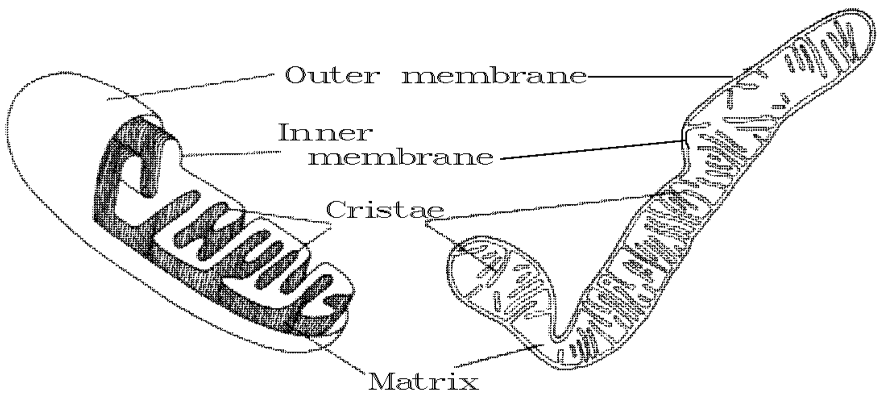
Unit II
Respiration and Photosynthesis

I. Bonds and chemical Energy

A. Respiration defined: the conversion of chemical energy within organic molecules into metabolically usable energy inside living cells.

B. Organelle involved: **Mitochondria**



Mitochondria

II. Oxidation and Reduction

Fuel→Fuel Fragments

$2e^-$ ↘

2H+ ↘

Oxygen →→→ Water

A. Oxidation defined: removal of hydrogen and electrons, and always followed by reduction; usually oxygen is the terminal acceptor.

B. Reduction defined: The acceptance of hydrogen and electrons.

III Fuels and Energy

A. What kind of molecule serve as fuel?

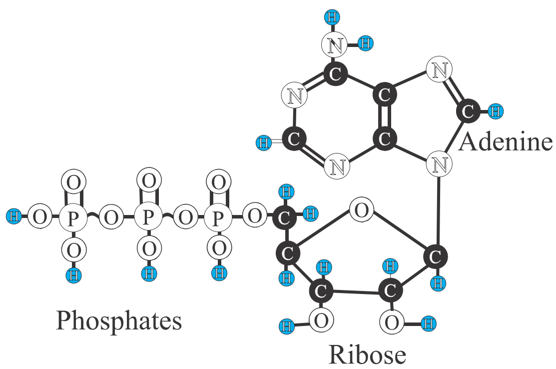
1) any organic constituent of a cell:
carbohydrate - used first
fats - used second
proteins - used last

2) Respiration does not differentiate between expendable and non expendable fuels. Although cell structure is usually used last, respiration will even break down mitochondria.

B. In what form is the energy initially stored?

1) Adenosine triphosphate or
ATP

2) ATP → ADP + P (energy) → ATP



IV. Energy Transfer

A. The shifting of bond energy within the fuel molecule.

1) Rearrangement reactions will often shift the bond energy around to special bonds within the molecule; these become the high energy bonds.

2) This is accomplished through oxidation such as:

dehydrogenation	$\rightarrow H^+$
dehydration	$\rightarrow H_2O$
decarboxylation	$\rightarrow CO_2$
ionization	$\rightarrow e^-$

3) Fuels with low energy bonds go through oxidation and become fuels with high energy bonds.

B. The Process of Energy capture

1)Principle type of high energy bond is the **Phosphate** bond.

2) Phosphate bonds have the capability of storing more energy than is necessary to maintain the bond.

3) A low energy phosphate bond can be converted to a high energy phosphate bond through oxidation.

Fuel-P $\xrightarrow{\text{Oxidation}}$ Fuel~P

$2\ H^+ \searrow$
$2e^-$

4) But before the above can occur, a phosphate must first be added to the fuel; this is called **Phosphorylation.**

Fuel $\xrightarrow{\text{Phosphorylation}}$ Fuel-P $\xrightarrow{\text{Oxidation}}$ Fuel~P

-P $\nearrow$ $\qquad$ $\searrow$ $2H^+$ 2e-

5) Generally the molecule supplying the phosphate is **ATP.**

ATP ------→ ADP + P

Fuel $\xrightarrow{\text{Phosphorylation}}$ Fuel-P → $\xrightarrow{\text{Oxidation}}$ Fuel~P

-P $\nearrow$ $\qquad$ $\searrow$

ATP→ ADP $\qquad$ $2H^+$,$2e^-$

6) The high energy phosphate bond is harvested from the fuel by a molecule of ADP.

ADP + fuel~P → ATP + fuel fragments

6) What happens to the $\mathbf{H^+}$ and $\mathbf{e^-}$ during oxidation?

C. Hydrogen Transport or the Electron Transport System

Fuel-Ⓟ <u>Oxidation</u> ➜Fuel~Ⓟ

↘

H^+, e^- both are release and transferred to electron carriers.

1) These carriers are special molecules which can be ionized to accept electrons (e^-) and then subsequently the protons (H^+).

2) When the carriers receive the electrons and protons they become **reduced** and when they pass them on they become **oxidized**.

e^-, H^+ --➜ Reduced*H_2	Oxidized--➜	Reduced*H_2
↘	↘	↘
Carrier A	Carrier B	Carrier C
↗	↗	↘
Oxidized ---➜	Reduced*H_2	Oxidized --➜$2e^-$,$2H^+$

3) The electrons which have been lost during oxidation are high energy electrons and the carriers take a little bit of energy away from the electrons and with each transfer they use the energy to do work.

