

Respiration

Introduction & Measurement

Mark Ritenour

Indian River Research and Education Center, Fort Pierce

Jeff Brecht

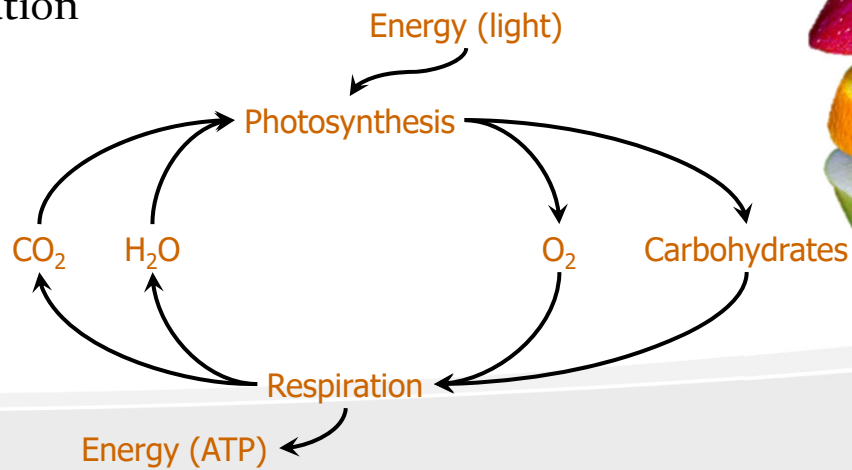
Horticultural Science Department, Gainesville



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Carbon Metabolism

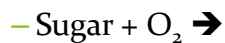
- Carbon cycles through photosynthesis and respiration



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Carbon Metabolism

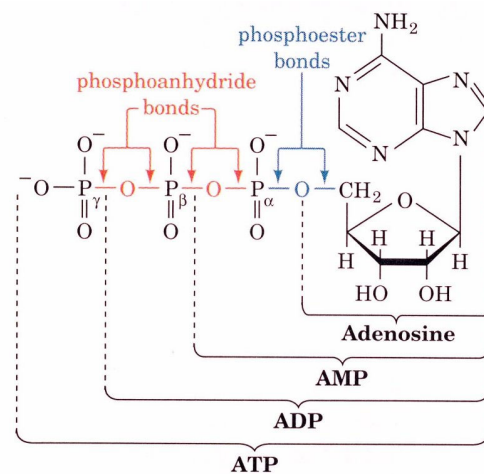
- **Photosynthesis** – occurs in chloroplasts (chlorophyll) mostly in the green leaves
- Carbohydrates produced in leaves are **translocated** throughout the plant (phloem)
- Carbohydrates are oxidized at destination sites to release energy, CO₂ & water = **RESPIRATION**



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Adenosine Triphosphate (ATP)

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



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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

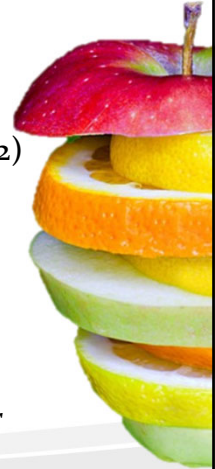
- During carbohydrate oxidation (respiration), energy (ATP) & heat are produced
 - ATP molecules are intermediate energy molecules that are easily transported within a cell to sites of action
 - At sites of action, ATP is coupled to different processes to “power” them
 - Energy that is not captured as 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 CO₂/kg-hr x 61 = kcal/MT/day**



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Thermodynamics - 2nd law

- 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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Thermodynamics - 2nd law

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



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



“Fuel” for Respiration

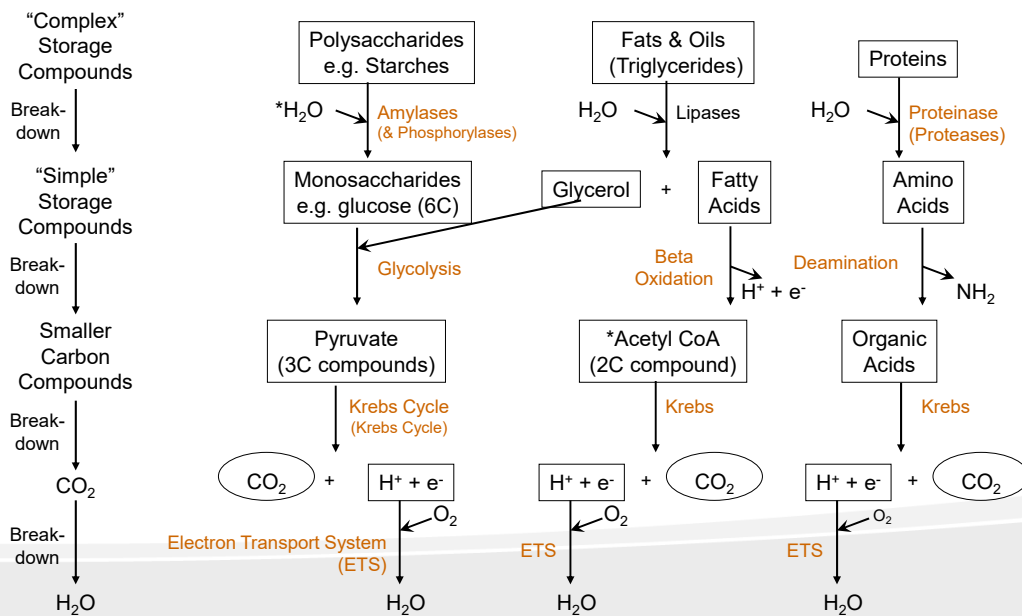
- Fuel sources:

