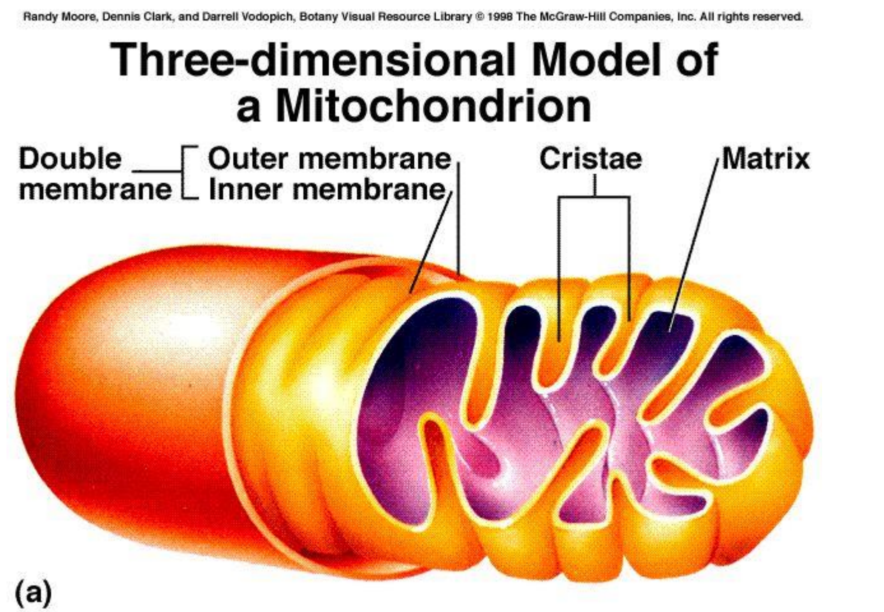
Respiration

- Respiration Is the Means to Turn Carbs into Usable Chemical energy (ATP) for many other Plant Reactions including PS
- All Living Plant and Animal Cells Carry out Respiration
- Respiration Occurs
  - At same Time as PS
  - During the Night
  - In Developing and Ripening Fruit
  - In Dormant Seeds

Mitochondria

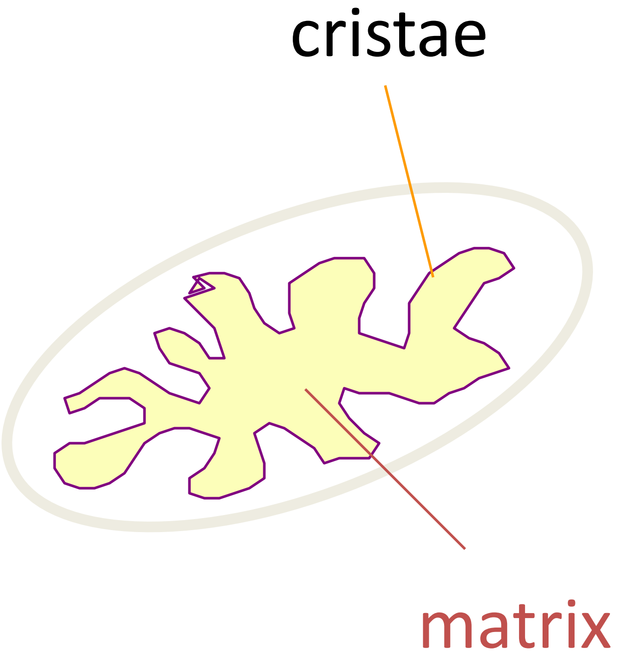
- Occurs in Mitochondria of Cells
- Mitochondria are membrane-enclosed organelles distributed through the cytosol of most eukaryotic cells. Their main function is the conversion of the potential energy of food molecules into ATP



http://www.science.siu.edu/plant-biology/PLB117/JPEGs%20CD/0077.JPG

Mitochondria

- Spherical to oval
  - about 1 micron diameter
  - # mito./cell increases with demand for respiration; 300-1000/root tip cell
- Double-membrane bound
  - outer smooth
  - inner folds forming cristae
    - controls movement in/out
    - site of electron transportm
- Matrix
  - soluble phase
  - site of TCA cycle; DNA, RNA, ribosomes



WHY IS RS NECESSARY?

PLANTS NEED ENERGY TO PERFORM MANY ESSENTIAL FUNCTIONS OF LIFE:

GROWTH,

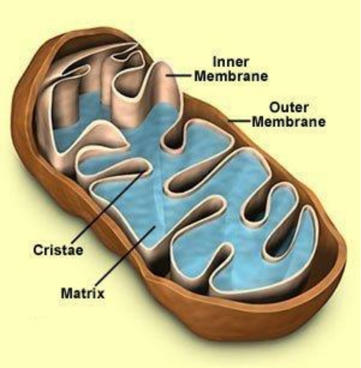
REPAIR,

NUTRIENT MOVEMENT,

REPRODUCTION, &

NUTRIENT TRANSPORT.

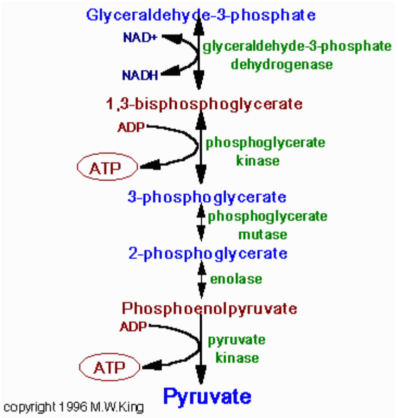
Aerobic Respiration



- Requires Oxygen
- Main Type of Respiration that Occurs in most Situations in Plants and Animals
- Involves Complete Breakdown of Glucose back to CO_2 and Water
- Not all of the Energy in Glucose Is Converted to ATP Formation
  - Only about 40% Efficient
  - Extra Energy Is Given off as Heat
    - In Plants, Heat Quickly Dissipates
    - For Animals, Heat Is Retained to Hold Body Temperature

http://www.kathleensworld.com/mitochondria.jpg

3 Main Respiration Steps



1. Glycolysis
   - Breakdown of Glucose to a 3-Carbon Compound Called Pyruvate
   - Occurs in Cytosol
   - Some ATP and NADH Are also Formed
     – Storage Energy Molecules
   - NADH Is Formed from NAD
   - Similar Type of Energy-Storing Rx as NADP + H2 → $NADPH_2$
     – NAD + H → NADH

http://www.med.unibs.it/~marchesi/glycpth2.gif

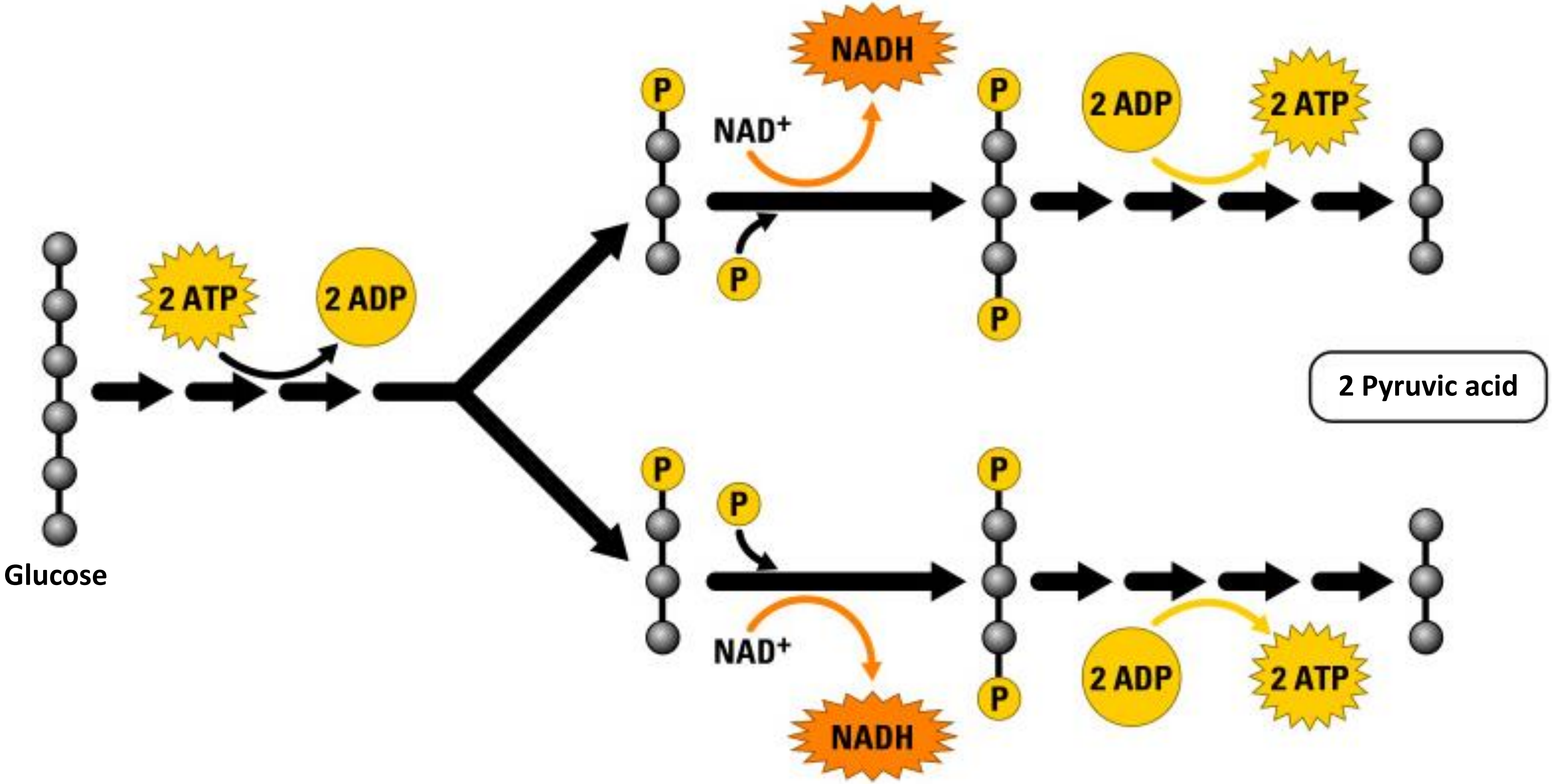
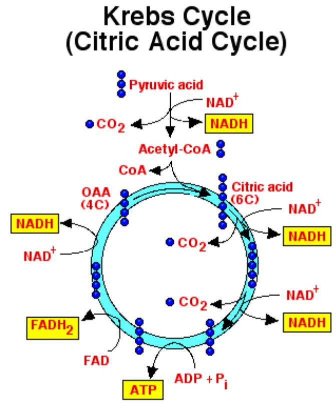