4) The work that is accomplished is the coupling of free phosphate with ADP to make ATP.

5) The final electron and hydrogen acceptor is **oxygen.**

$$2H^+ + 2e^- + O_2 \text{------}\rightarrow H_2O$$

6) Therefore, there are two sources of high energy phosphate bonds to make ATP; one from the substrate (or fuel) the other from Oxidation.

Substrate Phosphorylation

and

Oxidative Phosphorylation

7) Of the two, the second, oxidative Phosphorylation is most important. For every two electrons and two protons sent through the oxidative Phosphorylation system, three molecules of ATP are produced (reduced).

D. Aerobic Transport (Oxidative Phosphorylation) Major Carriers

1) Nicotinamide adenine dinucleotide (**NAD**)

Part derived from the nucleotides
Part derived from nicotinic acid (Vit. B)

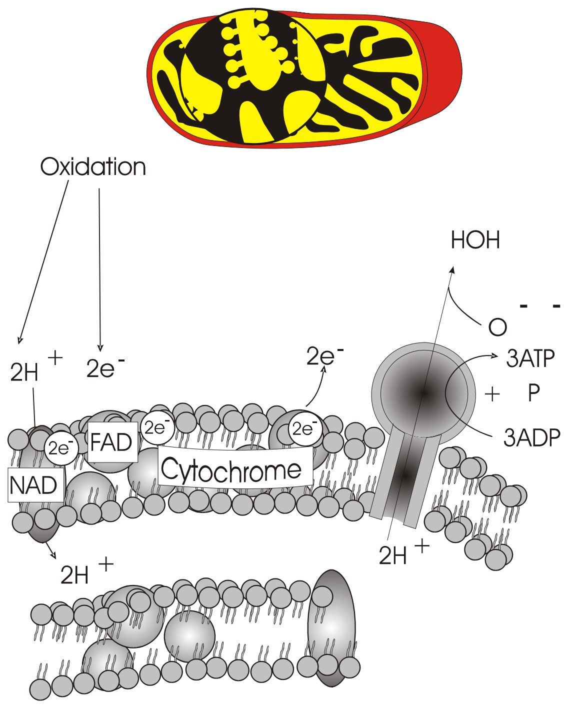
2) Flavin adenine dinucleotide (**FAD**)

Part derived from riboflavin (Vit. B)
Part derived from nucleotides

3) **Cytochrome System**

A complex series of carriers which are protein in nature and have reactive iron atoms that help them transfer electrons.

4) These carriers are located within the inner membranes of the mitochondria.
5) Theory of Chemosmosis (Peter Mitchell,1978)



Chemosmosis theory

a) All of these carriers are located within the inner membranes of the mitochondria.

b) **NAD** (reduced) accepts the electrons first followed by the protons.

c) NAD pumps the protons into the inner membrane space, building a pH gradient between the inner membrane space and the matrix of the mitochondria.

d) Gradually as energy is taken away from the electrons, the Oxidized NAD passes the electrons on **FAD** (now reduced).

e) Some more energy is taken away, and the electrons are passed on to the Cytochrome system.

f) The **Cytochrome system** takes the remaining electron energy away and the electrons move to the F_1 factors.

g) The protons from the inner membrane space move through the **F_1 factors** reuniting with the electrons and with the energy from the protons (pH gradient) a coupling of free phosphate with ADP to manufacture ATP is accomplished.

6) Metabolic Poisons -affect the electron transport chain

a) Lose of Oxygen, no terminal electron acceptor.
b) Cyanide - stops the Cytochrome system

c) Dinitrophenol - make inner membrane leaky to protons.

d) Dietary deficiencies of B vitamins would stop the manufacture of both NAD and FAD.

V. Fuel Combustion

A. The Pattern

1. Go through internal organization and the acquiring of high energy phosphate bonds.

2. Splitting of the fuel until only a single one carbon molecule is left- CO_2.

3. The complete breakdown to CO_2 can only occur in the presence of oxygen.

4.Working backwards from CO_2 to the fuel.

C_1 Carbon Dioxide
↑

C_2 Acetyl (combined with a carrier CoA)
↑

C_3 Pyruvic Acid
↑

C_6 Glucose

5. The organic fuels work their way into the glycolytic pathway.

C_{12} Disaccharide
↓
↓
Glycogen $(C_6)_n$ --→ C_6 Glucose ←----- $(C_6)_n$ Starch
↓
↓
Glycerin C_3 ----→ C_3 Pyruvic Acid ←--- C_3 Lactic Acid
Amino Acids
↓
↓
Alcohols C_2 -----→ C_2 Acetyl CoA ←--- C_2 Fatty Acids
↓
↓
C_1 Carbon Dioxide

6. Glycolysis
   a) Glucose is phosphorylated by a molecule of ATP.

   b) Glucose is again phosphorylated by a second molecule of ATP.

   c) This biphosphorylated six-carbon sugar is split into two three carbon phosphorylated sugars.

   d) Each three-carbon sugar is then phosphorylated with inorganic phosphate, a cheap source of phosphate.

e) An oxidation occurs to each three-carbon sugars yielding one high energy phosphate bond per molecule. Dephosphorylation occurs when two ADPs are used up to yield two ATP's and the subsequent oxidation removes two protons and two electrons yielding six ATP's through oxidative Phosphorylation.

f) A loss of a water molecule per sugar turns the remaining two phosphate bonds into high energy phosphate bonds. Two more molecules of ATP are generated, one per three carbon sugar.

