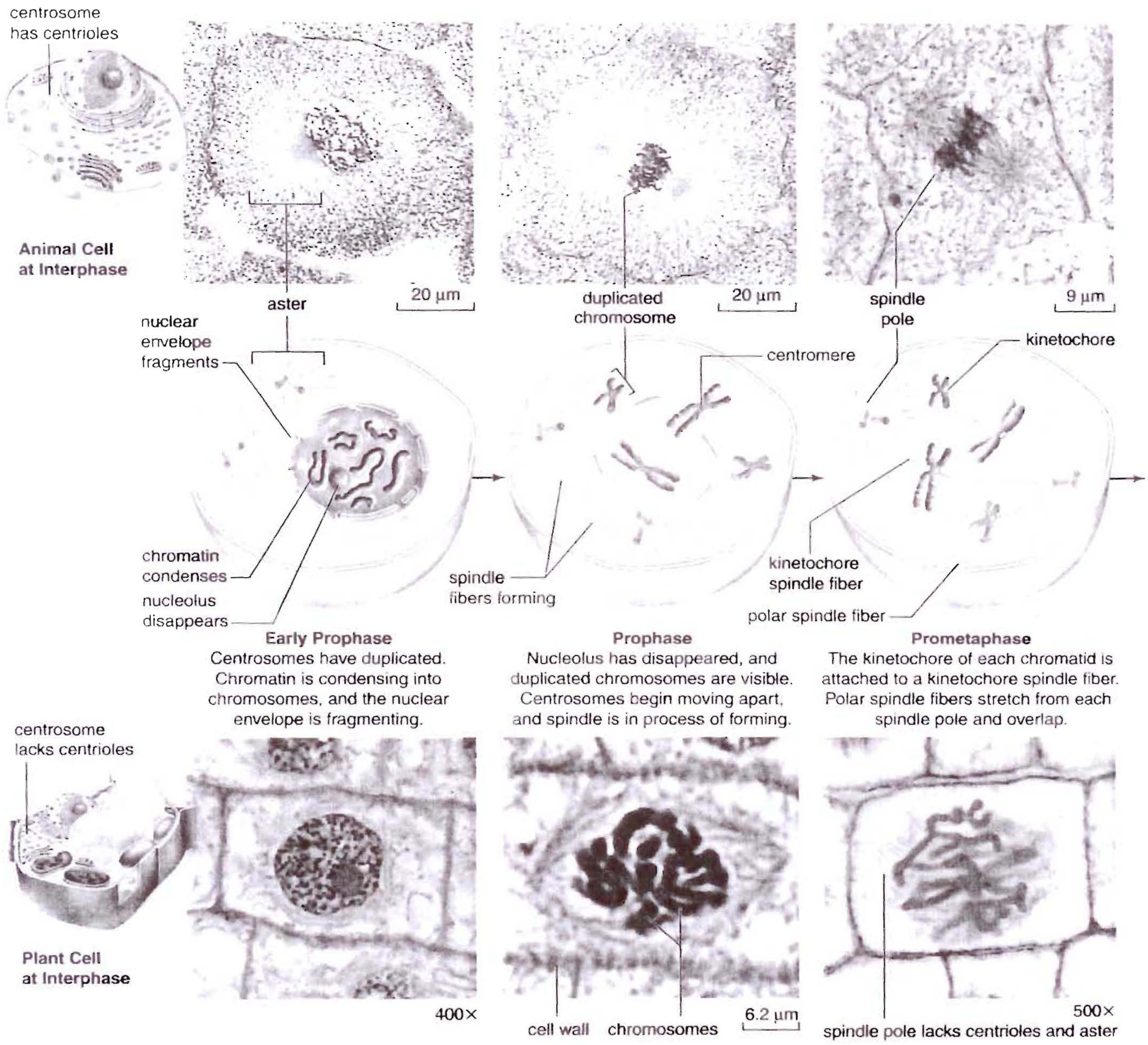


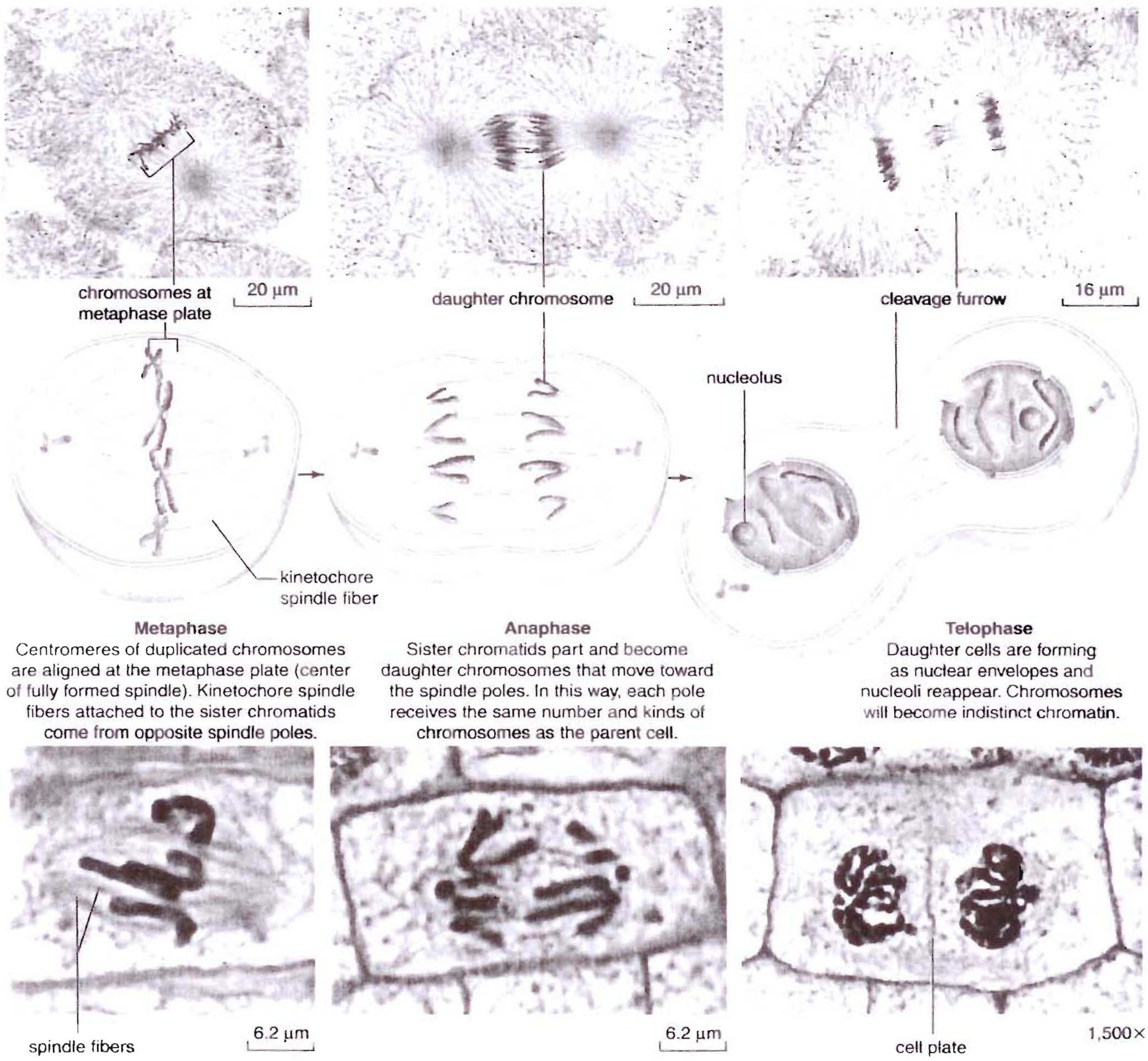

**Figure 8.1 The cell cycle.**
Immature cells go through a cycle that consists of four stages: $G_1$, S (for synthesis), $G_2$, and M (for mitosis). Eventually, some daughter cells "break out" of the cell cycle and become specialized cells.

## Mitosis Phases

**Figure 8.3 Phases of mitosis in animal and plant cells.**
The colors signify that the chromosomes were inherited from different parents.



The phases of mitosis are shown in Figure 8.3. Mitosis is the type of nuclear division that (1) occurs in the body (somatic) cells; (2) results in two daughter cells because there is only one round of division; and (3) keeps the chromosome number constant (same as the parent cell).




**Metaphase**
Centromeres of duplicated chromosomes are aligned at the metaphase plate (center of fully formed spindle). Kinetochore spindle fibers attached to the sister chromatids come from opposite spindle poles.

**Anaphase**
Sister chromatids part and become daughter chromosomes that move toward the spindle poles. In this way, each pole receives the same number and kinds of chromosomes as the parent cell.

**Telophase**
Daughter cells are forming as nuclear envelopes and nucleoli reappear. Chromosomes will become indistinct chromatin.