Glucose
2 ATP
2 ADP
P
NAD+
NADH
P
2 ADP
2 ATP
P
P
P
NAD+
NADH
P
2 ADP
2 ATP
P
P
2 Pyruvic acid

Figure 6.8



Respiration Steps

2. Krebs Cycle
   - 'Tricarboxylic acid Cycle (TCA Cycle)'
   - 'Citric Acid Cycle'
   - Occurs in Mitochondrial Matrix
   - A Cyclic Series of Rxs that Completely Break down Pyruvate to CO_2 and Various Carbon Skeletons
   - Skeletons Are Used in other Metabolic Pathways to Make various Compounds
     - Proteins
     - Lipids
     - Cell Wall Carbohydrates
     - DNA
     - Plant Hormones
     - Plant Pigments
     - Many other Biochemical Compounds
   - The Step where CO_2 Is Given off by the Plant
   - 10 NADH Are Generated

http://www.sp.uconn.edu/~bi107vc/images/mol/krebs_cycle.gif

- In the Krebs cycle, pyruvic acid from glycolysis is first “prepped” into a usable form, Acetyl-CoA

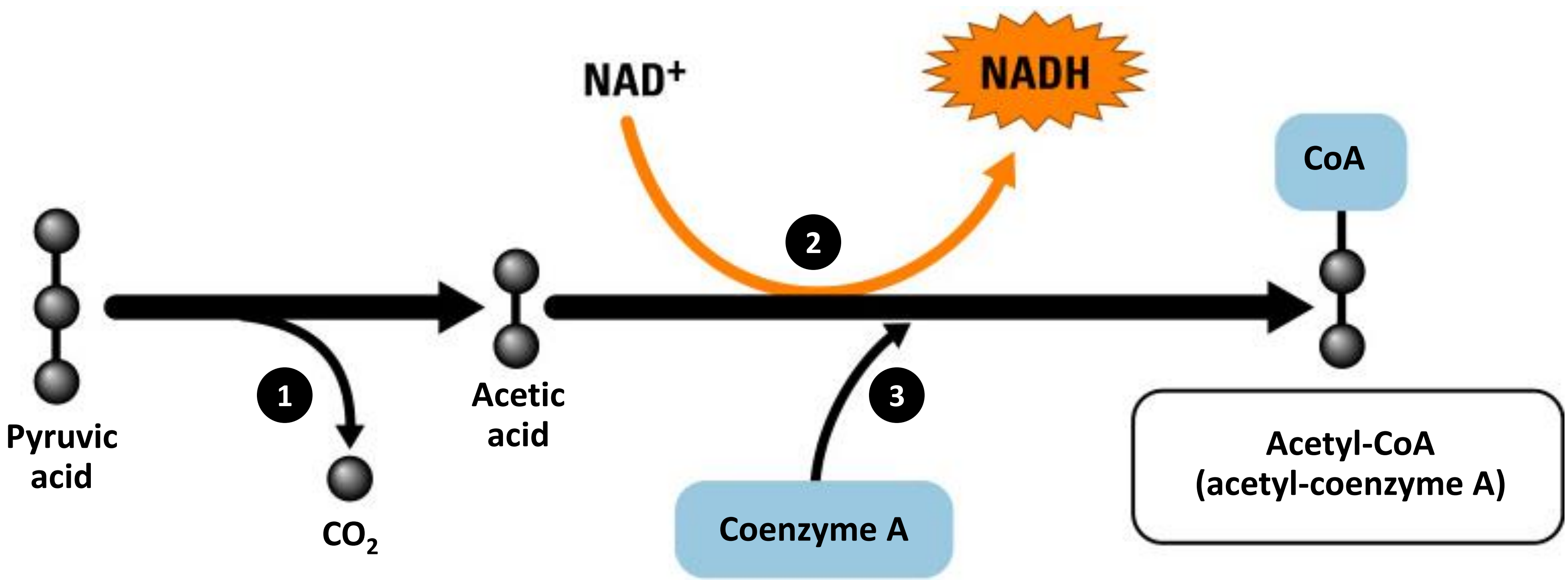
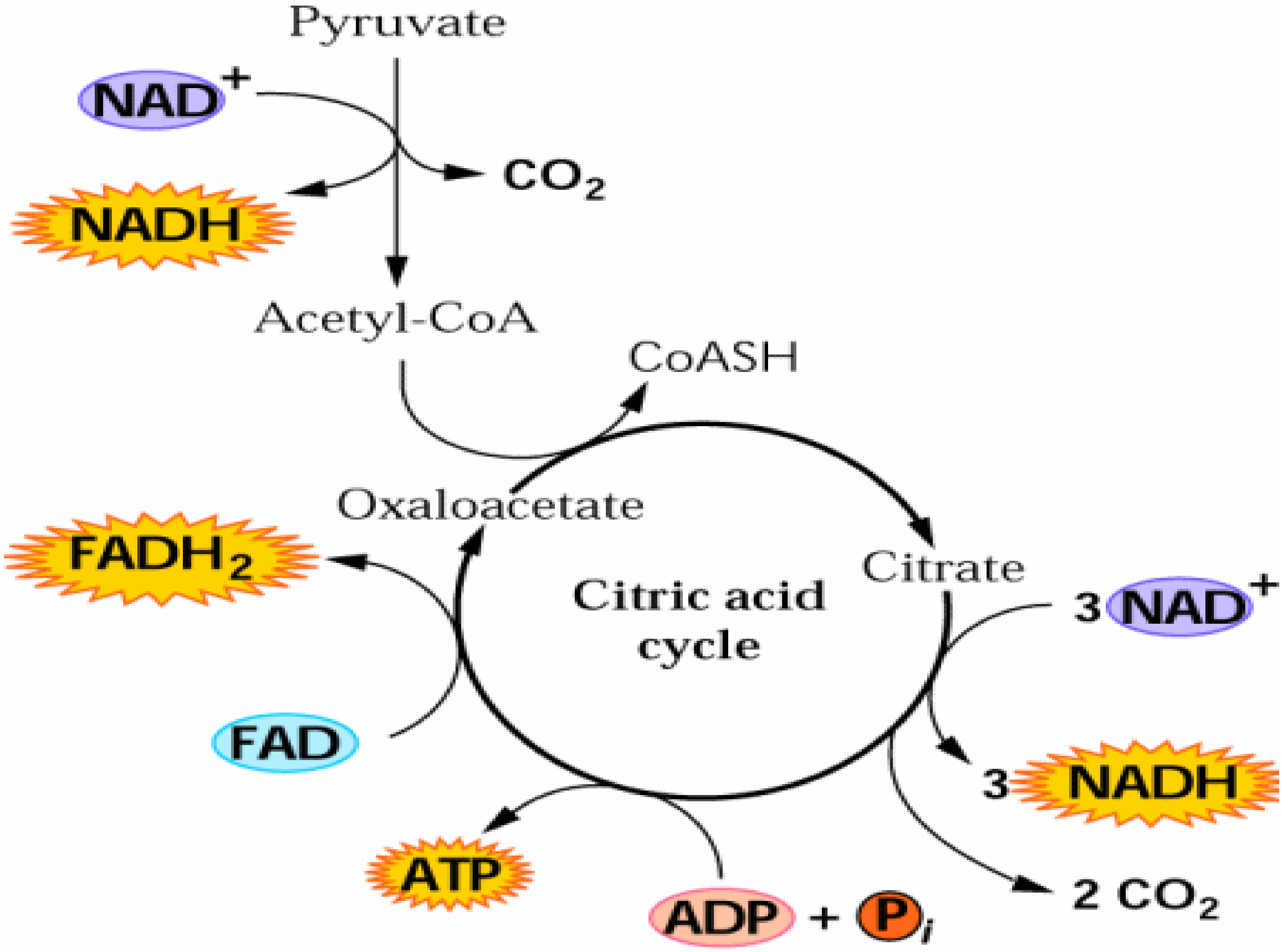


Figure 6.10


Pyruvate
NAD+
CO2
NADH
Acetyl-CoA
CoASH
Oxaloacetate
Citrate
Citric acid cycle
FADH2
3 NAD+
FAD
3 NADH
ATP
ADP + Pi
2 CO2