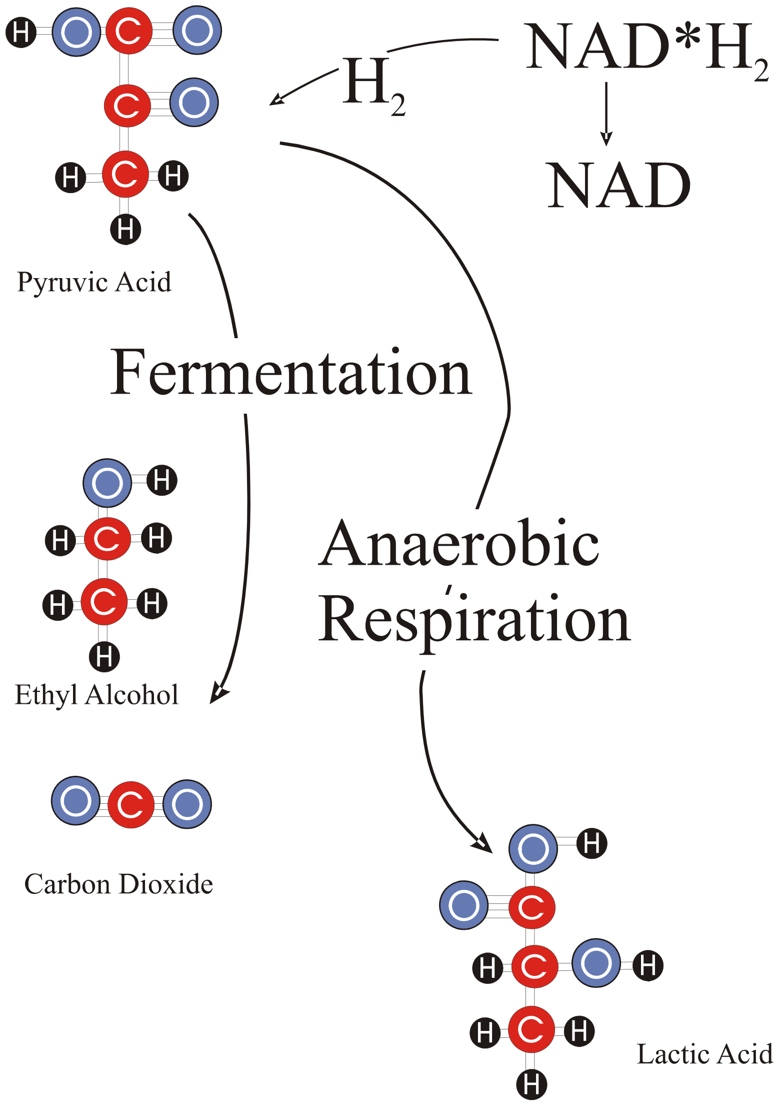
g) The resulting molecules are Pyruvic acid (pyruvate), which marks the end of glycolysis.

6. Transition from glycolysis to Krebs Cycle in Mitochondria.

a) Pyruvic Acid loses carbon dioxide with the aid of the enzyme cocarboxylase.

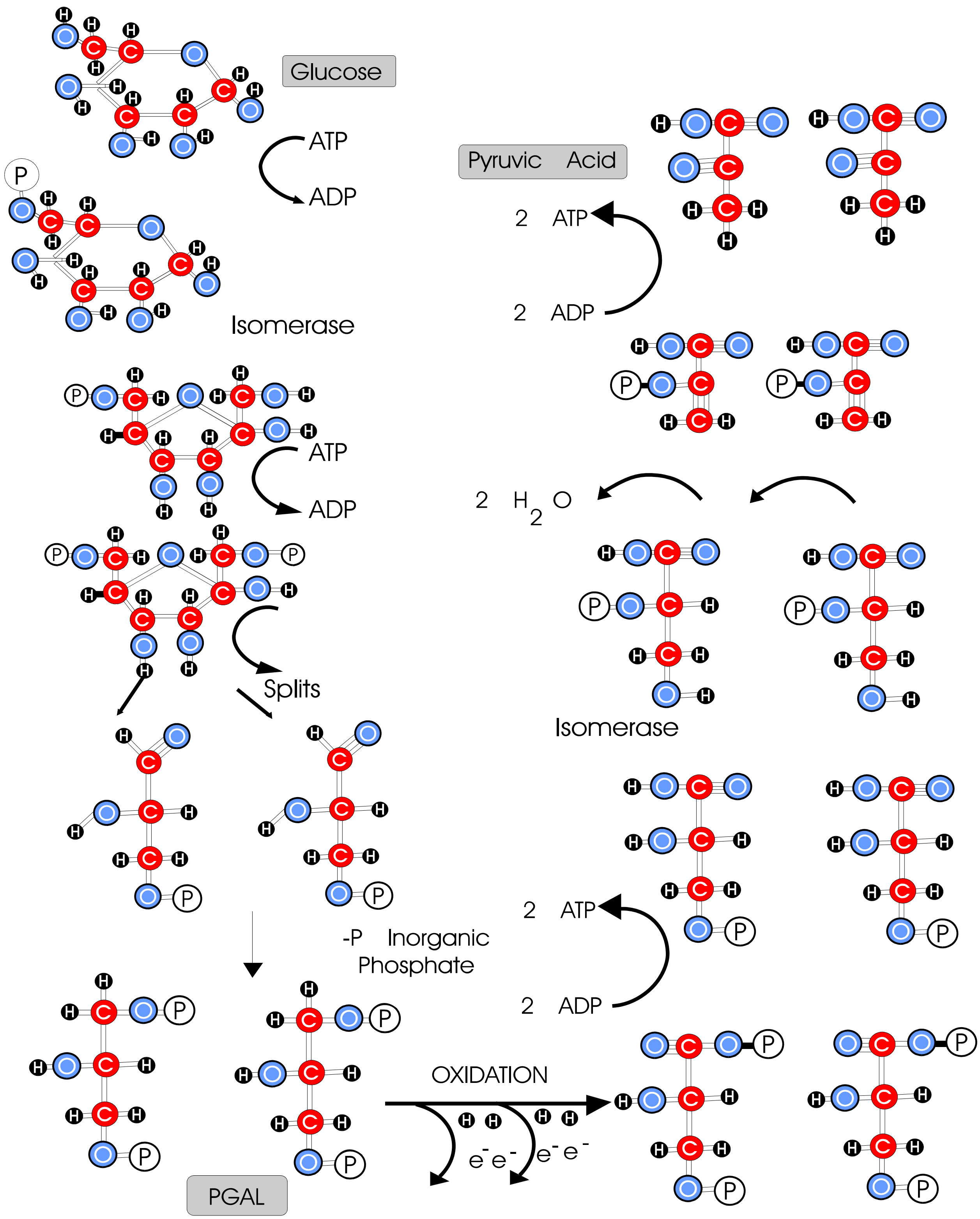
b) Oxidation removes two hydrogen ions (protons) and two electrons per molecule, for a total of six ATPs. (After going through oxidative Phosphorylation).

