Respiration

Introduction & Measurement

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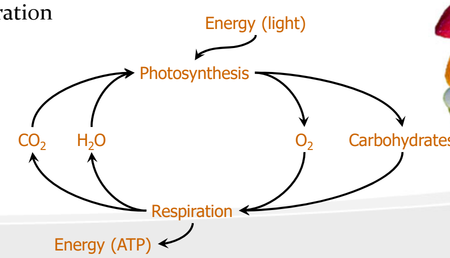
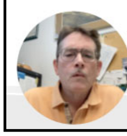
Carbon Metabolism

- Carbon cycles through photosynthesis and respiration





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Carbon Metabolism

- Photosynthesis – occurs in chloroplasts (chlorophyll) mostly in the green leaves
- Carbohydrates produced in leaves are translocates throughout the plant (phloem)
- Carbohydrates are oxidized at destination sites to release energy, CO_2 & water = RESPIRATION
  - Sugar + O_2 ➔

CO_2 + Water + Energy + Heat

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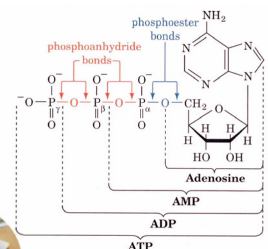
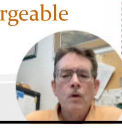
Adenosine Triphosphate (ATP)

- Adenosine triphosphate (-P-P-P)
  - Energy is stored in each P bond
- Intermediate energy molecules (ADP, AMP)
  - analogous to rechargeable batteries



http://lhs.lps.org/staff/sputnam/Biology/U4Metabolism/ch14_ATP.jpe



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Respiration & Heat

- ***First Law of Thermodynamics:***
  - Energy can not be created or destroyed
  - Thus, total energy at the beginning of a reaction must equal energy at the end

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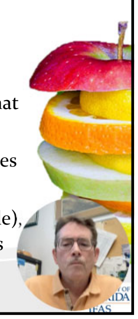
Use of Energy

- During carbohydrate oxidation (respiration), energy (ATP) & heat are produced
  - ATP molecules are intermediate energy molecules that are easily transported within a cell to sites of action
  - At sites of action, ATP is coupled to different processes to “power” them
  - Energy that is not captured as ATP (or other molecule), or is not completely used up in a biological process is lost as heat



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Respiration & Heat

- Respiration creates about 35 ATP per glucose molecule
  Per mole, glucose yields 686 kcal total energy
  - 1 mole ATP = ~ 12 kcal
  - 12 kcal * 35 mole ATP = 420 kcal/mole (estimates from 360 to 432)
  - 686 kcal – 420 kcal = 266 kcal/mole glucose lost as heat immediately
- If not removed, lost energy will raise the cell/tissue temperature
  - Heat pumps (refrigeration) move heat from one place to another (e.g., from inside to outside of the rooms)
  - Calculation of heat production: mg CO_2/kg-hr x 61 = kcal/MT/day

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Second Law of Thermodynamics

- Entropy (disorder) of a system will always increase with time
- Biological systems are very ordered (low entropy) and maintain their order by making their environment more disordered
  - Organisms expend energy to counteract the natural tendency to disorganize
  - Without a constant energy supply, organisms would disorganize and die
  - Living organisms are never at equilibrium

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Second Law of Thermodynamics

- When commodities are detached from the plant, they are severed from their food (energy) supply and must live on what they have stored
  - The less reserves they have stored, the shorter their postharvest life (immature vs. mature organs)

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Respiration Overview

- Respiration is central to overall cell metabolism, such as synthesis of important compounds
- Respiration is composed of three parts:
  - ***Glycolysis*** – located in the cytosol
  - ***Krebs cycle*** – located in the mitochondria matrix
  - ***Electron Transport System*** (ETS) – located on the inner mitochondria membrane

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"Fuel" for Respiration

- Fuel sources:
  - Starch
  - Sugars (glucose, fructose)
  - Organic acids
  - Sometimes amino acids
  - Sometimes lipds (fats)

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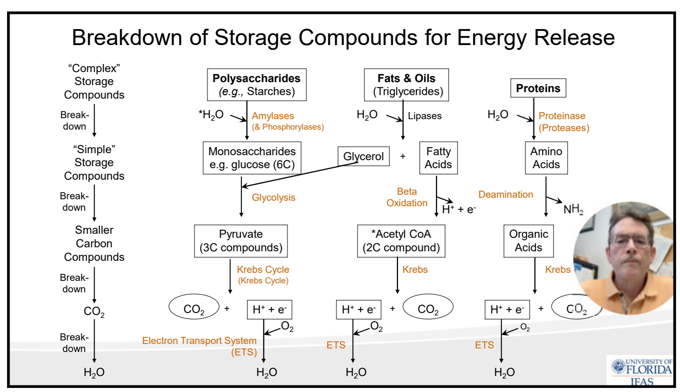