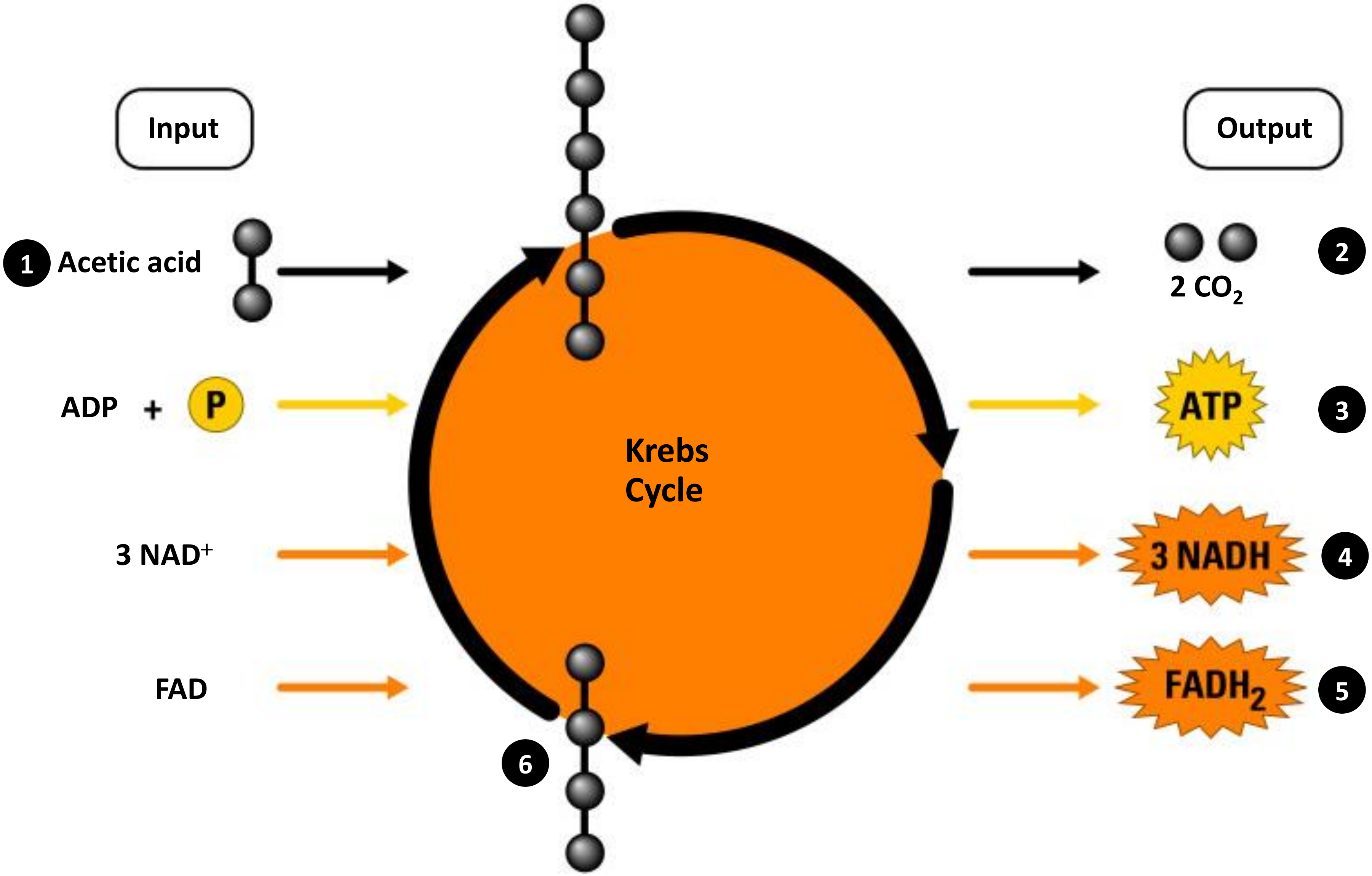
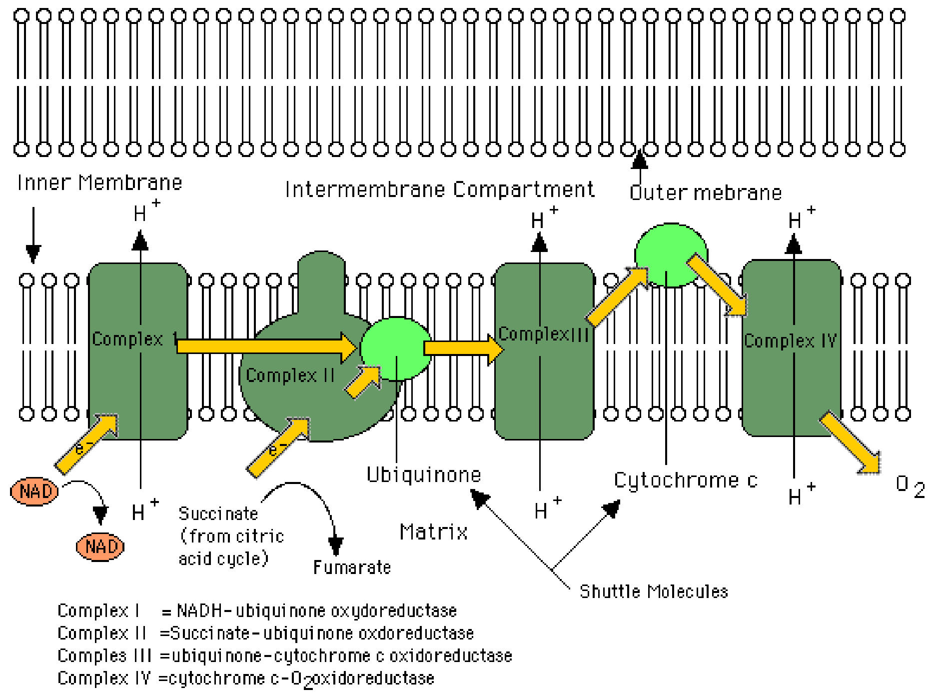

Input
Output
1 Acetic acid
2
2 CO_2
ADP + P
ATP
3
3 NAD^+
3 NADH
4
FAD
$FADH_2$
5
6
Krebs Cycle

Figure 6.11

Respiration Steps

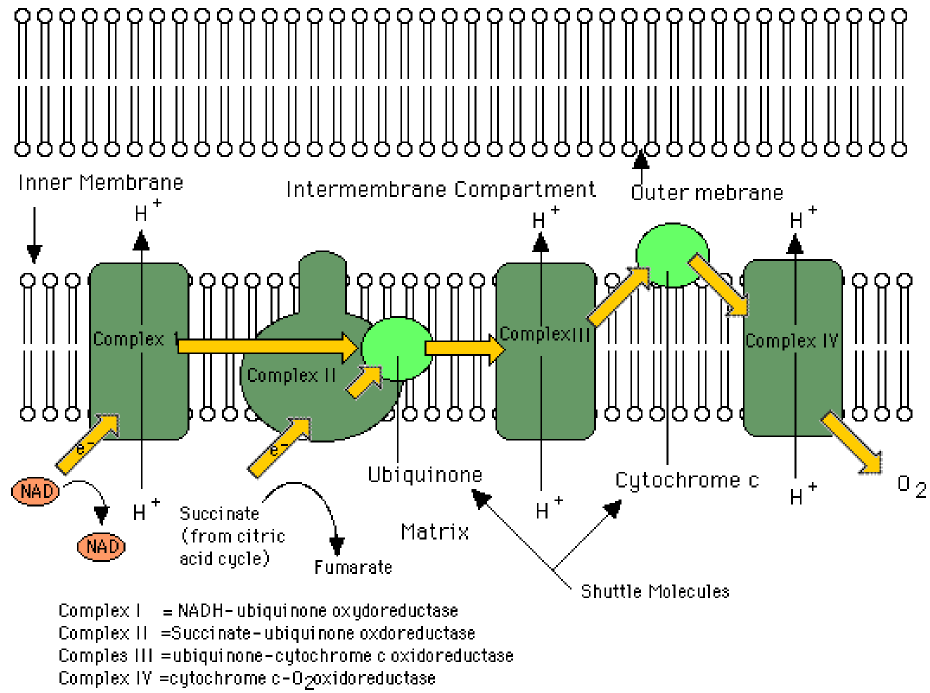
3. Electron Transport Chain
   - 'Oxidative Phosphorylation'
   - Series of Proteins in the Mitochondria Helps Transfer Electrons (e-) from NADH to Oxygen
     - Releases a Lot of Energy
   - Occurs on Mitochondrial Inner Membrane (Proteins Bound to Membrane)



http://www.uccs.edu/~rmelamed/MicroFall2002/Chapter%205/ch05.htm

Respiration Steps

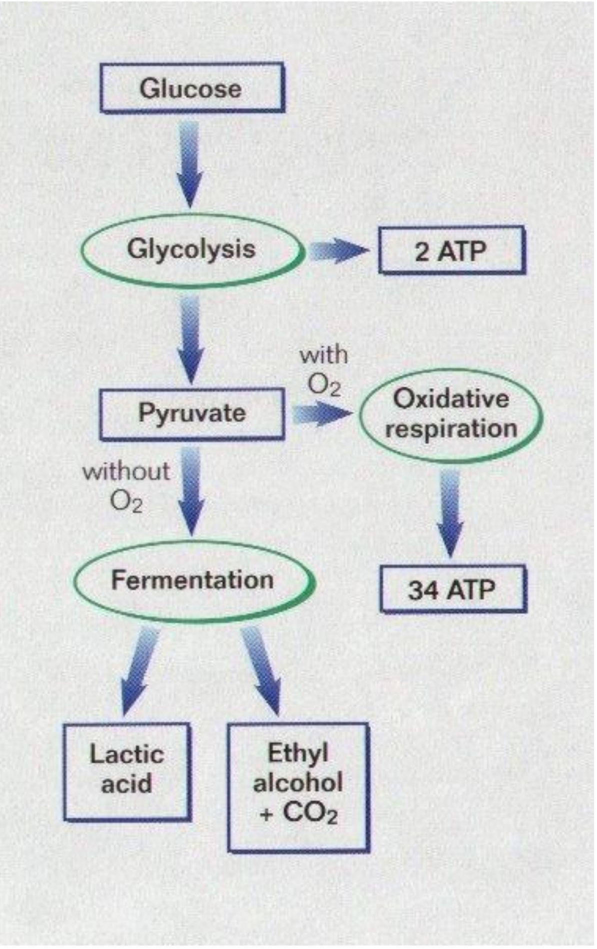
- Released Energy Is Used to Drive the Reaction ADP + P → ATP
  - Many ATP Are Made
- Oxygen Is Required for this Step
- Water Is Produced