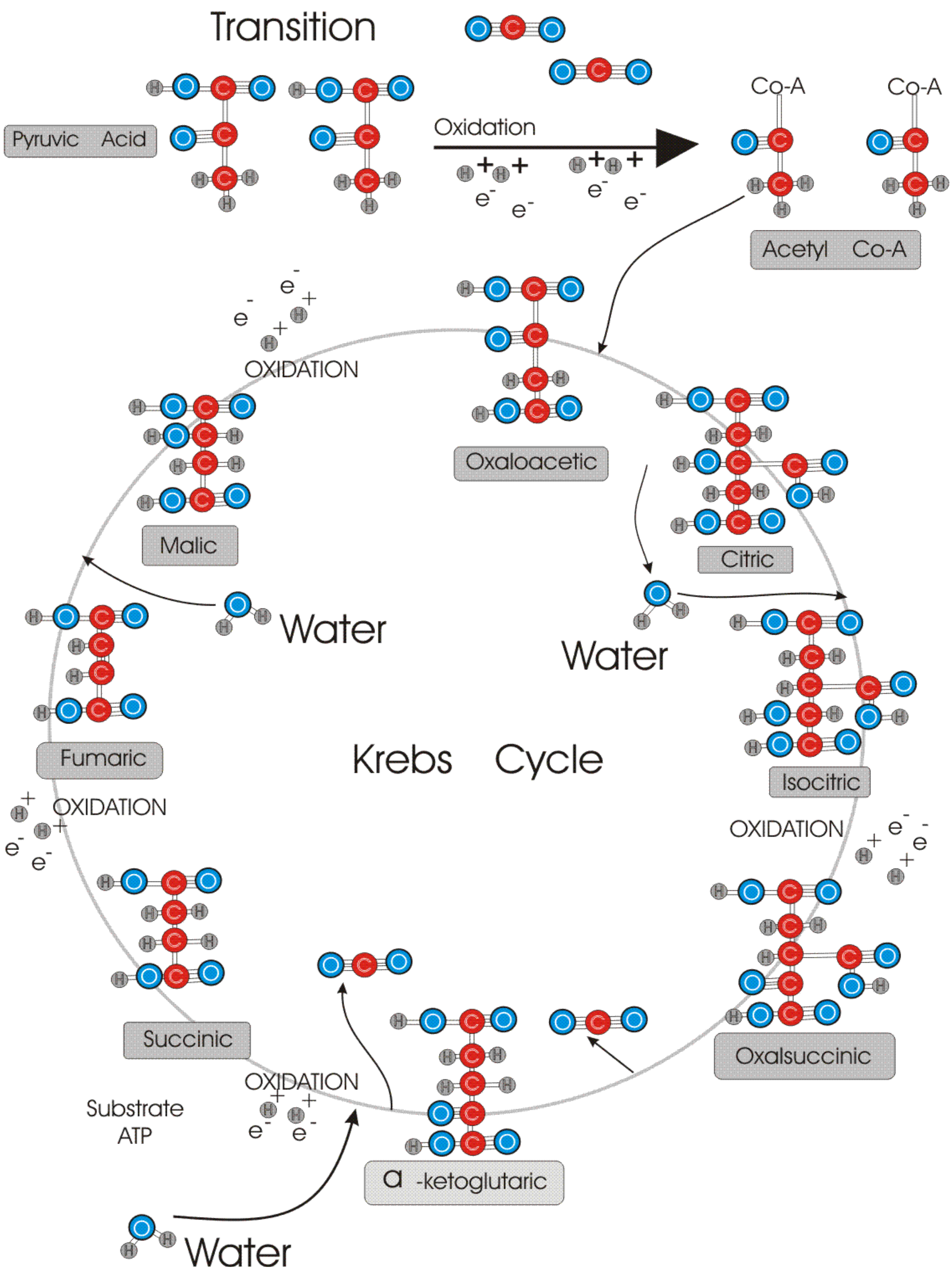
c) The two carbon fragments, Acetyl, is picked up by coenzyme A and transported to the mitochondria. Coenzyme A is a non protein enzyme, largely pantothenic acid, also part of the vitamin B complex.