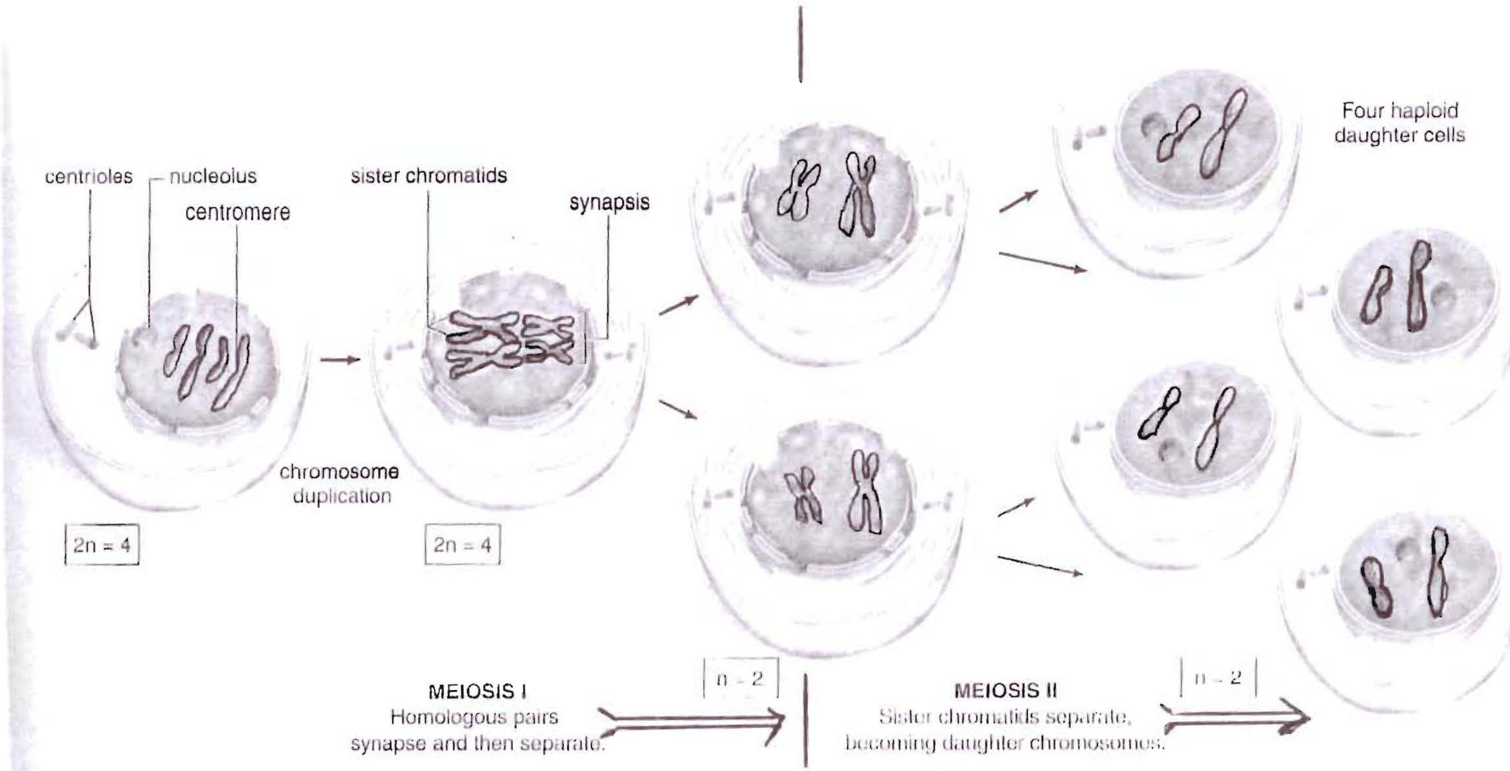



**FIGURE 10.2 Overview of meiosis.**

Following DNA replication, each chromosome is duplicated and consists of two chromatids. During meiosis I, homologous chromosomes pair and separate. During meiosis II, the sister chromatids of each duplicated chromosome separate. At the completion of meiosis, there are four haploid daughter cells. Each daughter cell has one of each kind of chromosome.

- ***Table*** comparing ***Meiosis*** and ***Mitosis***

| **Meiosis** | **Mitosis** |
|---|---|
| | |
| 1. occurs only in the reproductive organs | 1. occurs throughout the body |
| 2. purpose to produce sperm and eggs | 2 purpose to allow development, growth, and maintenance of organism |
| 3. requires 2 nuclear divisions | 3. requires only 1 nuclear division |
| 4. produces 4 daughter cells | 4. produces 2 daughter cells |
| 5. produces 4 haploid daughter cells | 5. produces 2 diploid daughter cells |
| 6. daughter cells genetically different from each other and from original germ cell | 6 daughter cells are genetically identical to each other and to the original somatic cell. |
| | |
| | |