http://www.uccs.edu/~rmelamed/MicroFall2002/Chapter%205/ch05.htm

Anaerobic Respiration

- 'Fermentation'
- Occurs in Low-Oxygen Environments
  - Wet or Compacted Soils for Plants
  - After Strong Exertion for Animals
- ATP Is still Produced from Glucose but not as Efficiently as with Aerobic Respiration



http://www.jracademy.com/~vinjama/2003pics/fermentation%5B1%5D.jpg

Anaerobic Respiration

- $C_6H_{12}O_6 + O_2 \rightarrow 2\ CH_2O_5 + 2\ H_2O + 2\ ATP$

or

- Glucose + Oxygen $\rightarrow$ 2 Ethanol + 2 Water + 2 ATP
- Same Rx Used to Produce Alcohol from Corn or to Make Wine or other Consumed Alcohol

Aerobic:

$C_6H_{12}O_6 + 6O_2 + 40\ ADP + 40\ Phosphates \rightarrow 6\ CO_2 + 6\ H_2O + 40\ ATP$

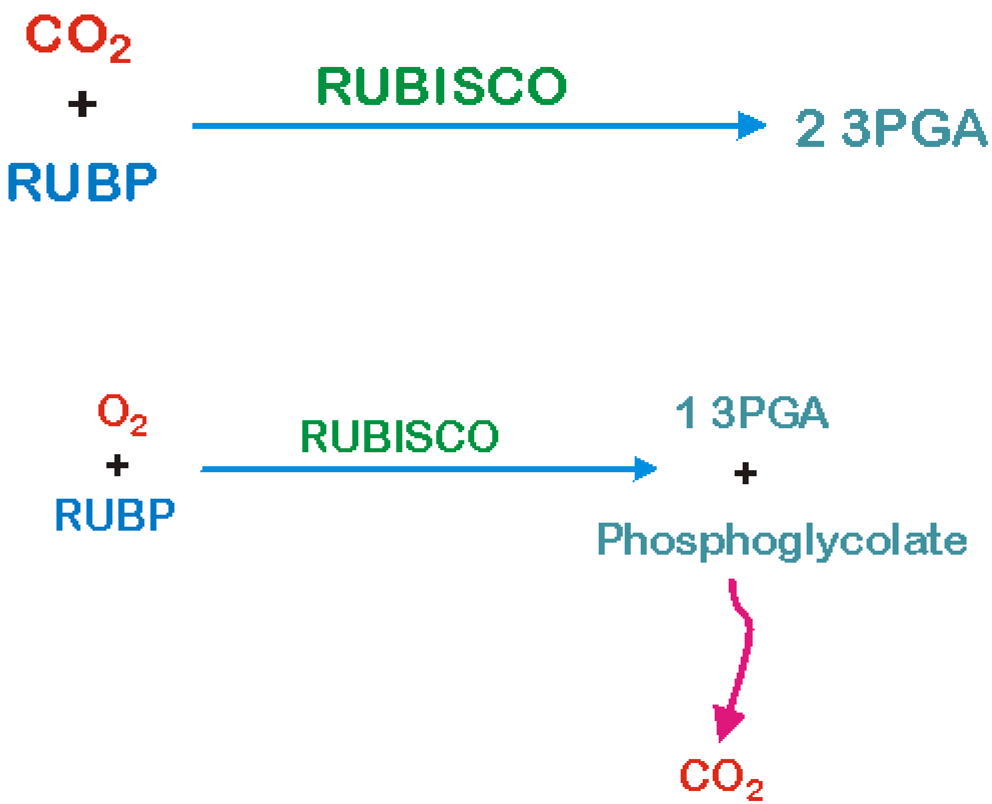
Anaerobic Respiration

- Only 2 ATP Are Formed instead of 40 from Aerobic Respiration
  - Plant Soon Runs out of Energy
  - Can Begin to Suffer from Toxic Levels of Ethanol and Related Compounds
- Extended Periods of Anaerobic Respiration will Seriously Reduced Plant Growth and Yields

Anaerobic:
$C_6H_{12}O_6 + O_2 \rightarrow 2\ CH_2O_5 + 2\ H_2O + 2\ ATP$
Aerobic:
$C_6H_{12}O_6 + 6O_2 + 40\ ADP + 40\ Phosphates \rightarrow 6\ CO_2 + 6\ H_2O + 40\ ATP$

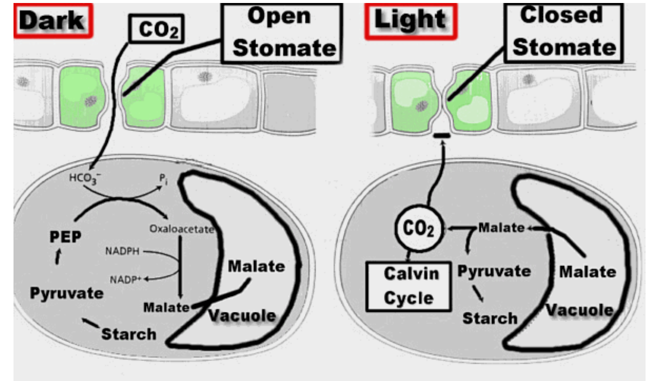
Photorespiration

- In the "normal" reaction, CO_2 is joined with RUBP to form 2 molecules of 3PGA
- In the process called **photorespiration**, O_2 replaces CO_2 in a non-productive, wasteful reaction
- It is believed that photorespiration in plants has increased over geologic time and is the result of increasing levels of O_2 in the atmosphere--the byproduct of photosynthetic organisms themselves
- The appearance of C4-type plants appears to be an evolutionary mechanism by which photorespiration is suppressed
- It has long been the dream of biologists to increase the production of certain crop plants, such as wheat, that carry on C_3 PS by genetically re-engineer them to perform C_4 PS
- It seems unlikely that this goal will be accomplished in the near future due to the complex anatomical and metabolic differences that exist between C3- and C4-type plants



http://www.marietta.edu/~spilatrs/biol103/photolab/photresp.html

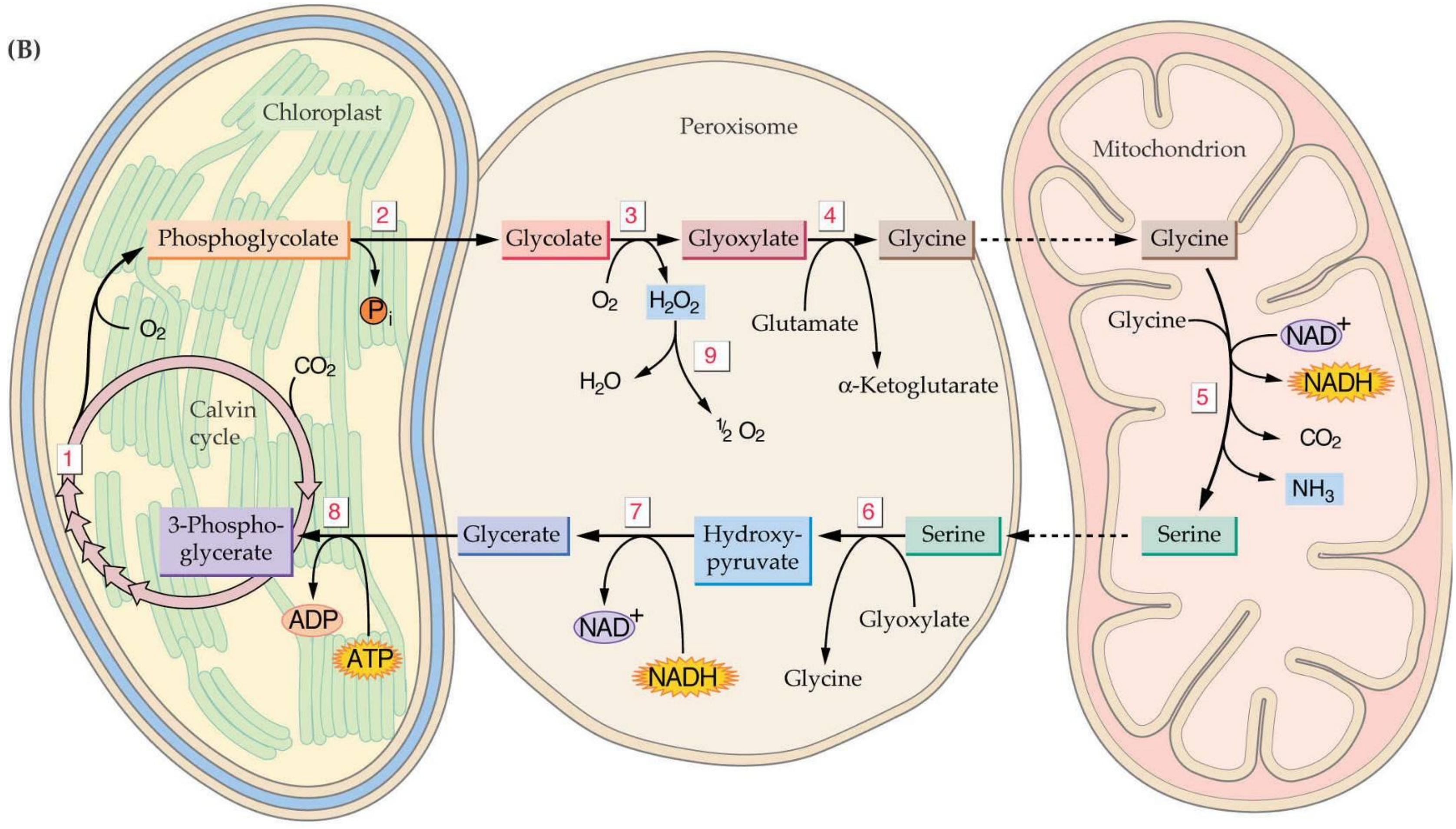
Photorespiration



- Respiration Driven by Light Energy
- Discovered when Scientists Realized that some Plants Have Faster Respiration Rate in Light than in Dark
- Occurs in Chloroplasts and other Structures in a Photosynthetic Cell
- Rubisco can React with Oxygen to Start a slightly Different Series of Rxs
  - Result in a Loss or no Net Gain of Dry Matter for the Plant
  - Less ATP Is Produced from the Photorespiration