Anaerobic respiration can result in either fermentation producing ethyl alcohol and carbon dioxide or an aerobic organism going anaerobic producing lactic acid, at least temporarily.

Glycolysis


Glucose
ATP
ADP
P
Isomerase
ATP
ADP
Splits
-P Inorganic Phosphate
PGAL
OXIDATION
e⁻ e⁻ e⁻ e⁻
2 ATP
2 ADP
2 H_2O
Isomerase
2 ATP
2 ADP
Pyruvic Acid



Transition
Pyruvic Acid
Oxidation
Co-A
Co-A
Acetyl Co-A
Oxaloacetic
Citric
Water
Isocitric
OXIDATION
Oxalsuccinic
α -ketoglutaric
OXIDATION
Substrate
ATP
Water
Succinic
OXIDATION
Fumaric
Water
Malic
OXIDATION
Krebs Cycle

7. Krebs Cycle Within the Mitochondria

a) A single Acetyl is picked up by a four-carbon carrier molecule to become citric acid.

b) After rearrangement, the six carbon molecule undergoes high energy oxidation, removing two protons and electrons, three ATPs are produced.

c) After rearrangement, cocarboxylase removes a single carbon dioxide.

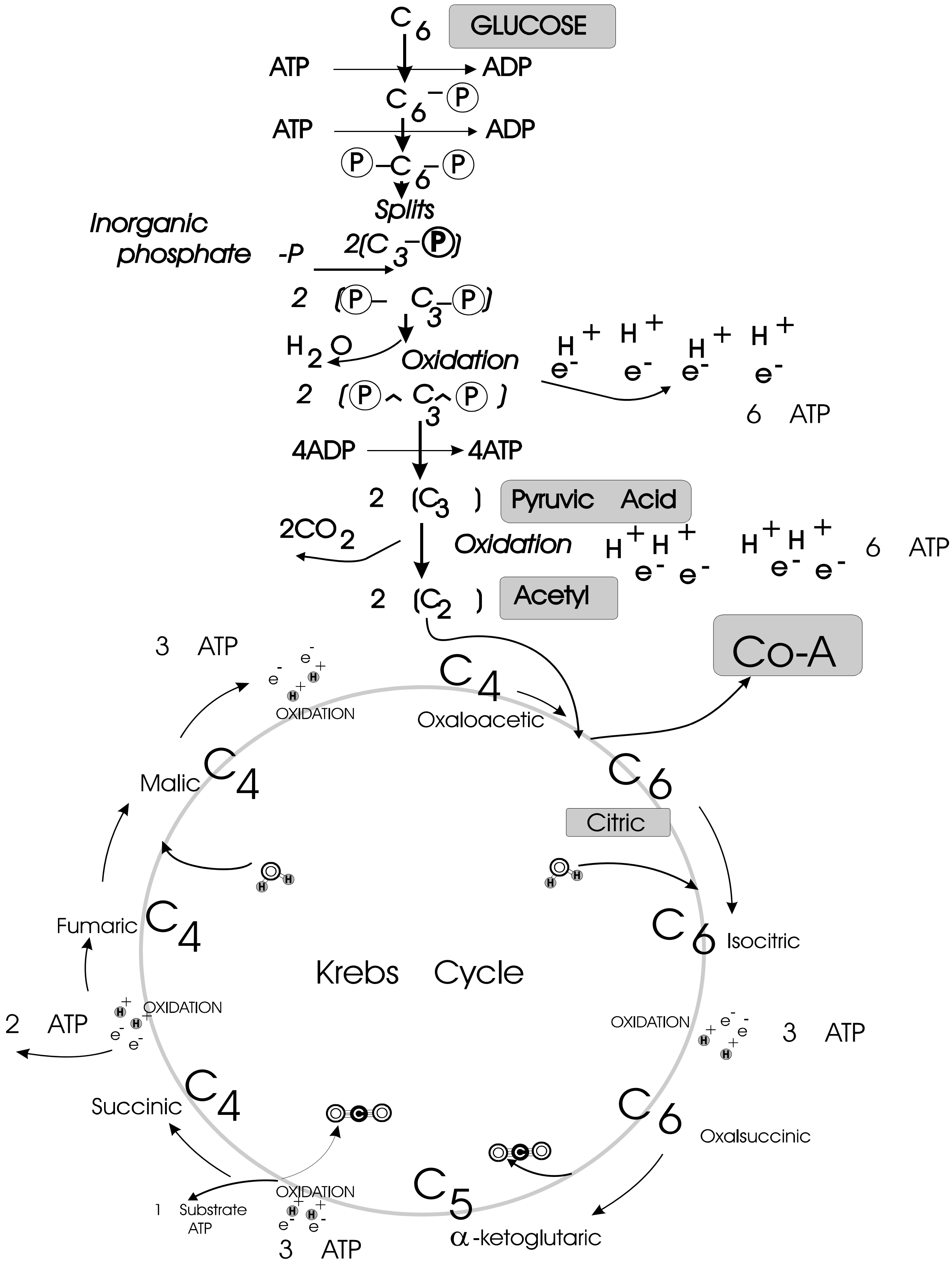
d) The new molecule is a five-carbon molecule, in which several things happen.

1) Substrate dephosphorylation, one ATP is generated.
2) Carbon dioxide is removed.
3) A second high energy oxidation occurs removing two more protons and electrons and three ATPs are produced.

e) The new molecule is now a four-carbon molecule. A low energy oxidation occurs removing two protons and two electrons, only two ATP's are produced.