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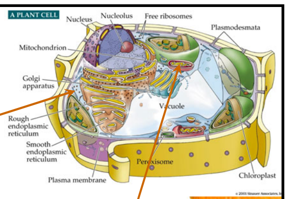
Glycolysis

- Processing of fuel
- Occurs in the cytosol
  - Converts carbohydrate "fuel" into pyruvate that will be transported to the mitochondria and used by the Krebs cycle
  - Also produces a little ATP



Sinauer, 2001, Life The Science of Biology 6th edition

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Glycolysis

(in the cytosol)

glucose
ATP
glucose 6-p
fructose 6-p
ATP
fructose 1,6-diphosphate
dihydroxyacetone p → (2) glyceraldehyde 3-p
(2) NAD+
(2) NADH
(2) 1,3-diphosphoglycerate
(2) ATP
(2) 3-phosphoglycerate
(2) 2-phosphoglycerate
(2) H_2O
(2) phosphoenolpyruvate
(2) ATP
(2) pyruvate → To Mitochondria & Krebs cycle

Prep Phase

Payoff Phase

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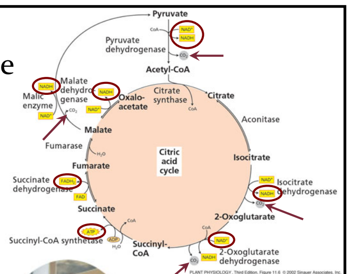
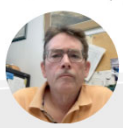
Krebs (or TCA) Cycle

- Furnace & Turbines (Krebs or TCA cycle)
  - Occurs in the mitochondria (powerhouses of the cell)
  - Produces NADH and FADH2 that are used to make ATP
  - Produces a little ATP directly
  - Produces CO2





Taiz & Zeiger, 2002, used with permission. Fig. 11.6

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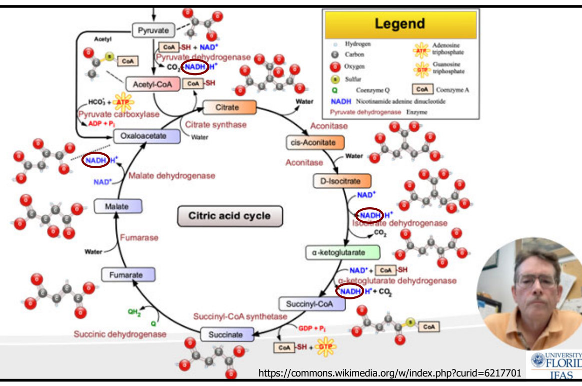

https://commons.wikimedia.org/w/index.php?curid=6217701

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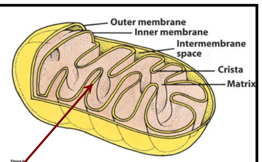
ETS

- Generator (ETS) [Electron Transport System]
  - ETS is located on the mitochondrion inner membrane
  - Products from the Krebs cycle are used to make ATP
  - Requires Oxygen (O_2)
    - In the process, electrons are ultimately passed to oxygen (final e[-] acceptor)



Freeman & Company, 2005, Biology of Plants, 7th edition

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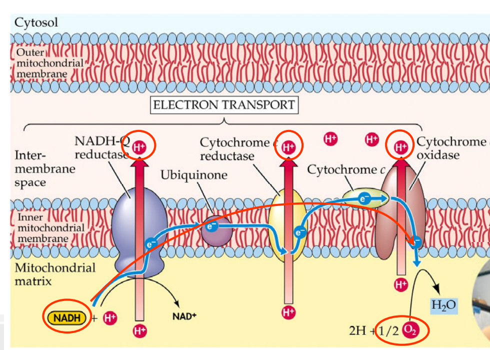
Sinauer, 2001, Life The Science of Biology 6th edition



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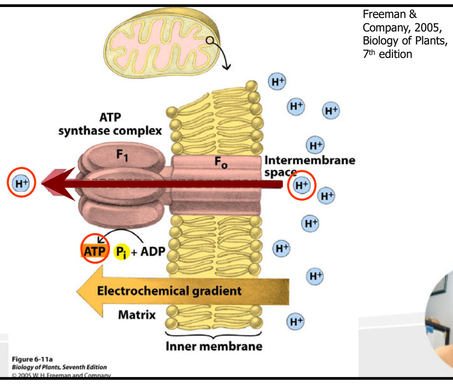

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Net Production of ATP

Krebs Cycle (per pyruvate = 1 turn)

- Directly created

  +1 ATP/pyruvate.