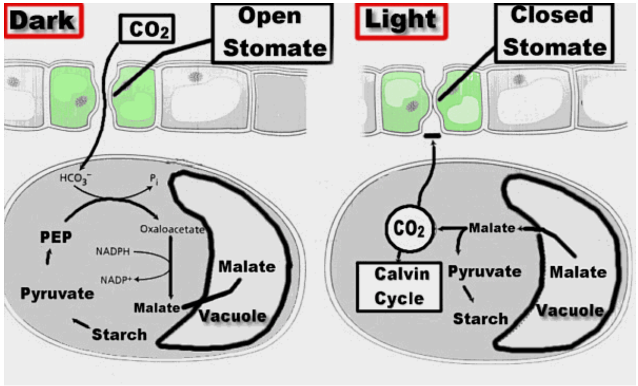
http://www.botany.hawaii.edu/faculty/webb/BOT311/BOT311-00/PSyn/Image81.gif

Photorespiration is highly compartmentalized



Buchannan et al. Fig. 1.40

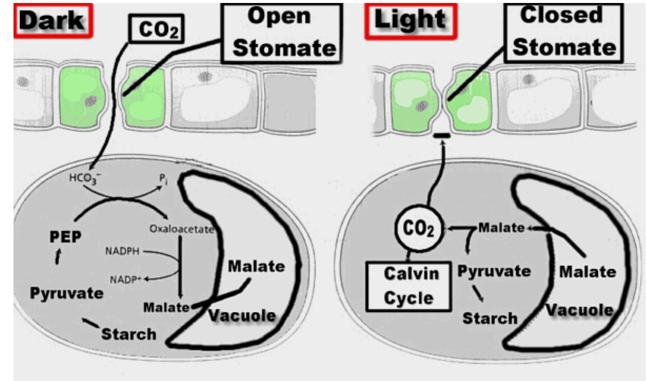
Factors Influencing Photorespiration



- O_2 : CO_2 Ratio
- If Cells Have Low O_2 but Higher CO_2, Normal PS Calvin Cycle Dominates
- C_4 Plants Have Little Photorespiration because They Carry the CO_2 to the bundle Sheath Cells and can Build up High [CO_2]
  – Calvin Cycle Rxs always Favored over Photorespiration
- If Cells Have Higher O_2 and Lower CO_2, Photorespiration Dominates

http://www.botany.hawaii.edu/faculty/webb/BOT311/BOT311-00/PSyn/Image81.gif

Factors Influencing Photorespiration

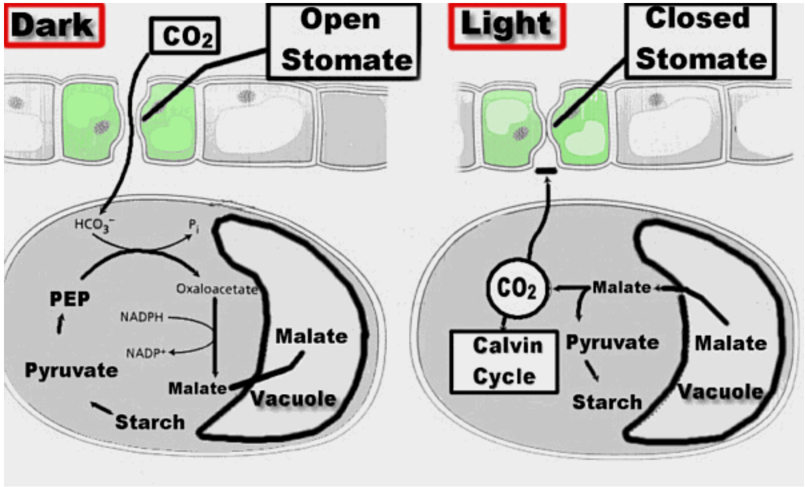


- Light Intensity
  - Increasing Light Intensity will Increase Energy for the Photorespiration Process and for PS
  - C_3 Plants Light-Saturate at Lower Light Intensities than C_4 Plants
    - Reach Their ‘Break-Even Point’ at much Lower Light Levels due to Increasing Photorespiration

http://www.botany.hawaii.edu/faculty/webb/BOT311/BOT311-00/PSyn/Image81.gif

Factors Influencing Photorespiration

- Temperature
  - Aerobic Respiration and Photorespiration Increase with Temp
  - Plants Have Optimum, Minimum and Maximum Temp Ranges



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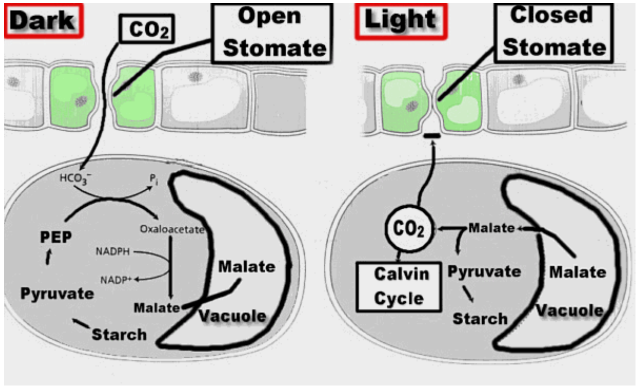
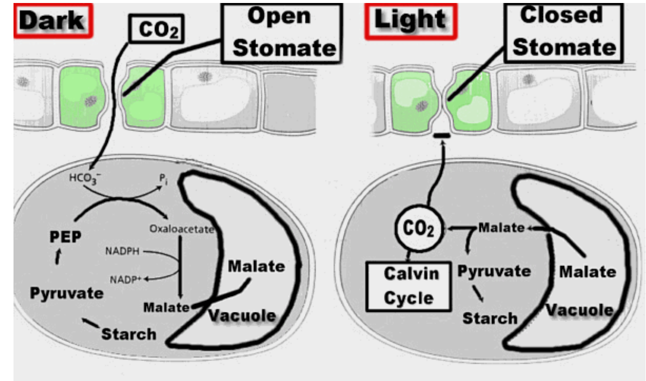
Factors Influencing Photorespiration



- Net Photosynthesis or Net Assimilation Rate
  - C_4 Plants generally Have Net Assimilation Rates about 2 to 3 Times that of C_3 Plants
  - C_4 Plants Are often Called Efficient Plants and C_3 Plants Called Non-Efficient Plants
  - A Few C_3 Plants Have Low Respiration and Similar Assimilation Rates as C_4 Plants
    - Sunflower
    - Peanut