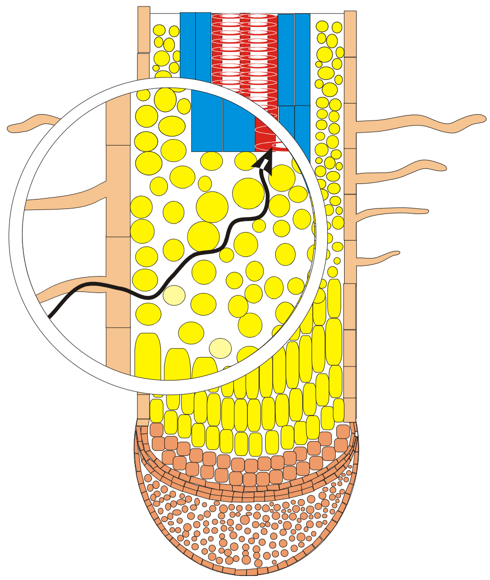
f) After rearrangement, a fourth and final oxidation occurs (high energy) producing three ATPs.

g) This must be repeated again for the second Acetyl molecule, the total ATP for the Krebs Cycle is 24.



C_6 GLUCOSE
ATP ADP
C_6–Ⓟ
ATP ADP
Ⓟ–C_6–Ⓟ
Splits
Inorganic phosphate -P
2[C_3–Ⓟ]
2 [Ⓟ– C_3–Ⓟ]
H_2O
Oxidation
H+ H+ H+ H+
e- e- e- e-
2 [Ⓟ^C_3^Ⓟ]
6 ATP
4ADP 4ATP
2 (C_3) Pyruvic Acid
$2CO_2$
Oxidation
H+ H+ H+ H+
e- e- e- e-
6 ATP
2 (C_2) Acetyl
Co-A
3 ATP
OXIDATION
C_4 Oxaloacetic
C_6 Citric
Malic C_4
C_6 Isocitric
Krebs Cycle
Fumaric C_4
2 ATP
OXIDATION
OXIDATION
3 ATP
Succinic C_4
C_6 Oxalsuccinic
1 Substrate ATP
OXIDATION
C_5
α-ketoglutaric
3 ATP

VI Plant Nutrition



1. Absorption

A. Carbon dioxide is taken directly from the air into the leaf.

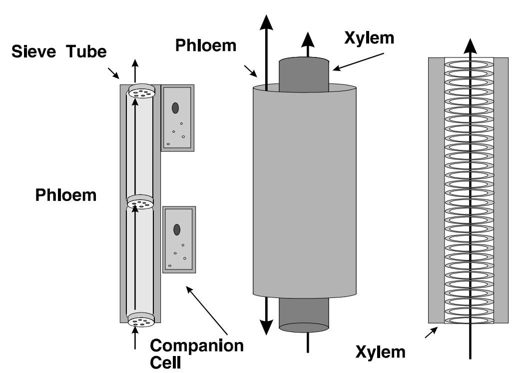
B. Minerals such as nitrates, phosphate, chloride, potassium, copper, calcium, magnesium, and iron, from the soil, are taken in as ions into the roots.

C. Osmosis from soil through special root hairs in the roots delivers the nutrients into the interior.

D. Active transport may be required in some environments due to the limited or excessive levels of salts in the soils.

E. The combination of these above forces generates what is known as **root pressure**.

2. Transport



A. Xylem cells are thick walled cells which are dead when they are functional. The end wall of each cell disintegrates to allow a continuous column of water from root to leaf, held in place by water's adhesive and cohesive force. The combined pressure is called capillary pull. Water and the ionic salts are the primary materials transported through the xylem.

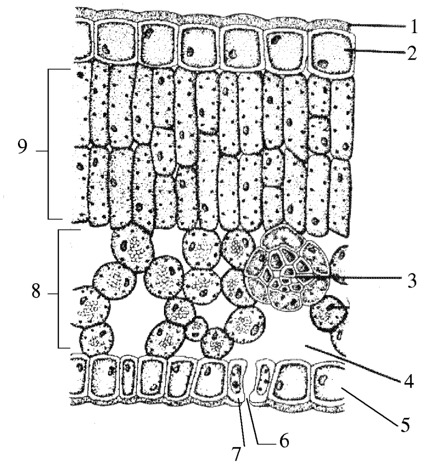
Leaves also aid in the movement of water by their connection with the water column. This drawing force is created when the water releases a fine fog of water through special pores on their surfaces called stomata. This force is called **transpiration**.

B. Phloem cells on the other hand are live cells when functional. They consist of two parts, an elongate sieve tube and the controlling companion cell. The transport through these cells is governed by diffusion. Products of photosynthesis and carbohydrate metabolites are the primary materials transported.

3. Photosynthesis

B. Leaf Structure

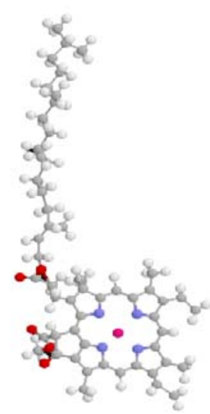
Cuticle
epidermis
palisade layer
spongy layer
air spaces
stomata
guard cells
Vascular cylinder



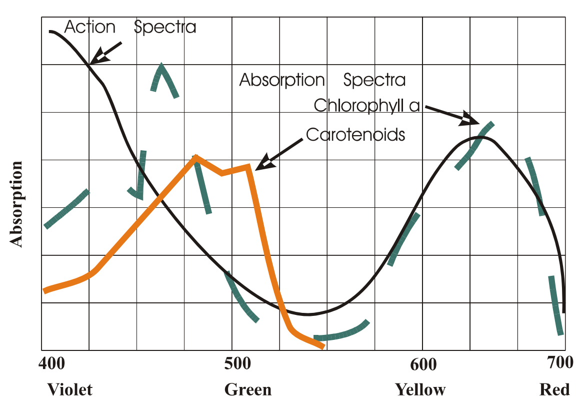
C. Nature of chlorophyll

1) Antennae molecules

2) Light Absorption



3) Action Spectra



D. Photosynthesis

Light Reaction

Noncyclic Photophosphorylation

(1) Light activates both chlorophyll A's Photosystem I and Photosystem II and split water (photolysis).