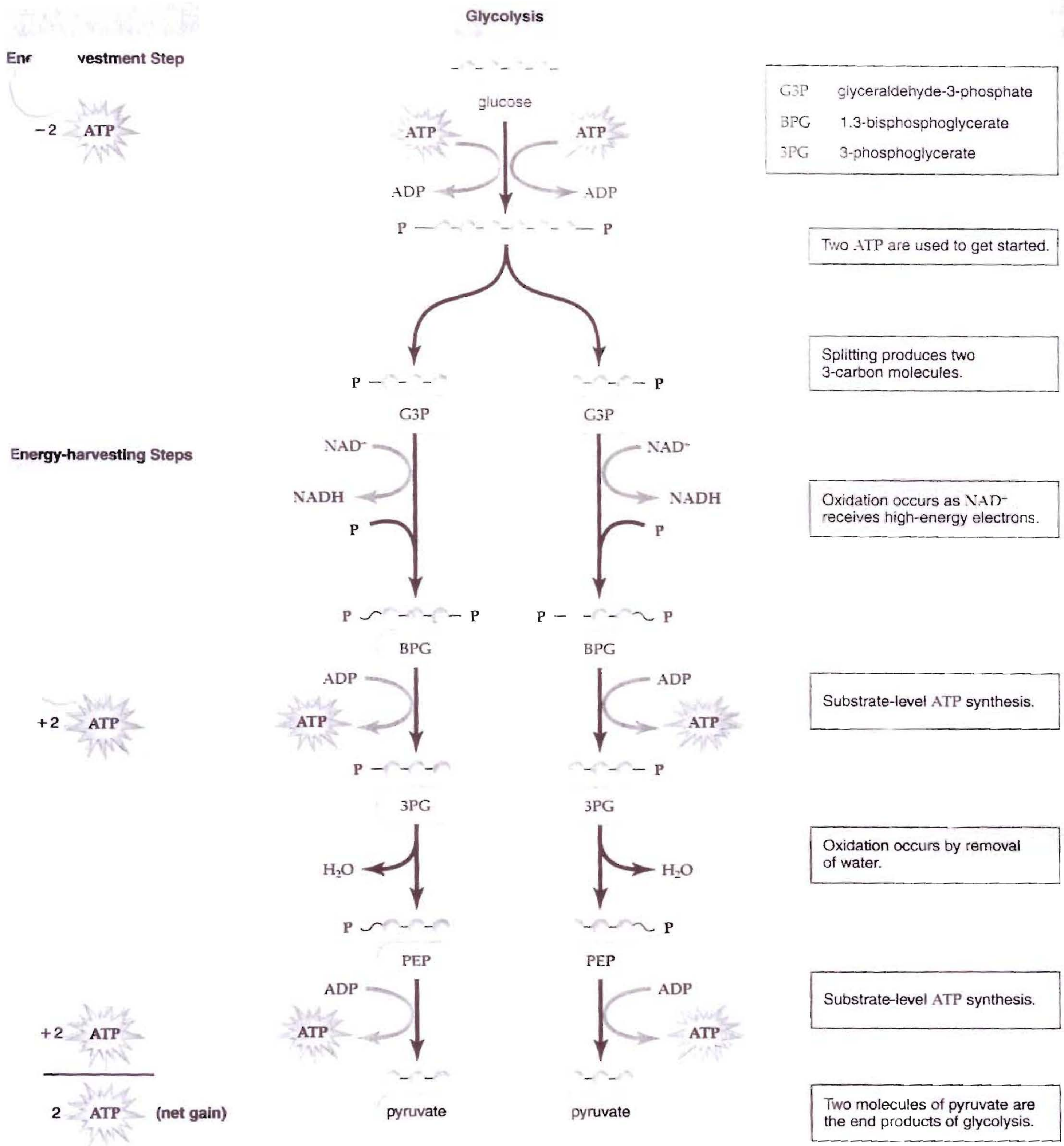



**FIGURE 8.4 Glycolysis.**

This metabolic pathway begins with $C_6$ glucose (each gray ball is a carbon atom) and ends with two $C_3$ pyruvate molecules. Net gain of two ATP molecules can be calculated by subtracting those expended during the energy-investment step from those produced during the energy-harvesting steps.