http://www.botany.hawaii.edu/faculty/webb/BOT311/BOT311-00/PSyn/Image81.gif

Factors Influencing Photorespiration

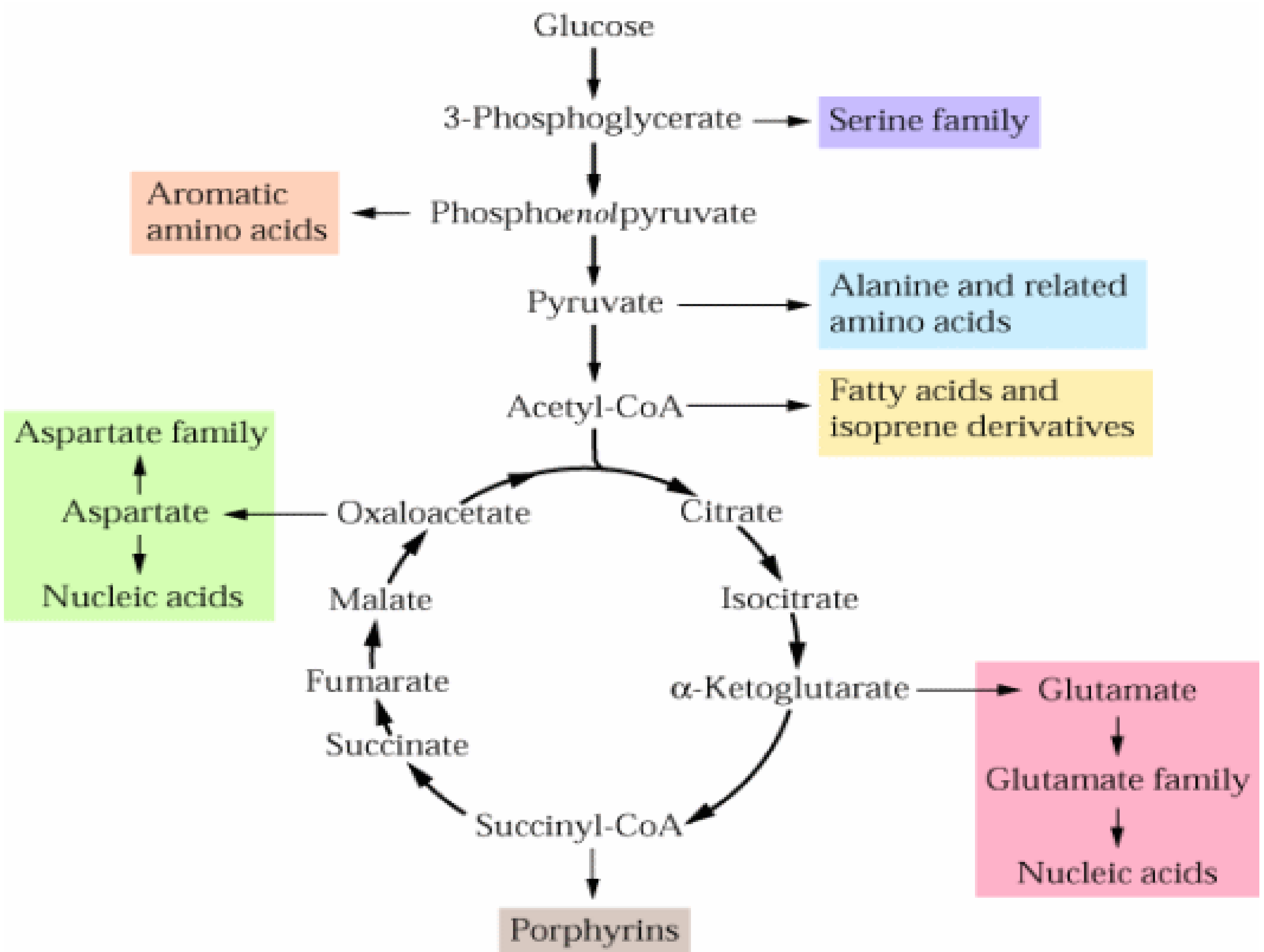


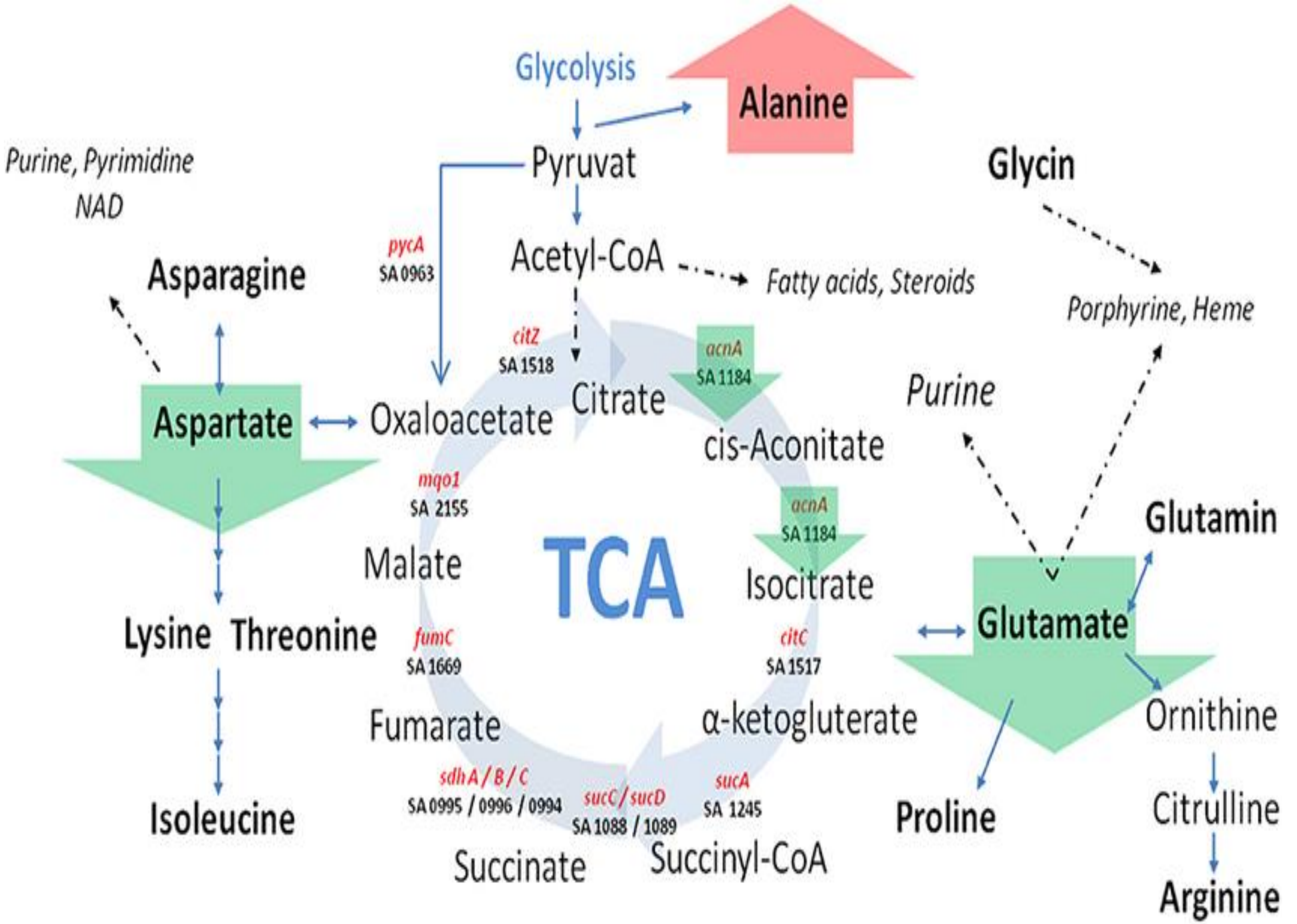
- Net Photosynthesis or Net Assimilation Rate
  - Cooler Temps Are the only Time when C_3 Plants Have Higher Net Assimilation Rates than C_4 Plants
    - PEP Carboxylase Needed to Incorporate CO_2 into the 4-Carbon Structure no Longer Functions
    - C_4 PS Rates Drop Dramatically or Stop

http://www.botany.hawaii.edu/faculty/webb/BOT311/BOT311-00/PSyn/Image81.gif

Alternate Fates of Glucose C

- Not all C respired to CO_2
- Intermediates of respiration branch off:
  - amino acids
  - pentoses for cell wall structure
  - nucleotides
  - porphyrin biosynthesis
  - fatty acid synthesis
  - lignin precursors
  - precursors for carotenoid synthesis, hormones

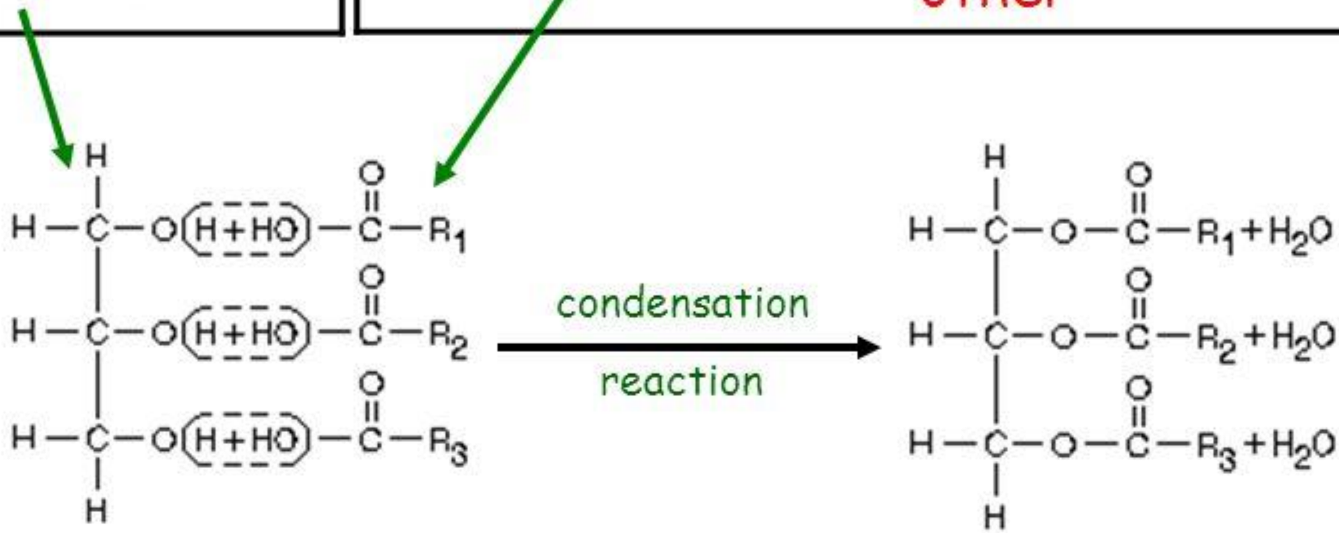

Glucose
3-Phosphoglycerate
Serine family
Aromatic amino acids
Phosphoenolpyruvate
Pyruvate
Alanine and related amino acids
Acetyl-CoA
Fatty acids and isoprene derivatives
Aspartate family
Aspartate
Nucleic acids
Oxaloacetate
Citrate
Malate
Isocitrate
Fumarate
α-Ketoglutarate
Glutamate
Succinate
Glutamate family
Succinyl-CoA
Nucleic acids
Porphyrins