(2) Electrons leave Photosystem II and are transported through a number of electron carriers and pass to Photosystem I.

(3) Electrons activate electron transport system pumping protons into Thylakoid membrane.

(4) Protons generate the pH gradient needed to couple phosphate to ADP by passing through CF_1 factors.

(5) Photosystem I electrons pass on to NADP to energize the molecule to pick up a proton.

(6) Photolysis results in water splitting into three components: electrons, protons, and atomic oxygen.

(7) Electrons from photolysis replace the electrons lost from Photosystem II.

(8) Protons from photolysis are picked up by NADP after being reduced by an electron.

Cyclic Photophosphorylation

(1) Electrons are passed from Photosystem I to the electron carriers pumping protons into the thylakoid space and when release through the CF_1 factors, generating ATP.

(2) The saturation of NADP with protons is the controlling factor to switch Photosystem I from noncyclic to cyclic Photophosphorylation.

Photolysis

Involves the splitting of water by light into protons, electrons and free atomic oxygen. Twelve molecules of water are used in all. Six water molecules are used to generate eighteen molecules of ATP and then these six waters are reformed. Six molecules of water are needed to supply the protons and electrons for the glucose molecule being formed. These six water molecules are not reformed because of the loss of protons, the remaining atomic oxygen combines with other atomic oxygen to form molecular oxygen.

Light Independent Reaction

(1) The Calvin Cycle takes place in the stroma of the chloroplast.

(2) The Cycle contains a number of carrier molecules which preform certain functions in the Carbon Fixation process.

(3) The Cycle begins when five three-carbon sugars are left in the cycle. (PGAL).

(4) These five three-carbon sugars reorganize and change through a complicated series of reactions resulting in three five-carbon sugars remaining. This sugar is called Ribulose phosphate.

(5) Each of these three sugars is phosphorylated by a molecule of ATP (three in all) resulting in a double phosphorylated sugar (Ribulose bisphosphate).

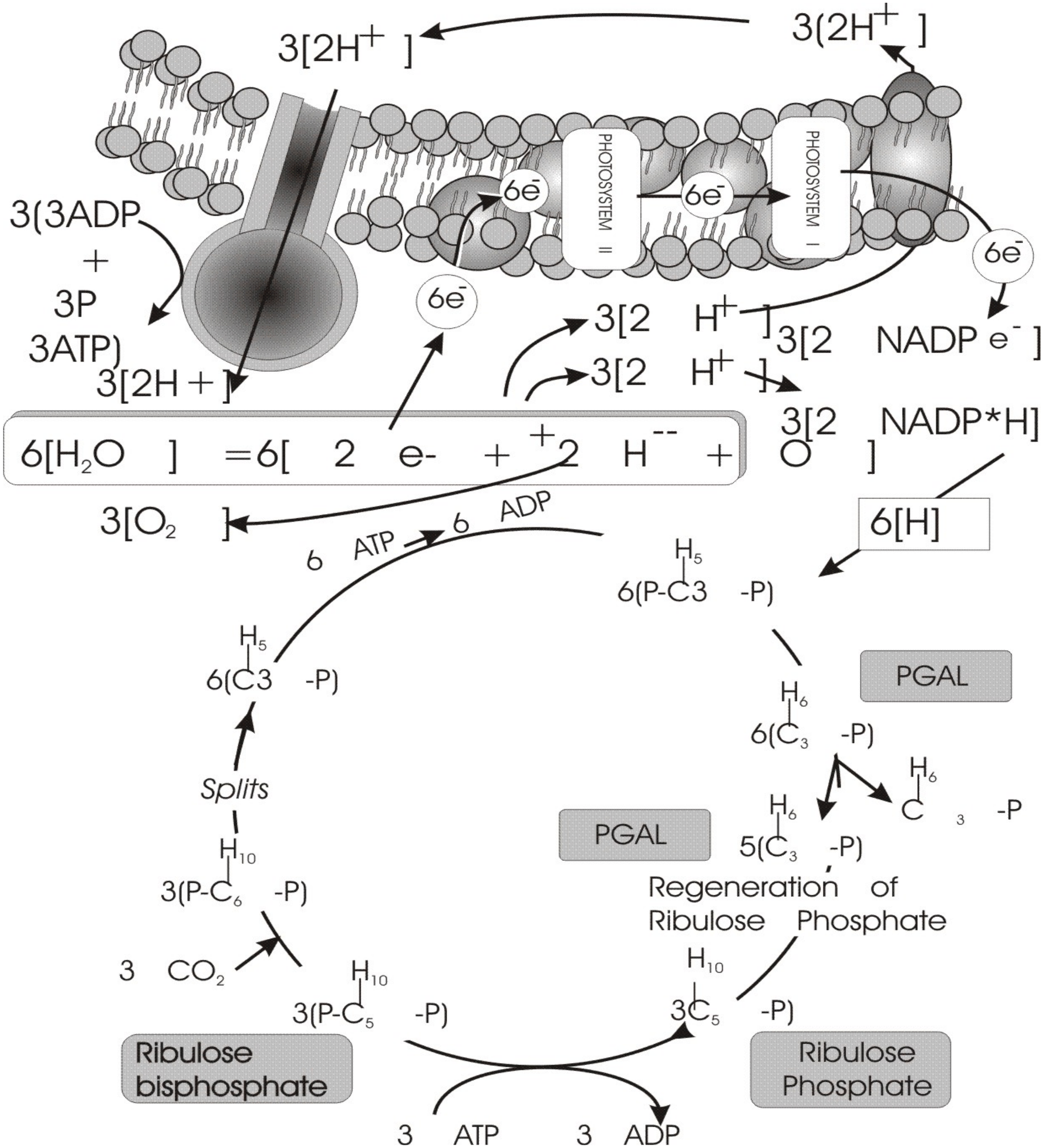
(6) At this point, three molecules of Carbon dioxide are incorporated into the three ribulose bisphosphate molecules (one per ribulose).