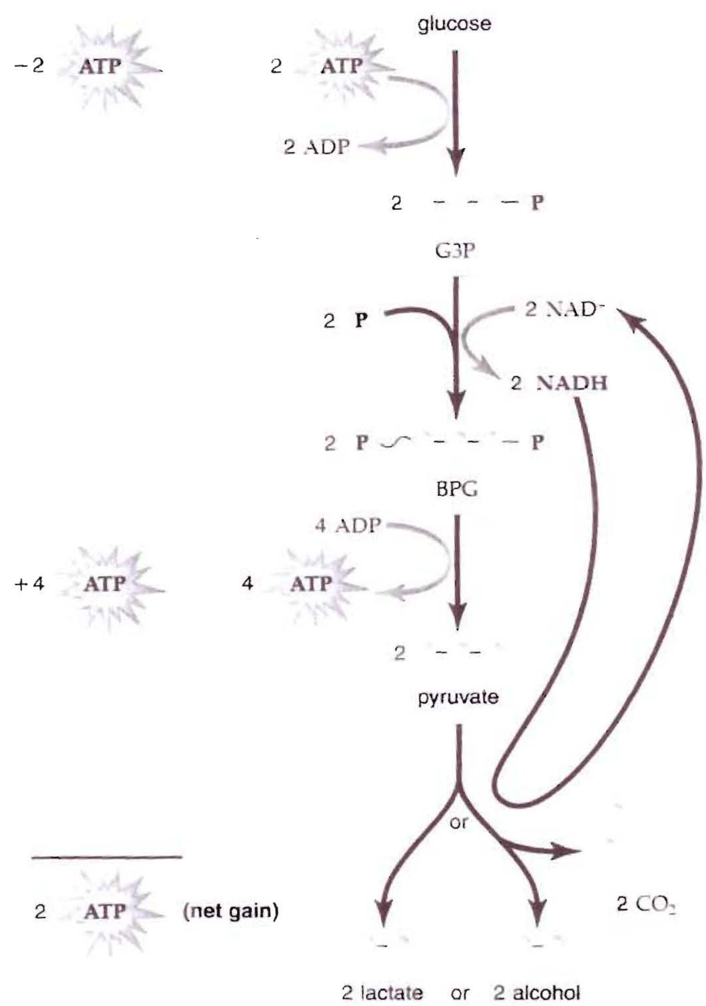



**FIGURE 8.5 Fermentation.**

Fermentation consists of glycolysis followed by a reduction of pyruvate. This "frees" $NAD^+$ and it returns to the glycolytic pathway to pick up more electrons.

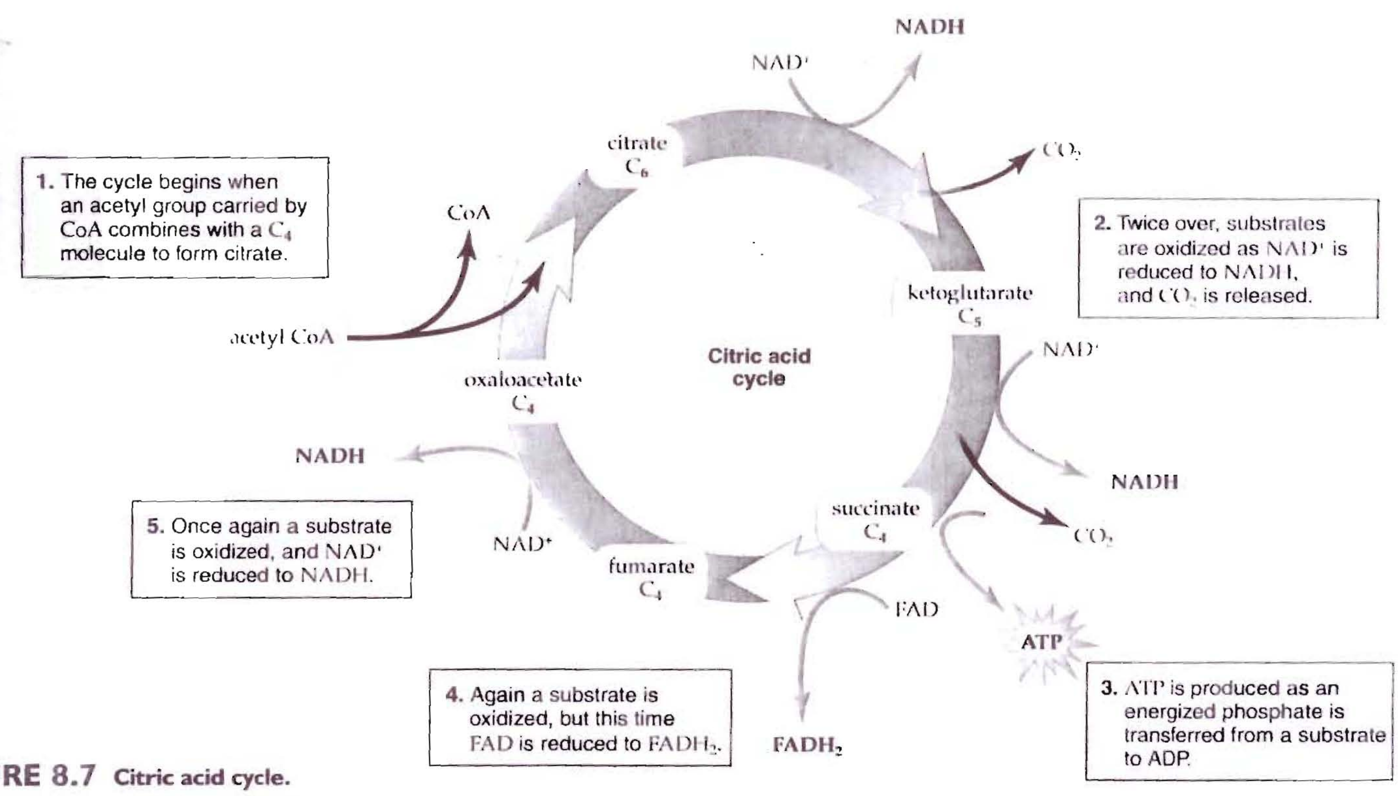



**FIGURE 8.7 Citric acid cycle.**

…ric acid cycle turns twice per glucose molecule.