Glycolysis
Alanine
Pyruvat
Purine, Pyrimidine
NAD
Glycin
pycA
SA 0963
Acetyl-CoA
Fatty acids, Steroids
Asparagine
Porphyrine, Heme
citZ
SA 1518
acnA
SA 1184
Citrate
Purine
Aspartate
Oxaloacetate
cis-Aconitate
mqo1
SA 2155
acnA
SA 1184
Glutamin
Malate
TCA
Isocitrate
Glutamate
Lysine
Threonine
fumC
SA 1669
citC
SA 1517
Ornithine
Fumarate
α-ketogluterate
sdhA / B / C
SA 0995 / 0996 / 0994
sucC / sucD
SA 1088 / 1089
sucA
SA 1245
Isoleucine
Proline
Citrulline
Succinate
Succinyl-CoA
Arginine

Triglycerides Are Esters of Glycerol and Fatty Acids

Glycerol "backbone" is a water-soluble alcohol	Fatty Acids are chains of carbon atoms with a methyl ($-CH_3$) group at one end and a carboxylic acid (-COOH) group at the other



Glycerol + 3 Fatty Acids

Triglyceride + 3 water molecules

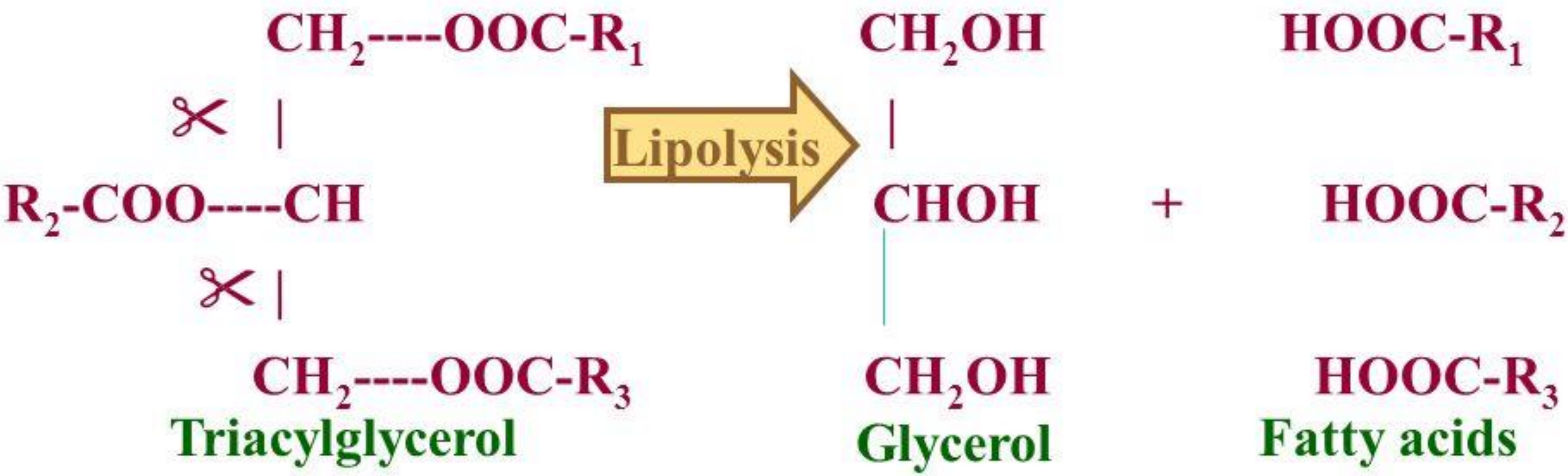
Structures linked by ester bonds (R-COOR') and water is released

FATTY ACID OXIDATION

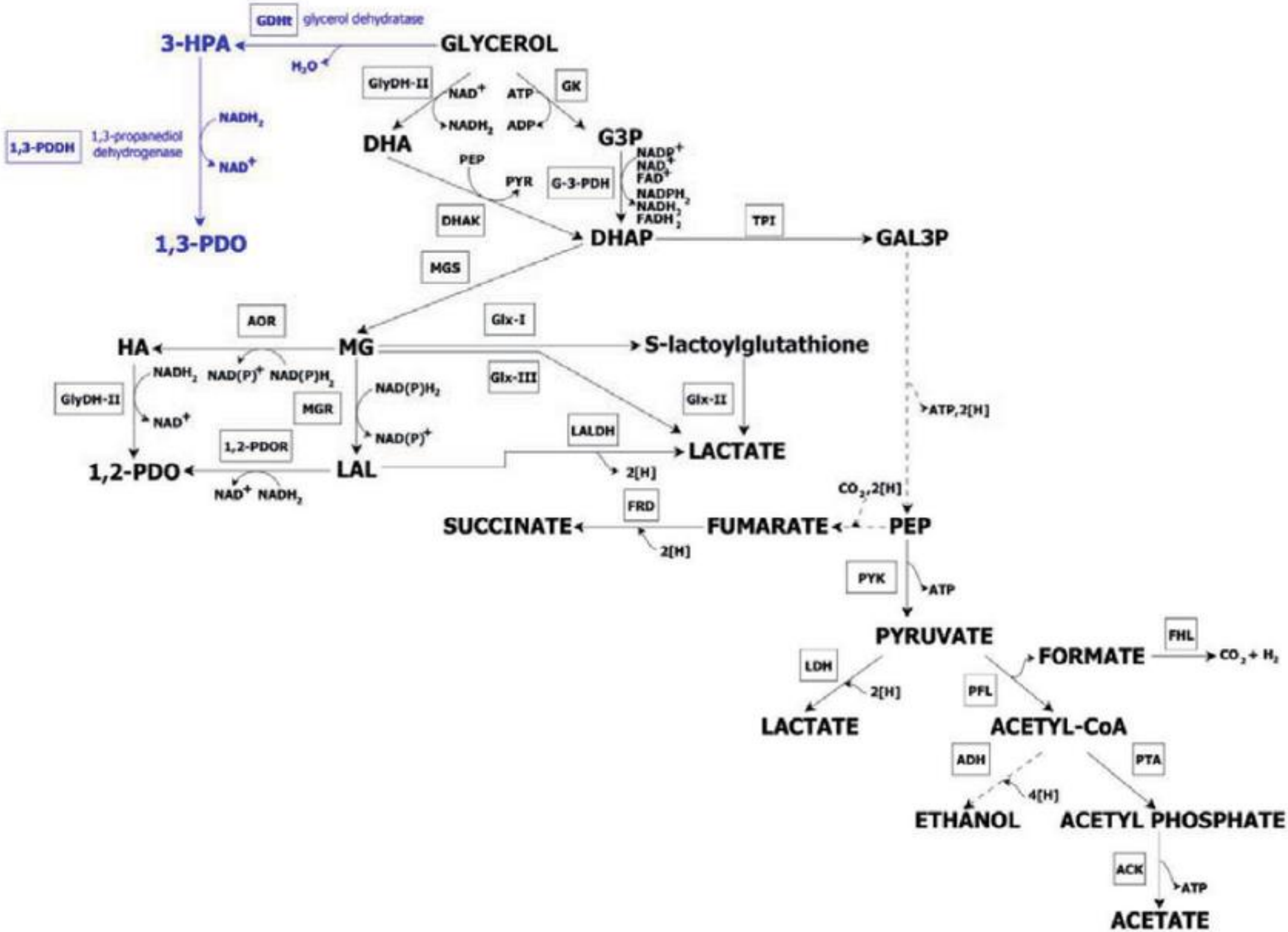
saturated fatty acid: $CH_3\text{-}(CH_2)_n\text{-}COOH$

unsaturated fatty acid: $CH_3\text{-}CH{=}CH\text{-}(CH_2)_n\text{-}COOH$

polyunsaturated fatty acid: $CH_3\text{-}CH{=}CH\text{-}CH_2\text{-}CH{=}CH\text{-}(CH_2)_n\text{-}COOH$



General structures of fatty acids and triacylglycerol. Lipolysis of stored triacylglycerol by lipases produces fatty acids plus glycerol.



GDHt glycerol dehydratase
3-HPA
GLYCEROL
H2O
GlyDH-II
NAD+
ATP
GK
NADH2
1,3-PDDH
1,3-propanediol dehydrogenase
NAD+
NADH2
ADP
DHA
G3P
PEP
NADP+
NAD+
FAD+
PYR
G-3-PDH
NADPH2
NADH2
FADH2
DHAK
TPI
1,3-PDO
DHAP
GAL3P
MGS
AOR
Glx-I
HA
MG
S-lactoylglutathione
NADH2
NAD(P)+
NAD(P)H2
Glx-III
GlyDH-II
NAD(P)H2
MGR
Glx-II
NAD+
ATP,2[H]
1,2-PDOR
NAD(P)+
LALDH
1,2-PDO
LAL
LACTATE
NAD+
NADH2
2[H]
CO2,2[H]
FRD
SUCCINATE
FUMARATE
PEP
2[H]
PYK
ATP
PYRUVATE
FHL
FORMATE
CO2 + H2
LDH
2[H]
PFL
LACTATE
ACETYL-CoA
ADH
PTA
4[H]
ETHANOL
ACETYL PHOSPHATE
ACK
ATP
ACETATE

Oxidation of Fatty Acids

keystone concepts

- The insolubility of triglycerides in dietary lipids and adipose tissue must be accommodated
- Fatty acids are oxidized in the mitochondria
- Fatty acids must be transported across the inner mitochondrial membrane
- Oxidation of fatty acids in the mitochondria has three stages
- Oxidation of unsaturated and odd chain fatty acids requires additional reactions
- In mammals, an alternative pathway for acetyl-CoA produces ketone bodies

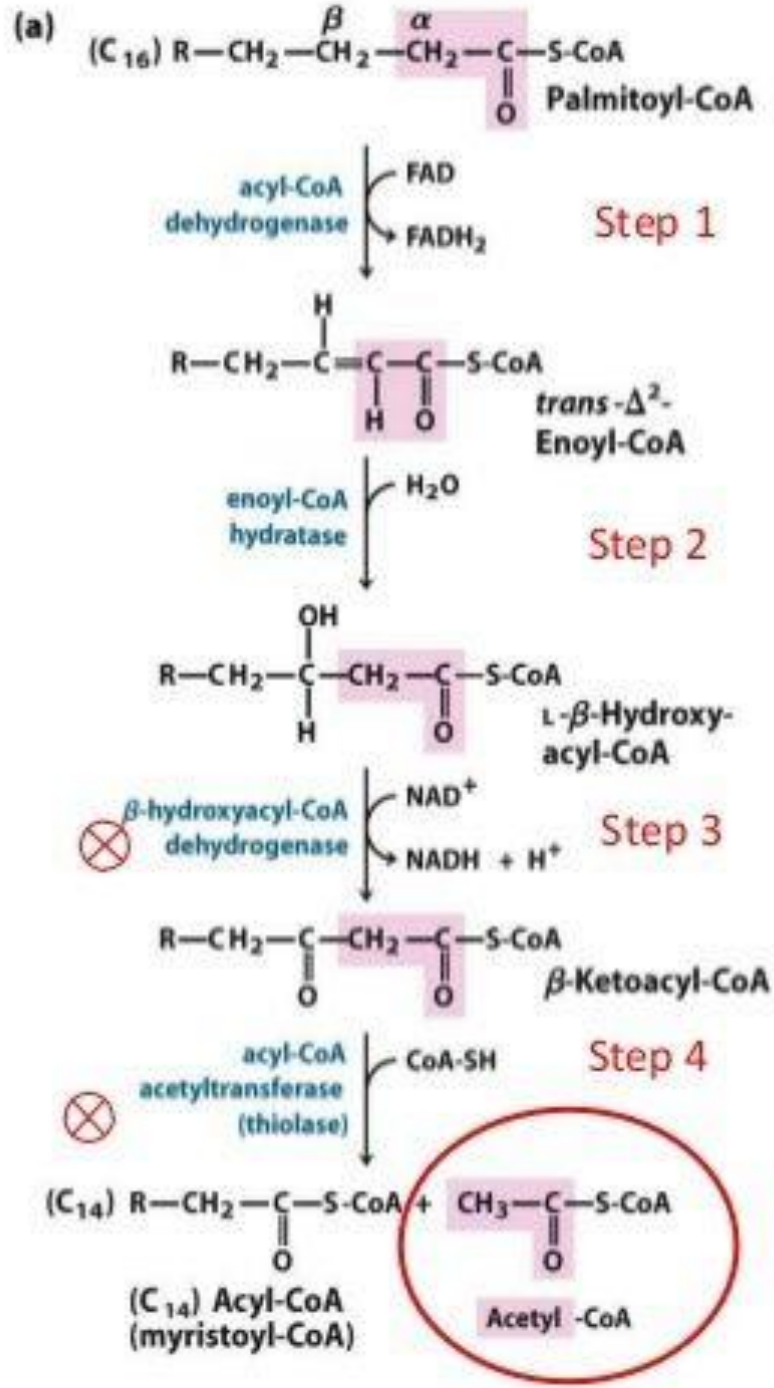
4 Steps of β-oxidation

1. Dehydrogenation of the fatty acyl-CoA to make a trans double bond between α and β carbon.
   - Short, medium, and long chain acyl-CoAdehydrogenases
   - e^- removed transferred to FAD
2. Hydration of the double bond

1. Dehydrogenation of the β-hydroxyl group to a ketone

   - e^- removed transferred to NAD^+

1. Acylation – addition of CoA and production of acetyl-CoA



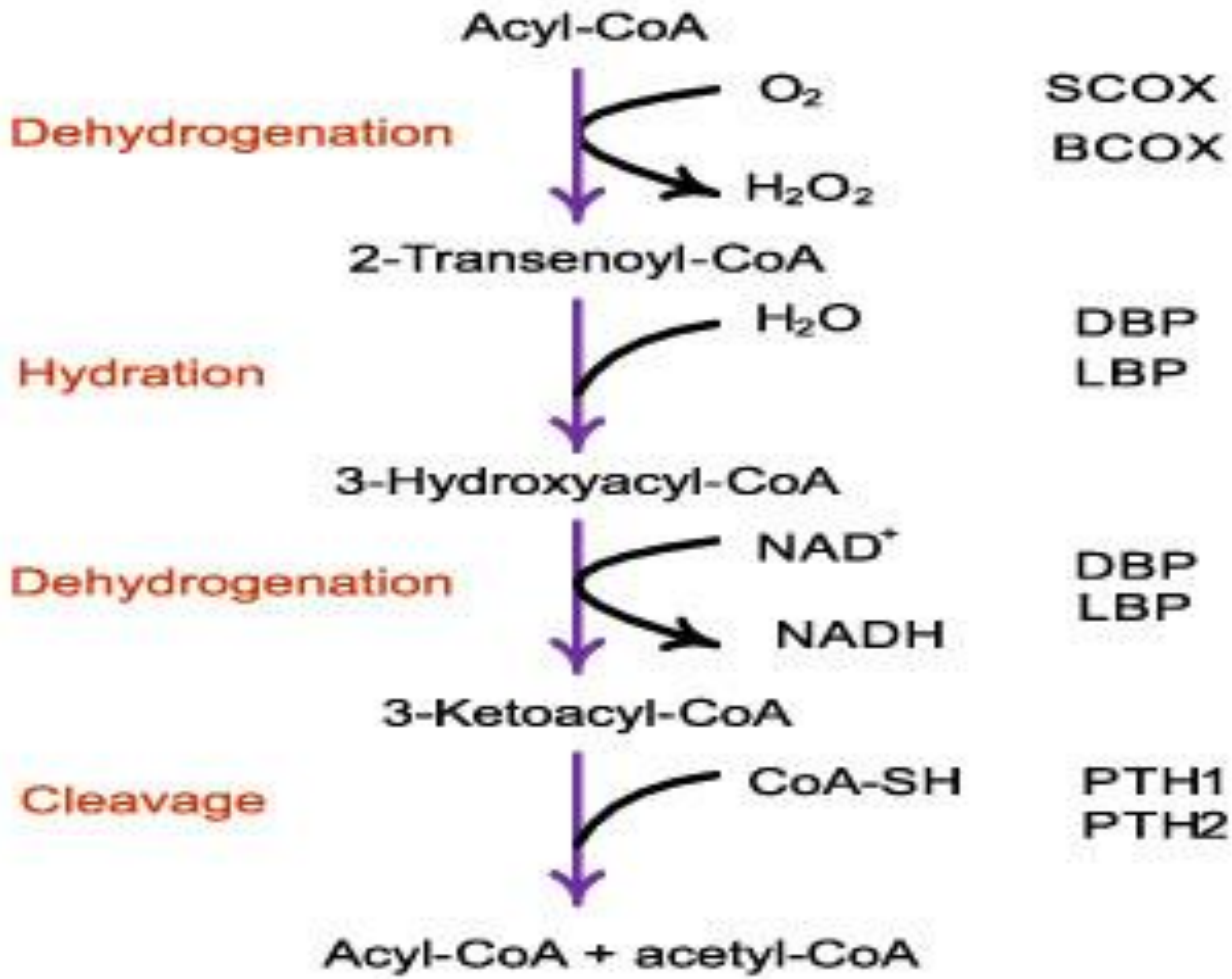


Figure 1. Process and enzymology of fatty acid β-oxidation in human peroxisomes. SCOX: straight chain acyl-CoA oxidase; BCOX: branched chain acyl-CoA oxidase; DBP: D-bifunctional protein; LBP: L-bifunctional protein; PTH: peroxisomal thiolase.

Energy Yield from β-Oxidation

- Yield of ATP per mole of stearic acid (C_{18}).

Step	Chemical Step	Happens	ATP
1	Activation (stearic acid -> stearyl CoA)	Once	-2
2	Oxidation (acyl CoA -> trans-enoyl CoA) produces $FADH_2$	8 times	16
4	Oxidation (hydroxy-acyl CoA to ketoacyl CoA) produces $NADH + H^+$	8 times	24
	Oxidation of acetyl CoA by the common metabolic pathway, etc.	9 times	108
		TOTAL	146

Protein Oxidation

- Proteins are continuously oxidized, even under normal physiological conditions.
- This oxidation may increase in various disorders
  - including atherosclerosis, Parkinson's disease and aging.
- All amino acid residues of a protein are subject to radical attacks by reactive oxygen and nitrogen species; however,
- Tyr, Phe, Trp, His, Met, and Cys residues are the preferred target sites for hydroxyl radicals.

Amino acid oxidation

keystone concepts:

- Dietary proteins - primary source of biologically useful N in animals
- Amino groups transferred to α-ketoglutarate forming glutamate and an α-keto acid
- Deaminated amino acids produce carbon skeletons that enter the citric acid cycle
- Most amino acids are glucogenic, some are both glucogenic and ketogenic,

  just 2 are solely ketogenic

first step in amino acid oxidation

- Removal of the amino group
- Formation of an a-keto acid
- How?
- Aminotransferases (transaminases)
- Collects the amino groups from many amino acids in the form of L-glutamate → amino group carrier