(7) These new six carbon sugars immediately break down into two, three-carbon sugars, six in all.

(8) Each of the six three-carbon sugars is phosphorylated by a molecule of ATP (six ATPs).

(9) Six Nicotinamide dinucleotide phosphates (NADP), the hydrogen transport system, bring a proton to each of the six three-carbon sugars.

(10) The end of one cycle leaves six, three carbon sugars (PGAL) and the cycle only needs five PGALs to run. One PGAL is released. The cycle repeats a second time from step three on the previous page until two PGALs are surplus. These two PGALs are then combined into one glucose molecule, and the cycle is now complete.


3(2H+]
3[2H+]
PHOTOSYSTEM II
PHOTOSYSTEM I
6e-
3(3ADP
+
3P
3ATP)
3[2H +]
3[2 H+]
3[2 NADP e-]
3[2 H+]
3[2 NADP*H]
6[H2O] =6[2 e- + 2 H+ + O]
3[O2]
6 ATP 6 ADP
6[H]
6(P-C3 -P)
PGAL
6(C3 -P)
Splits
3(P-C6 -P)
3 CO2
3(P-C5 -P)
Ribulose bisphosphate
3 ATP 3 ADP
PGAL
6(C3 -P)
5(C3 -P)
C3 -P
Regeneration of Ribulose Phosphate
3C5 -P)
Ribulose Phosphate

Review Questions.

1. What happens to the water molecules when it undergoes photolysis.

2. What is the procedure to separate out a mixture of unknown pigments such as chlorophyll?

3. What element is in the center of the chlorophyll molecule?

4. What are the main energy products of respiration?

5. In what kind of organisms does the process of respiration occur?

6. What are the three parts of respiration?

7. What are the terms which address loss of hydrogen, carbon dioxide, water, electrons called?

8. What is the gain of atoms or electrons called?

9. What is the beginning product of respiration?

10. Why are two phosphorylations required to start respiration?

11. What is the end product of glycolysis?

12. Be able to label an unlabeled diagram of respiration.

13. What is the end product of anaerobic respiration?

14. What is the end product of fermentation?

15. How many PGAL molecules are needed to generate how many Ribulose monophosphate?

16. Be able to label an unlabeled diagram of Chemosmosis.

17. Name the three carriers in oxidative Phosphorylation.

18. Which of the three carriers can handle protons and which can handle electrons.

19. Name the metabolic poisons and which system they affect.

20. Which is more efficient? Aerobic or anaerobic respiration?

21. How many molecules of ATP are generated in each of the three parts of respiration?

22. What would happen to sugar metabolize in human oxygen depleted muscles?

23. What is the difference between substrate and oxidative Phosphorylation?

24. What part of respiration occurs in the cytoplasm what part occurs in the mitochondria?

25. What generates ATP in the process of Chemosmosis?

26. Where in the mitochondria does the proton buildup occur?

27. Name the substructures of mitochondria and relate them to Chemosmosis.

28. What happens to 60% of the energy released in respiration but not trapped in ATP?

29. How many ATPs' are produced in transition, glycolysis, and Krebs?

30. Which wavelengths are used in photosynthesis?

31. The release of oxygen in photosynthesis is derived from what input material?

32. How many molecules of NADP are needed to supply hydrogens to the Calvin cycle?

33. How many water molecules are used up to manufacture a single glucose molecule?

34. How many ATPs' are used in the Calvin cycle to manufacture a single glucose?

35. What is the relationship of phloem and xylem in the stem cross section?

36. Which of the two: phloem or xylem is living when functional?

37. Which vascular cells take the products of photosynthesis and distribute them throughout the plant?

38. What are the processes that represent root absorption?

39. Where in the chloroplasts are the protons pumped to generate ATP?

40. Be able to label an unlabeled photosynthesis diagram.

41.The energy of light converted into what form of chemical energy?

42. What shifts noncyclic Photophosphorylation to cyclic Photophosphorylation?

43. Be able to label an unlabeled leaf cross section.

44. Know the function(s) of each leaf cell layer.

45. What is the product of one rotation of the Calvin cycle?

46. How many cycles are needed to produce a glucose molecule from the Calvin cycle?

47. What is the significance of oxygen in respiration?

48. What is the function of coenzyme A?

49. How many ATP’s are produced per cycle of the Krebs?

50. How many carbons in acetyl, pyruvic acid, lactic acid and carbon dioxide?

51. For each pair of protons and electrons how many ATPs are produced?

52. What is the difference between action spectra and absorption spectra?

53. How many phosphorylations occur per rotation of the Calvin Cycle?