- Starch
- Sugars (glucose, fructose)
- Organic acids
- Sometimes amino acids
- Sometimes lipids (fats)



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Breakdown of Storage Compounds for Energy Release



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Glycolysis

- Processing (Glycolysis)
 - 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

cytosol

glucose → glucose 6-p → fructose 6-p → fructose 1,6-diphosphate

fructose 1,6-diphosphate → dihydroxyacetone p → (2) glyceraldehyde 3-p

(2) glyceraldehyde 3-p → (2) 1,3-diphosphoglycerate → (2) 3-phosphoglycerate

(2) 3-phosphoglycerate → (2) 2-phosphoglycerate → (2) phosphoenolpyruvate → (2) pyruvate

(2) pyruvate → To Mitochondria & Krebs cycle

Prep Phase

Payoff Phase

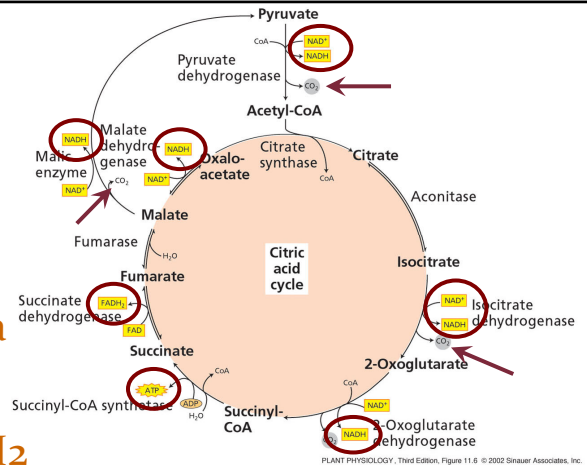
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Krebs (or TCA) Cycle

• Furnace & Turbines (Krebs or TCA cycle)

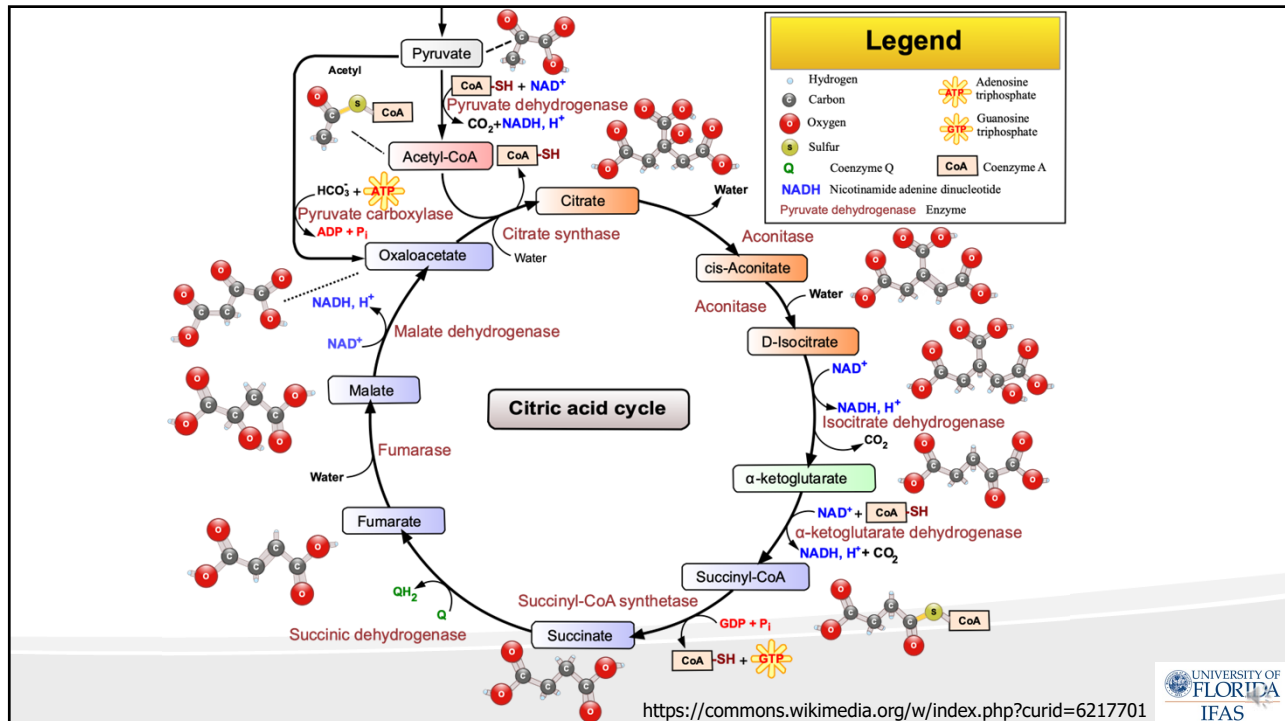
- Occurs in the mitochondria (powerhouses of the cell)
- Produces NADH and FADH₂ that are used to make ATP
- Produces a little ATP directly
- Produces CO₂