Total ATP from Krebs Sub-Phos/pyruvate = **1 ATP**
Total ATP from Krebs Sub-Phos/glucose (2 cycles) = **2 ATP**

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Net Production of ATP

Krebs Cycle (per pyruvate = 1 turn)

- After ETS

+5 NADH/pyruvate x 2.5 ATP/NADH	= 12.5 ATP
+1 $FADH_2$/pyruvate x 1.5 ATP/$FADH_2$	= 1.5 ATP

Total ATP from Krebs ETS/pyruvate = **14 ATP**
Total ATP from Krebs ETS/glucose = **28 ATP**

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Net Production of ATP

Krebs (TCA) Cycle (per glucose = 2 turns)

1 Turn of Krebs	2 Turns of Krebs
1 ATP Directly	2 ATP Directly
14 ATP from ETS	28 ATP from ETS

Total ATP from Krebs/glucose = **30 ATP**

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Net Production of ATP

Grand Total from Respiration

Glycolysis = 5 ATP

Krebs Cycle (TCA) = 30 ATP

Grand Total = **35 ATP/glucose**

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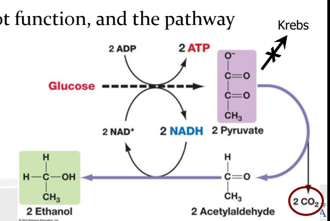
Anaerobic Respiration

- Anaerobic respiration = without O_2
  - Also called fermentation
- Without O_2, normal ETS cannot function, and the pathway backs up (at pyruvate)
- Glycolysis can still function
  - Pyruvate is shunted off to make Ethanol or Lactic Acid
- Only 2 ATP formed per glucose
  - Compared to 35 total in aerobic respiration (30 TCA + ETS)



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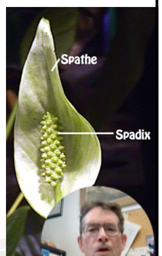
http://www.pssc.ttu.edu/pss1411cd/IMAGES/flowers/spthnspd.jpg

Cyanide Resistant Pathway

- Many plant tissues have a cyanide resistant pathway (or alternative oxidase pathway)
  - Produces only ~ 1/3 the ATP of the normal pathway (complexes 3 & 4 are bypassed)
  - The loss in efficiency results in much greater heat production
    - In arum spadices, the cyanide resistant pathway increases tissue temperature up to 10C
- May serve as a stress mechanism to supply carbohydrate metabolites &/or minimize ROS (reactive oxygen species) production



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Measuring Respiration

- Measure loss of substrates, or appearance of products
  - Loss of carbohydrates (dry weight)
  - Measure gas exchange
    - Loss of oxygen (O_2) Ambient concentration = ~21%
    - Production of carbon dioxide (CO_2) Ambient concentration ~0.03% (& increasing)
  - Production of heat

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Dry Weight Loss

$$\text{Rate of Dry Wt. Loss (g/kg-hr)} = \frac{\text{Respiration Rate (mg } CO_2\text{/kg-hr)}}{1000 \text{ mg/g}} \times \frac{180}{264}$$

OR

$$\text{\% of Dry Wt. Loss per hr.} = \text{Respiration Rate (mg } CO_2\text{/kg-hr)} \times 68.2 \times 10^{-6}$$

OR

mg CO_2 produced X 0.68 = mg sugar consumed

- e.g., onions held at 30°C (respiration = 35 mg CO_2/kg-hr) will lose 1.72% dry wt. per month (30 d)

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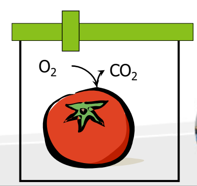
Measuring Gas Exchange

- Static System
  - Tissue is placed in a sealed container and the loss of O_2 or increase of CO_2 are measured
    - Measure over brief periods so that CO_2 does not accumulate above 0.2% (can inhibit respiration)



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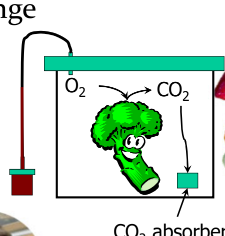
Measuring Gas Exchange

- Static System
  - Easy to use and does not depend on a flow rate. However, any leaks (even small ones) will result in large errors.



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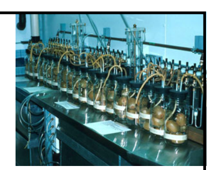
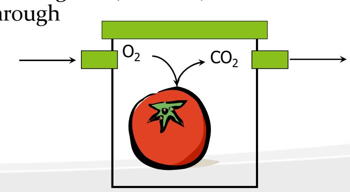
Measuring Gas Exchange



- Flow-Through System
  - Tissue is placed in a container and a flow of known gases (often air) is passed through



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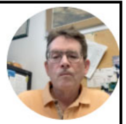
Measuring Gas Exchange



- Flow-Through System
  - O_2 uptake and CO_2 production is calculated by measuring the concentration differences between the inlet and outlet & knowing the gas flow rate
  - Small leaks are not critical (due to positive pressure) and gas concentrations are not altered far from ambient
  - Convenient for repeated measures, but more involved to set up

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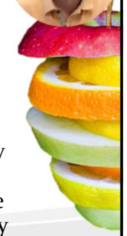
Heat Production



- Newer, more sensitive & precise equipment now allows measuring respiration via this technique
  - 1 mg CO2 = 2.55 cal heat production
  - 1 mg CO2/kg-hr = 61.2 kcal/metric ton per day

    = 220 BTU per ton of produce per day

1 ton refrigeration = 3023.9491 kcal/hr

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