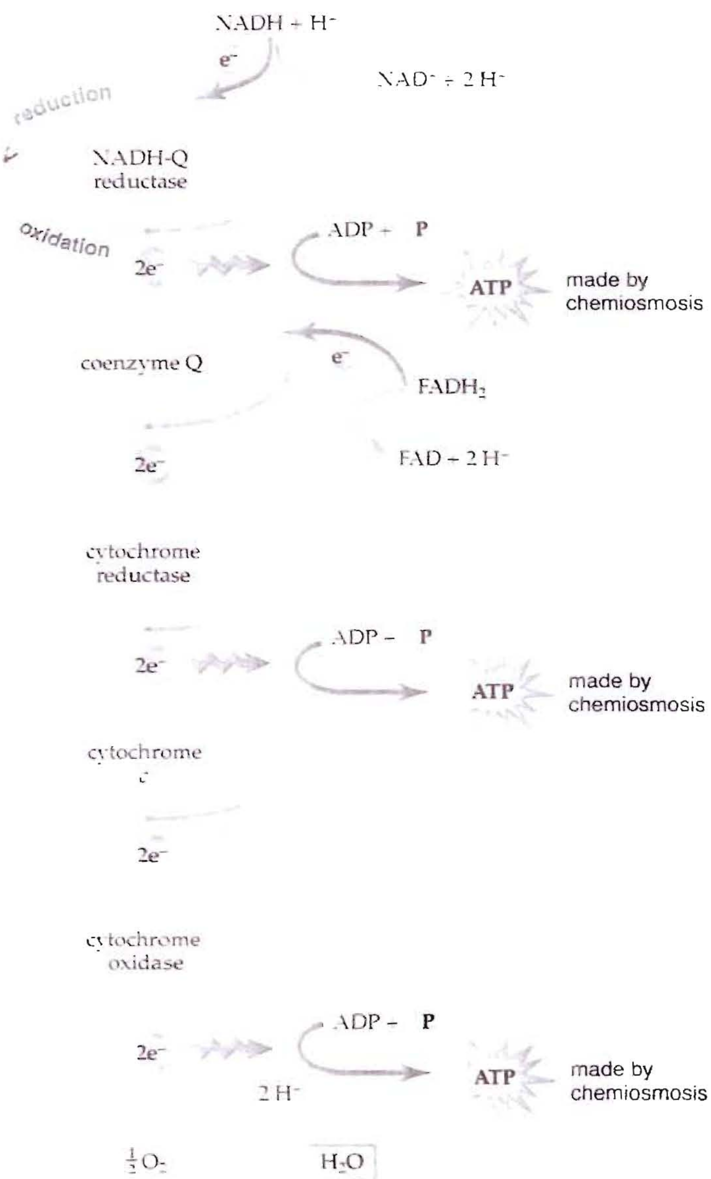


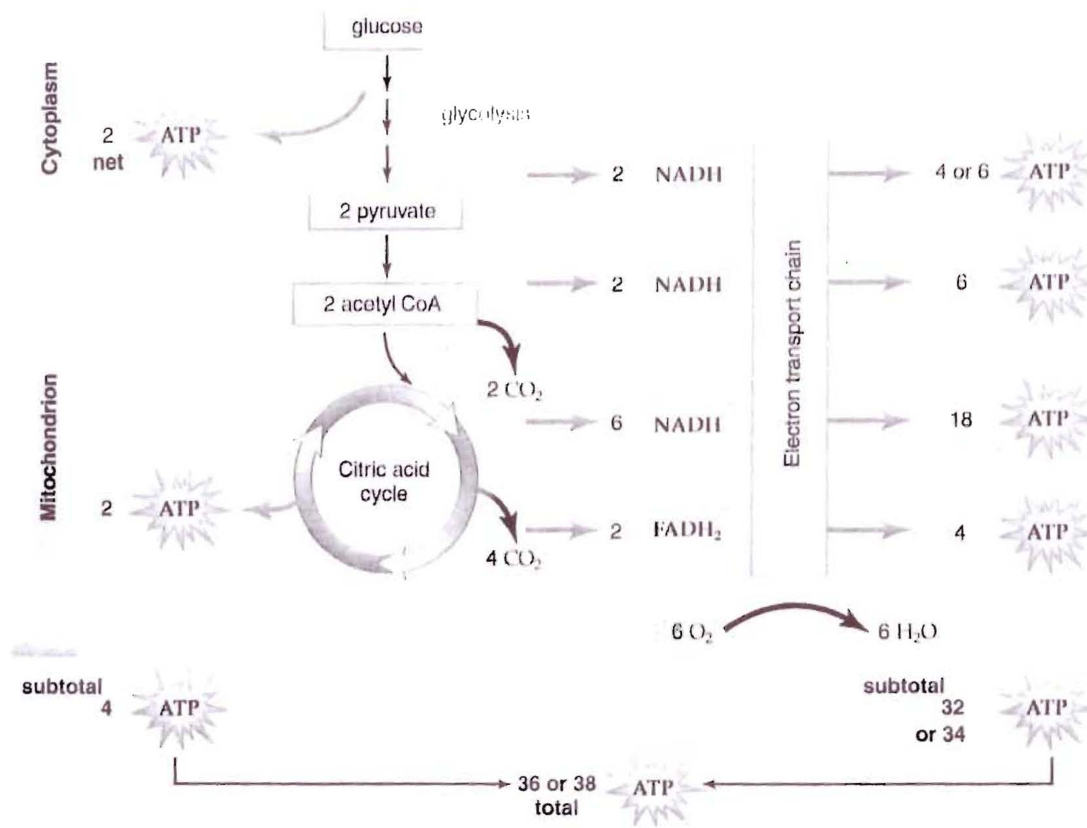

**FIGURE 8.8 The electron transport chain (ETC).**

NADH and $FADH_2$ bring electrons to the electron transport chain. As the electrons move down the chain, energy is captured and used to form ATP. For every pair of electrons that enters by way of NADH, three ATP result. For every pair of electrons that enters by way of $FADH_2$, two ATP result. Oxygen, the final acceptor of the electrons, becomes a part of water.

**FIGURE 8.10**

**Accounting of energy yield per glucose molecule breakdown.**

Substrate-level ATP synthesis during glycolysis and the citric acid cycle accounts for 4 ATP. The electron transport chain accounts for 32 or 34 ATP, and the grand total of ATP is therefore 36 or 38 ATP. Cells differ as to the delivery of the electrons from NADH generated outside the mitochondria. If they are delivered by a shuttle mechanism to the start of the electron transport chain, 6 ATP result; otherwise, 4 ATP result.



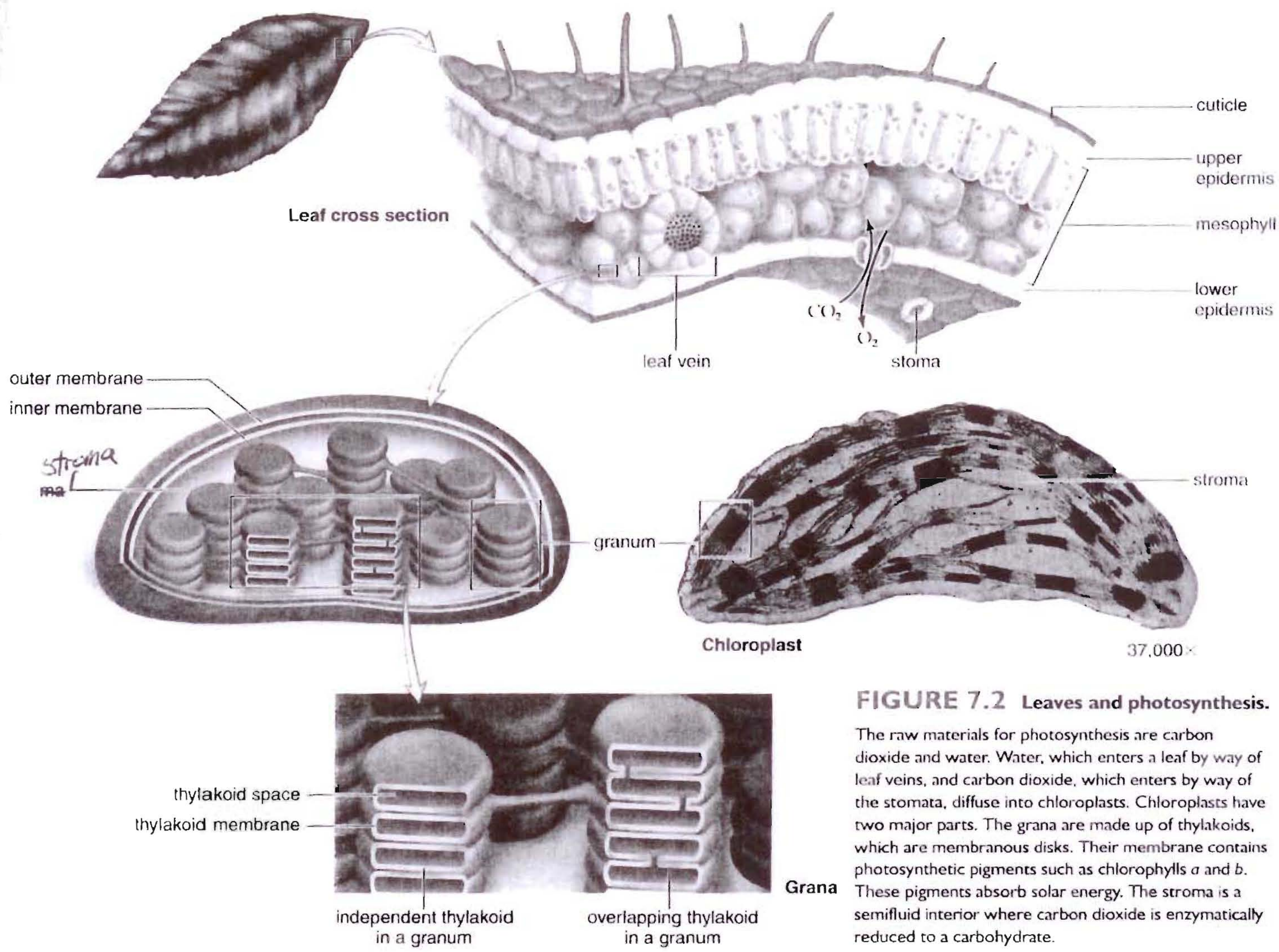



**FIGURE 7.2 Leaves and photosynthesis.**

The raw materials for photosynthesis are carbon dioxide and water. Water, which enters a leaf by way of leaf veins, and carbon dioxide, which enters by way of the stomata, diffuse into chloroplasts. Chloroplasts have two major parts. The grana are made up of thylakoids, which are membranous disks. Their membrane contains photosynthetic pigments such as chlorophylls *a* and *b*. These pigments absorb solar energy. The stroma is a semifluid interior where carbon dioxide is enzymatically reduced to a carbohydrate.

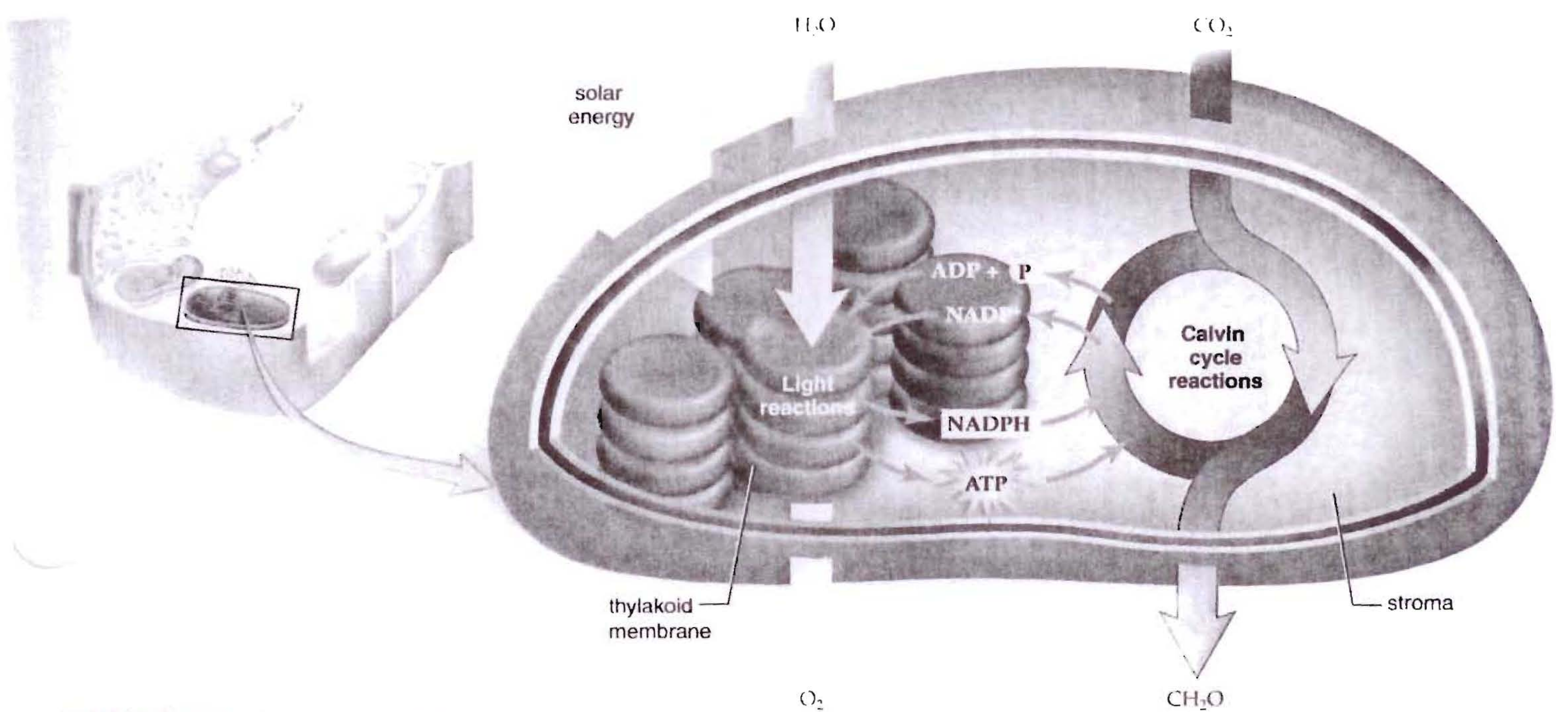



**FIGURE 7.4 Overview of photosynthesis.**

The process of photosynthesis consists of the light reactions and the Calvin cycle reactions. The light reactions, which produce ATP and NADPH, occur in the thylakoid membrane. These molecules are used in the Calvin cycle reactions which take place in the stroma. The Calvin cycle reactions reduce carbon dioxide to a carbohydrate.