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 (O₂)**
 - In the process, electrons are ultimately passed to oxygen (final e⁻ acceptor)

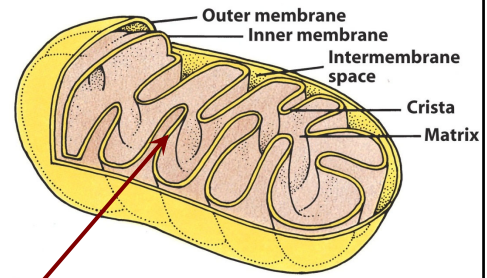


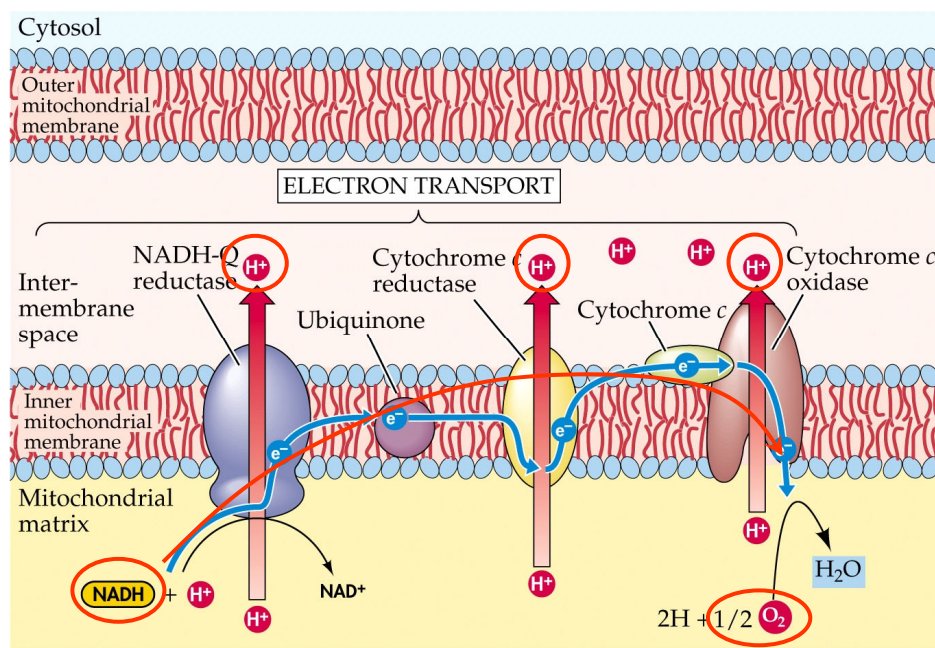
Figure 6-11
Biology of Plants, Seventh Edition
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Freeman & Company, 2005, Biology of Plants, 7th edition



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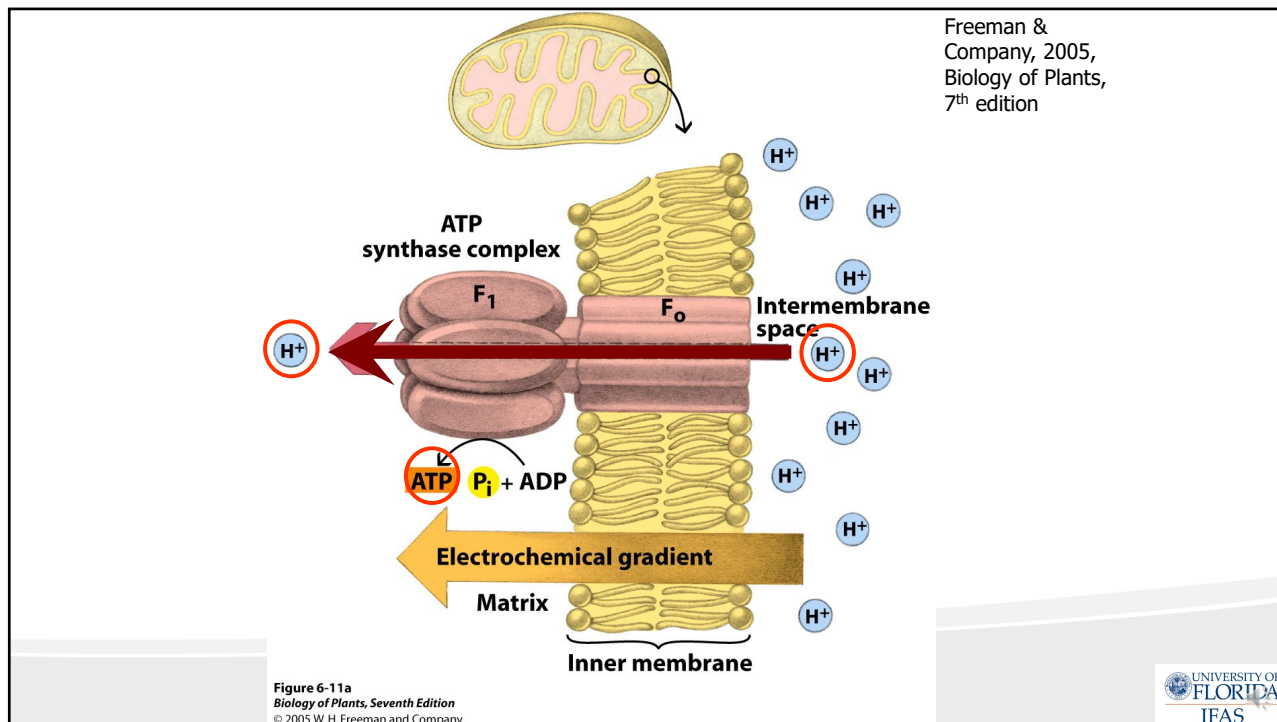
Sinauer, 2001, Life The Science of Biology 6th edition



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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

$$\begin{aligned} +5 \text{ NADH/pyruvate} &= 12.5 \text{ ATP} \\ \times 2.5 \text{ ATP/NADH} & \end{aligned}$$

$$\begin{aligned} +1 \text{ FADH}_2/\text{pyruvate} &= 1.5 \text{ ATP} \\ \times 1.5 \text{ ATP/FADH}_2 & \end{aligned}$$

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

1 ATP Directly
14 ATP from ETS

2 Turns of Krebs

2 ATP Directly
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

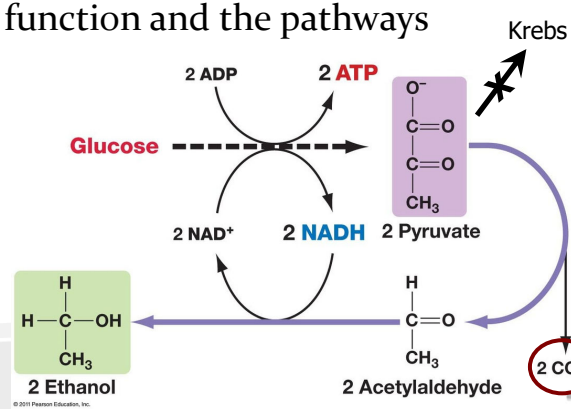
Grand Total = **35 ATP/glucose**



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Anaerobic Respiration

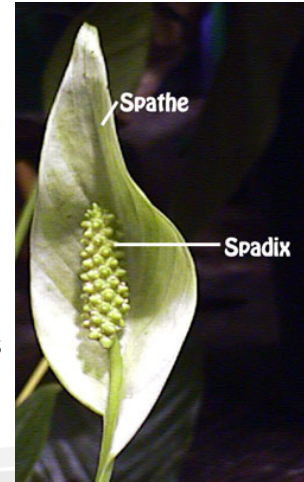
- Anaerobic respiration = without O_2
 - Also called fermentation
- Without O_2 , normal ETS cannot function and the pathways backs up (at pyruvate)
- Glycolysis can still function
 - Pyruvate is shunted off to make Ethanol or Lactic Acid
- Only 2 ATP formed per glucose**
 - Compared to 35 total in aerobic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



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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 of gas exchange
 - Loss of oxygen (O₂) Ambient concentration = ~21%
 - