Name: ____ Date: ____________________________

AP Biology Exam Review 5: Enzymes & Metabolism (Photosynthesis & Respiration)

Helpful Videos and Animations:

1. Bozeman Biology: Photosynthesis and Respiration
2. Bozeman Biology: Photosynthesis
3. Bozeman Biology: Cellular Respiration

Relevant Objectives:

86. Explain the function of an enzyme and describe how an enzyme works
87. Explain factors influencing enzyme activity ([Substrate], [Enzyme], pH, temperature, [Ion], and describe how these factors influence activity
88. Be able to determine the rate of an enzyme catalyzed reaction from a graph or data table and compare and contrast rates
89. Explain how activators and inhibitors effect enzyme activity
90. Differentiate between different types of inhibitors - competitive, non-competitive, irreversible
91. Describe the function of plant pigments and explain the adaptive purpose of plants having multiple pigments
92. Explain how ATP stores and releases energy
93. Know the equation for photosynthesis
94. Describe the light reaction of photosynthesis and explain the purpose of it
95. Be able to name the reactants and products of the light reactions
96. Name the electron carrier in photosynthesis
97. Describe the Calvin Cycle (Light-Independent Reactions) of photosynthesis and explain the purpose of it
98. Be able to name the reactants and products of the Calvin Cycle
99. Explain how water potential effects the movement of water
100. Describe how plants transport water and nutrients throughout
101. Describe transpiration and explain how guard cells regulate water loss and CO_2 levels
102. Name the electron carriers in cellular respiration
103. Describe the process of glycolysis, naming the reactants, products, and where it occurs in the cell
104. Explain how NAD^+ is recycled after glycolysis
105. Describe the difference between aerobic and anaerobic respiration
106. Describe the Krebs cycle, naming the reactants, products, and where it occurs in the cell
107. Describe the ETC, naming the reactants, products, and where it occurs in the cell
108. Explain how the ETC is used to produce ATP
109. Be able to do energy accounting for each step in respiration
110. Explain how exercise effects the rate of cellular respiration

Topic Outline:

1. Photosynthesis (Endergonic reaction – captures energy and stores in glucose)
   - Autotophs (producers) – organism that uses energy from the sun (photosynthesis) or chemicals (chemosynthesis) to producer their own food; different from heterotrophs, which must eat food
   - Equation:
     - $6CO_2 + 6\ H_2O \xrightarrow{\text{in the presence of sunlight}} C_6H_{12}O_6 + 6O_2$
   - Structure of a chloroplast – double membrane bound organelle; outer membrane and inner membrane of sacs
   - Cells with high concentrations of chloroplasts in mesophyll tissue of leaf
   - Structures within a chloroplast:
     - Stroma – open space within the chloroplast; light-independent reactions (Calvin Cycle) take place here
     - Thylakoid – membrane bound sacs within the chloroplast, in stacks of grana; ; light-dependent reactions take place here
     - Granum – stacks of thylakoid
     - Thylakoid space – space within the membranes of thylakoids

- Stomata – on bottom of leaves
    - Open to allow CO_2 <u>in</u> to leaves and O_2 <u>out</u> of leaves, allows H_2O <u>out</u> of leaves.
        - H_2O leaving stomata (transpiration) aids in water transport throughout plant
        - Low water content = stoma <u>close</u> (no CO_2 coming in for photosynthesis); high water content = stoma <u>open</u>; controlled by turgor pressure in guard cells
- Two steps in Photosynthesis: Light Reactions and Calvin Cycle (Light-Independent Reactions)
    I. Light Reactions (in thylakoid membrane)
    - In Photosystem II, light is absorbed by chlorophyll. Light excites electrons in photosystem II and the electrons travel down an electron transport chain to photosysthem I, generating ATP using chemiosmosis to power the addition of a phosphate group to ADP (ADP → ATP); this process is called photophosphorylation
        - Water is split when electrons are removed from photosystem II, and O_2 is released from the stomata; replenishes e^- in photosystem II, and provides H^+ ions to drive production of ATP
    - Light re-excites the electrons at photosystem I, and again the electrons fall down an electron transport chain. This time, they do not fall all the way down the transport chain, instead they are transferred to $NADP^+$ in a high energy state, along with an H^+ ($NADP^+$ → NADPH)
    - $NADP^+$ and ATP go to the stroma to be used in the Calvin cycle
    - Other accessory pigments are able to absorb light as well (carotenoids, xanthophylls); these pigments transfer light energy to the reaction centers of photosystem I or II
        - Reading absorption spectra – light reflected (not absorbed) = color of pigment

    II. Calvin Cycle (in stroma)
    - Electrons and H^+ from NADPH and energy from ATP are used to reduce CO_2 into organic molecules (Glyceraldehyde-3 Phosphate/G3P, the precursor molecule to glucose) in a process called carbon fixation
    - Ribulose bisphosphate (RuBP) is the molecule that combines with CO_2 to start the Calvin cycle; RuBisCO enzyme catalyzes this reaction, thus fixing carbon

2. Cellular Respiration (Exergonic reaction – releases energy from glucose)
- Aerobic cellular respiration and anaerobic cellular respiration (aka fermentation)
    - Aerobic = with oxygen, in the mitochondria; anaerobic = without oxygen, in the cytoplasm
- Equation:
    - $C_6H_{12}O_6 + 6O_2 \xrightarrow{\text{enzymes}} 6H_2O + 6CO_2$
- Structure of mitochondria – double membrane bound organelle; outer membrane and highly folded inner membrane (cristae) to increase surface area for maximum number of reactions
- Structures within a mitochondria:
    - Outer membrane – outermost membrane of mitochondria
    - Intermembrane space – space between outer and inner membrane
    - Inner membrane – inner most membrane of mitochondria, highly folded
    - Cristae – folds of inner membrane
    - Matrix – space inside the inner membrane of the mitochondria
- A Series of Redox Reactions: Oxidation (loss of electrons/energy); reduction (gain of electrons/energy)
- Step 1: Gycolysis
    - In cytosol
    - Glucose broken apart → 2 Pyruvate
        - electrons and H^+ taken from glucose to reduce 2NAD+ → 2NADH; 2 net ATP gained
- Intermediate Step: Oxidation of Pyruvate
    - Transport protein moves pyruvate from cytosol to matrix of mitochondrion
    - 2 Pyruvate → 2 Acetyl CoA
        - an enzyme removes CO_2 from pyruvate, takes away electrons to reduce NAD+ → NADH, and adds coenzyme A
        - Happens twice (once per pyruvate) = 2 NADH, 2 CO_2, 2 Acetyl CoA
- Step 2: Citric Acid Cycle (Krebs Cycle)
    - In mitochondria
    - 2 turns of the cycle (1 per acetyl CoA) → one molecule of glucose is fully oxidized to CO_2
        - A series of redox reactions produces 2 CO_2, 3 NADH, 1 $FADH_2$ and 1 ATP per turn of the cycle
        - Total (1 turn x 2 acetyl CoA) = 4 CO_2, 6 NADH, 2 $FADH_2$, 2 ATP

- Step 3: Electron Transport Chain and Chemiosmosis
  - Both happen inside the mitochondira
  - ETC
    - NADH and $FADH_2$ "dump" high-energy electrons off to the inner mitochondrial membrane's electron transport chain
    - Electrons lose energy as they are transferred from one protein to the next
    - Proteins use energy from electrons passed between them to pump H^+ across the inner mitochondrial membrane into the intermembrane space
    - Final electron acceptor is O_2 (O_2 combines with H^+ after chemiosmosis → H_2O released)
  - Chemiosmosis
    - H^+ flow back down their gradient (proton motive force) through a channel in ATP synthase into the matrix
    - ATP synthase turns and creates ATP from ADP and Pi; 26-28 ATP produced
    - Chemiosmosis is an energy-coupling mechanism that uses energy stored in the form of an H^+ gradient across a membrane to drive cellular work (creation of ATP by ATP synthase)
    - This method of making ATP is known as oxidative phosphorylation (ADP is phosphorylated and oxygen is necessary to keep the electrons flowing)
    - Oxidative phosphorylation accounts most of the ATP created during cellular respiration
- Fermentation/Anaerobic Respiration (creating ATP without oxygen)
  - Occurs after glycolysis (the Kreb's/Citric Acid Cycle and Electron Transport Chain are not used)
  - Glycolysis = 2 ATP
  - Reactions regenerate NAD^+ to act as an electron acceptor for electrons released during the breakdown of glucose to pyruvate
  - 2 Types of Fermentation – alcoholic fermentation and lactic acid fermentation
    - Alcohol Fermentation – pyruvate is converted to ethanol, releasing CO_2 and regenerating NAD_+ from NADH
    - Lactic Acid Fermentation – pyruvate is reduced by NADH (NAD^+ is formed in the process), and lactate is formed as a waste product
  - Facultative anaerobes can use aerobic respiration if oxygen is present but can switch to fermentation under anaerobic conditions; obligate anaerobes cannot survive in the presence of oxygen

3. Enzymes – see review packet 1 (Biochemistry)

Practice Multiple Choice Questions:

1. An airtight, temperature-controlled glass box containing actively growing tomato plants was placed under a light source. Plastic wrapping that only transmits green light was placed over the box, and two days later air samples from inside the box were collected and analyzed. The most likely change in air quality is
a. an increase in nitrogen (N_2)
b. an increase in carbon dioxide (CO_2)
c. an increase in oxygen (O_2)
d. a decrease in carbon dioxide (CO_2)

2. In photosynthesis, if the input water is labeled with a radioactive isotope of oxygen, ^{18}O, then the oxygen gas released as the reaction proceeds is also labeled with ^{18}O. Which of the following is the most likely explanation?
a. During the light reactions of photosynthesis, water is split, the hydrogen atoms combine with the CO_2, and oxygen gas is released.
b. During the light reactions of photosynthesis, water is split, removing electrons and protons, and oxygen gas is released.
c. During the Calvin cycle, water is split, regenerating NADPH from NADP+, and oxygen gas is released.
d. During the Calvin cycle, water is split, the hydrogen atoms are added to intermediates of sugar synthesis, and oxygen gas is released.

3. The end products of the light-dependent reactions of photosynthesis are
a. ADP, H_2O, NADPH
b. ADP, G3P, RuBP
c. ATP, CO_2, H_2O
d. ATP, NADPH, O_2
e. CO_2, H^+, G3P

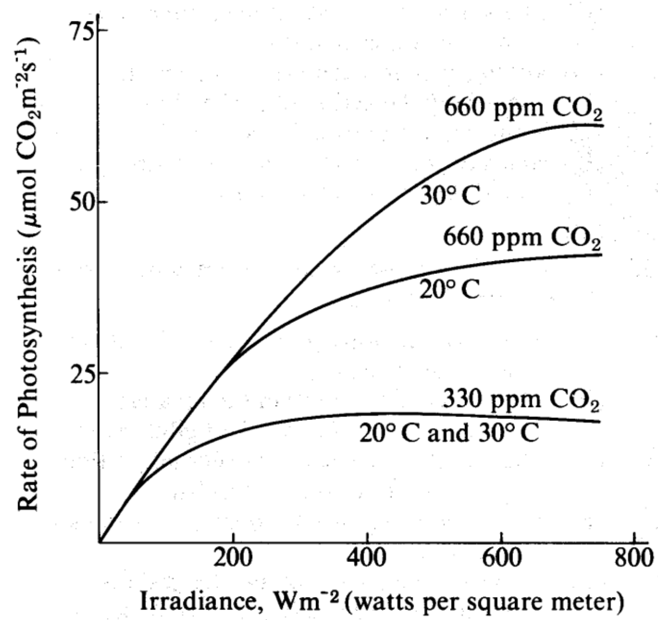
Questions 4 & 5. Frogs of three different species are weighed and the amount of oxygen consumed by each species is determined by placing them in a respirometer for 1 hour. The results of this experiment are listed below.

Species	Average Weight in Grams	Total Cubic Centimeters of Oxygen Consumed in 1 Hour
1	15	0.75
2	11	0.55
3	21	1.05

4. From the information in the table, it is most reasonable to conclude that
a. since all frogs respire through their skin, smaller frogs with smaller surface areas will consume less oxygen per gram of body weight than larger frogs with larger surface areas
b. frogs placed in a warm environment will respire more rapidly than frogs placed in a colder environment
c. each species of frog has its own unique rate of respiration
d. the amount of oxygen consumed per gram of body weight for each species is the same

5. During aerobic cellular respiration, oxygen gas is consumed at the same rate as carbon dioxide gas is produced. In order to provide accurate volumetric measurements of oxygen gas consumption, the experimental setup should include which of the following?
a. A substance that removes carbon dioxide gas
b. A plant to produce oxygen
c. A glucose reserve
d. A valve to release excess water

Questions 6-8. The graph below shows the relationship of photosynthetic rate and irradiance (light intensity) influenced by both temperature and carbon dioxide level.



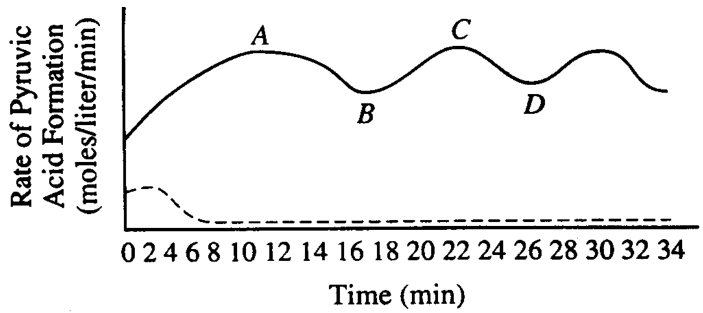
6. According to the graph, the greatest rate of photosynthesis occurs when CO_2 is present at
a. high concentrations and low temperatures
b. low concentrations and high temperatures
c. high concentrations and low irradiance levels
d. high concentrations and high irradiance levels

7. From the data in the graph, which of the following conclusions is most reasonable?
a. The rate of photosynthesis is inversely proportional to light intensity.
b. The rate of photosynthesis at 660 ppm CO_2 is more dependent on temperature than the rate at 330 ppm CO_2.
c. There is no theoretical maximum for the rate of photosynthesis.
d. Attempts to increase the photosynthetic yield in field crops should involve the lowering of CO_2 levels.

8. Which of the following seems most likely from the data?
a. Light produces heat, which causes increases in the rates of photosynthesis.
b. Light causes the saturation of cytochrome oxidase, which then limits the use of CO_2.
c. The photosynthetic rate could be increased further by decreasing the CO_2 concentration.
d. Increasing irradiance levels above 800 Wm^{-2} would have less effect on the rate of photosynthesis than would increasing the CO_2 concentration.

9. Which of the following enzymes is responsible for CO_2 fixation in C3 plants?
a. succinate dehydrogenase
b. RuBP carboxylase
c. hexokinase
d. amylase
e. DNA polymerase

Questions 10-13. A tissue culture of vertebrate muscle was provided with a constant excess supply of glucose under anaerobic conditions starting at time zero and the amounts of pyruvic acid and ATP produced were measured. The solid line in the graph below represents the pyruvic acid produced in moles per liter per minute. ATP levels were also found to be highest at points *A* and *C*, lowest at *B* and *D*. A second culture was set up under the same conditions, except that substance X was added, and the results are indicated by the dotted line.



10. The rate of pyruvic acid formation fluctuates because
a. all glucose has reacted
b. all enzymes have been used up
c. the reaction is accelerated by positive feedback
d. the reaction is affected by negative feedback

11. Which of the following best accounts for the shape of the solid line between points *A* and *D*?
a. After ten minutes the cellular enzymes became ineffective
b. Respiration became uncontrolled
c. ATP acted as an allosteric inhibitor on one or more of the enzymes
d. The measurements of pyruvic acid were unreliable

12. It is most reasonable to hypothesize that, in the breakdown of glucose, substance X is
a. an activator
b. an inhibitor
c. a substrate
d. a coenzyme

13. Which of the following is most likely to result if oxygen is added to the tissue culture?
a. Lactic acid formation will increase
b. For each glucose molecule consumed, more ATP will be formed
c. The levels of ATP produced will decrease
d. Ethyl alcohol will be produced

14. If plants are grown for several days in an atmosphere containing $^{14}CO_2$ in place of $^{12}CO_2$, one would expect to find
a. very little radioactivity in the growing leaves
b. large amounts of radioactive water released from the stomates
c. a large increase in ^{14}C in the starch stored in the roots
d. a large decrease in the rate of carbon fixation in the guard cells
e. an increase in the activity of RuBP carboxylase in the photosynthetic cells

15. During respiration, most ATP is formed as a direct result of the net movement of
a. potassium against a concentration gradient
b. protons down a concentration gradient
c. electrons against a concentration gradient
d. electrons through a channel
e. sodium into the cell

16. On a sunny day, the closing of stomata in plant leaves results in
a. a decrease in CO_2 intake
b. a loss of water from the plant
c. an increase in transpiration
d. an increase in the concentration of CO_2 in mesophyll cells
e. an increase in the rate of production of starch

17. Oxygen consumption can be used as a measure of metabolic rate because oxygen is
a. necessary for ATP synthesis by oxidative phosphorylation
b. necessary to replenish glycogen levels
c. necessary for fermentation to take place
d. required by all living organisms
e. required to break down the ethanol that is produced in muscles

18. All of the following statements are correct about enzymes EXCEPT
a. they enable reactions to occur at a relatively low temperature
b. they remain unchanged during a reaction
c. they raise the energy of activation of all reactions
d. they are often located within the plasma membrane of a cell

19. The role of oxygen in aerobic respiration is
a. to transport CO_2
b. most important in the Krebs Cycle
c. to provide electrons for the electron transport chain
d. as the final H_2 acceptor in the electron transport chain

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6H_2O + 6CO_2 + 38ATP$$

20. The process shown above is
a. reduction and is endergonic
b. reduction and is exergonic
c. oxidation and is endergonic
d. oxidation and is exergonic

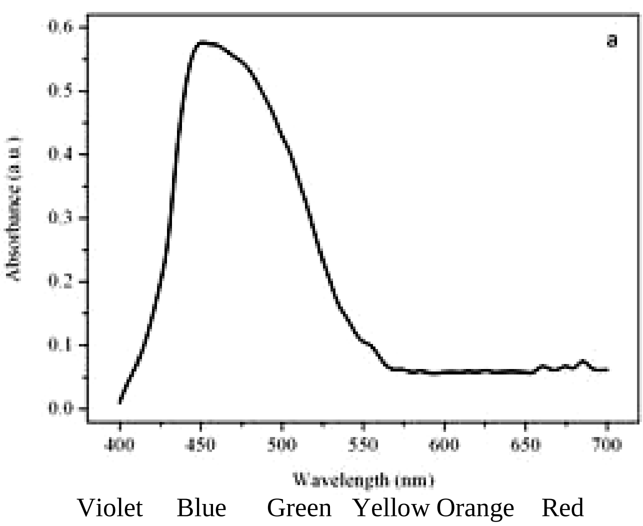
21. Most energy during cellular respiration is harvested during
a. the Krebs cycle
b. oxidative phosphorylation
c. glycolysis
d. anaerobic respiration

22. After strenuous exercise, a muscle cell would contain decreased amounts of ______ and increased amounts of _____.
a. glucose; ATP
b. ATP; glucose
c. ATP; lactic acid
d. lactic acid; ATP

23. The ATP produced during glycolysis is generated by which of the following?
a. the electron transport chain
b. substrate level phosphorylation
c. oxidative phosphorylation
d. chemiosmosis

24. Glycolysis is a complex, enzyme-controlled set of reactions. One of the enzymes at the beginning of glucose is PFK, phosphofructokinase, an enzyme which is allosterically inhibited by ATP. Which of the following statements best explains the importance of the enzyme PFK in glycolysis?
a. PFK inhibits glycolysis when oxygen levels are high
b. PFK enables glycolysis to continue when no oxygen is present
c. PFK inhibits the production of ATP when ATP levels are high
d. PFD enhances the production of ATP when ATP levels are high

25. The graph below shows an absorption spectrum for an unknown pigment molecule. What color would this pigment appear?
a. red
b. orange
c. green
d. blue



Questions 26-32. Indicate which of the following events occurs during
a. light-dependent reactions
b. light-independent reactions

26. Oxygen is released

27. Carbon gets reduced

28. Oxidative phosphorylation

29. ATP is produced

30. Electrons flow through an electron transport chain

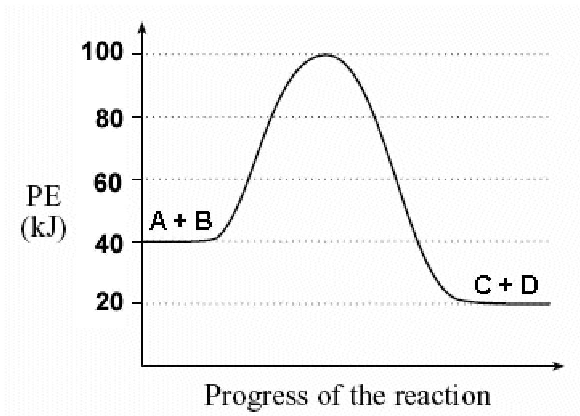
31. Oxidation of NADPH

32. Reduction of $NADP^+$

33. Which of the following probably evolved first?
a. the Krebs cycle
b. oxidative phosphorylation
c. glycolysis
d. the electron transport chain

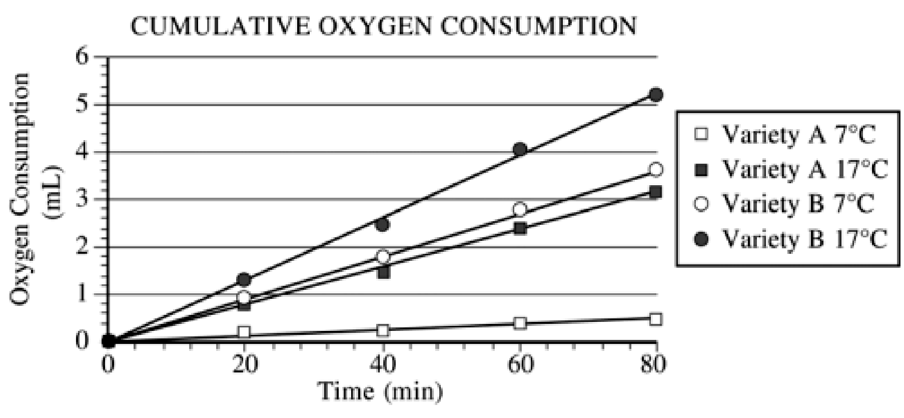
34. Which process of cell respiration is most closely associated with intracellular membranes?
a. oxidative phosphorylation
b. the Krebs Cycle
c. glycolysis
d. substrate level phosphorylation

35. The reaction shown to the right is
a. endergonic because energy is released
b. exergonic because energy is released
c. endergonic because energy is captured
d. exergonic because energy is captured



Practice Long Response Questions:

1. An agricultural biologist was evaluating two newly developed varieties of wheat as potential crops. In an experiment, seedlings were germinated on moist paper towels at 20ºC for 48 hours. Oxygen consumption of the two-day-old seedlings was measured at different temperatures. The data are shown in the graph below.



(a) **Calculate** the rates of oxygen consumption in mL/min for each variety of wheat at 7°C and at 17°C. **Show** your work (including your setup and calculation).
(b) **Explain** the relationship between metabolism and oxygen consumption. **Discuss** the effect of temperature on metabolism for each variety of seedlings.
(c) In a second experiment, variety *A* seedlings at both temperatures were treated with a chemical that prevents NADH from being oxidized to NAD^+. **Predict** the most likely effect of the chemical on metabolism and oxygen consumption of the treated seedlings. **Explain** your prediction.

2. ATP and GTP are primary sources of energy for biochemical reactions.
a. Describe the structure of the ATP or the GTP molecule.
b. Explain how chemiosmosis produces ATP.
c. Describe TWO specific cell processes that require ATP and explain how ATP is used in each process.

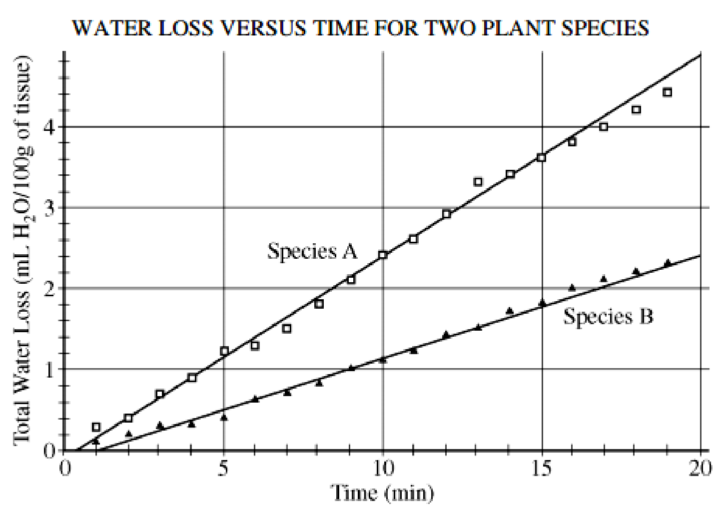
3. A controlled experiment was conducted to analyze the effects of darkness and boiling on photosynthetic rate of incubated chloroplast suspension. The dye reduction technique was used. Each chloroplast suspension was mixed with DPIP, an electron acceptor that changes from blue to clear when it is reduced. Each sample was placed in individually in a spectrophotometer and the percent transmittance was recorded. *(Hint: The percent transmittance is higher through clear liquid than blue liquid!)* The three samples used were prepared as follows:

- Sample 1 – chloroplast suspension + DPIP
- Sample 2 – chloroplast suspension surrounded by foil wrap to provide a dark environment + DPIP
- Sample 3 – chloroplast suspension that has been boiled + DPIP

Time (min)	**Light, unboiled % Transmittance Sample 1**	**Dark, Unboiled % Transmittance Sample 2**	**Light, Boiled % Transmittance Sample 3**
0	28.8	29.2	28.8
5	48.7	30.1	29.2
10	57.8	31.2	29.4
15	62.5	32.4	28.7
20	66.7	31.8	28.5

a. Construct and label a graph showing the results of the three samples
b. Identify and explain the control or controls for this experiment
c. The differences in the curves of the graphed data indicate that there were differences in the number of electrons produced in the three samples during the experiment. Discuss how electrons are generated in photosynthesis and why the three samples gave different transmittance results.

4. The regulation of transpiration is an important homeostatic mechanism in plants.
(a) Under controlled conditions, a transpiration experiment was conducted using two plant species. The data collected are shown in the figure to the right. Using the data from the experiment, **calculate** the rate of transpiration for species A and species B between the times of 5 and 15 minutes (show your work). **Summarize** the difference between the two transpiration rates.



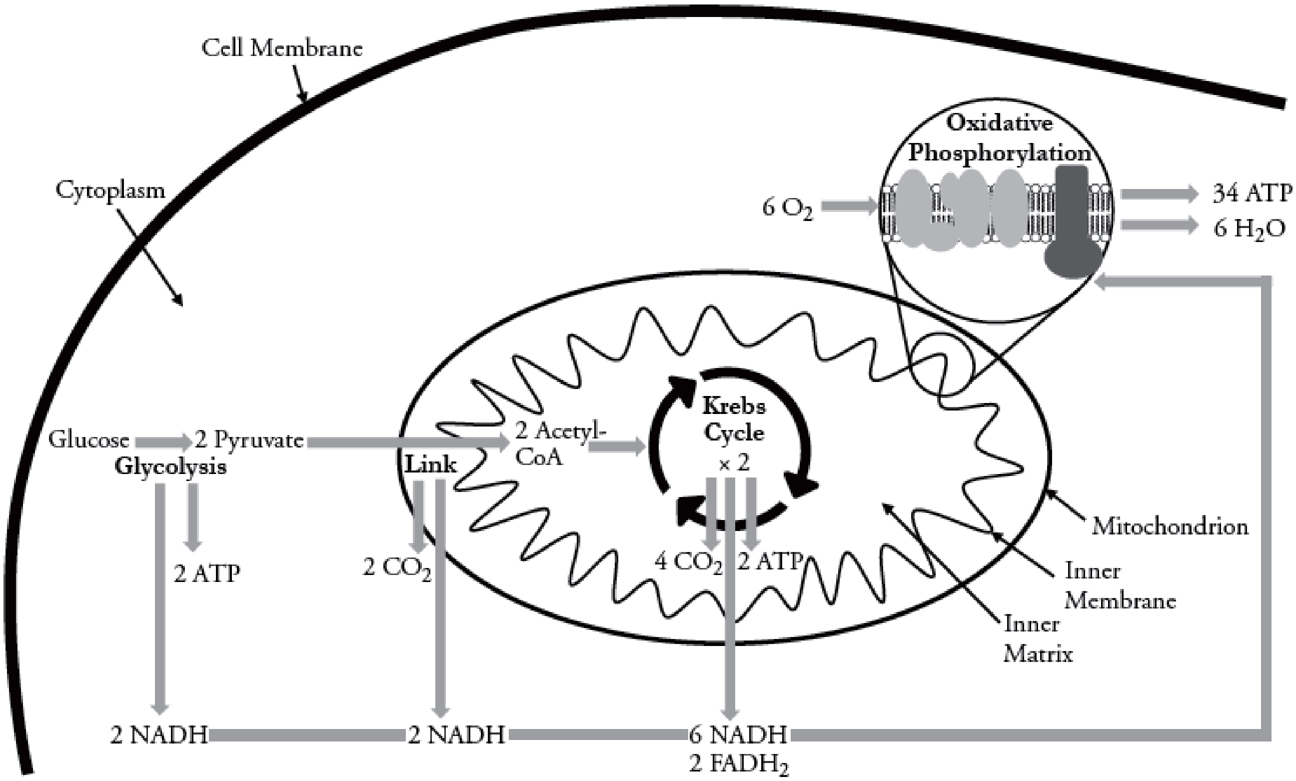
b) **Identify** and **explain** THREE different structural or physiological adaptations that could account for the different transpiration rates of species A and B.
(c) Water potential (Ψ) is described by the following formulas.

$\Psi = \Psi_p + \Psi_s$ & $\Psi_s = -iCRT$

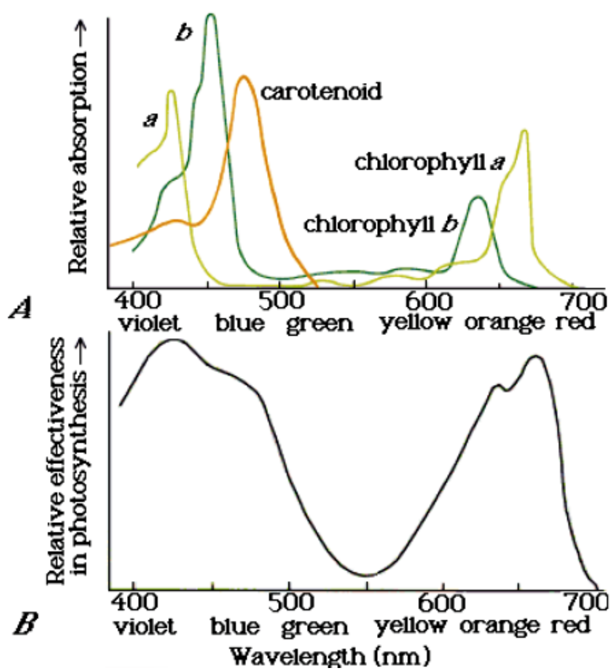
Discuss the variables in both formulas and how they affect water potential.

Thinking Practice Questions:

1. The figure below outlines the process of cellular respiration. Glucose and oxygen are both reactants in this process.
    a. Describe the journey of a single carbon atom from glucose in cellular respiration
    b. Describe the journey of a single hydrogen atom from glucose in cellular respiration
    c. Describe the function of the oxygen molecules in cellular respiration



2. The figures below display the absorption range for several different pigments found in plants (top) and the rate of photosynthesis at varying conditions of wavelength in one plant species (bottom)
    a. What color and wavelength of light is reflected by the plant species tested? How do you know?
    b. What wavelength(s) increase the rate of photosynthesis in the plant species tested? What pigment does this correspond to? How do you know?



3. The figure below outlines the process of photosynthesis. Carbon dioxide and water are both reactants in this process.
   a. Describe the journey of a single hydrogen atom from water in photosynthesis.
   b. Describe the journey of a single oxygen atom from water in photosynthesis.
   c. Describe the journey of a carbon dioxide molecule in photosynthesis.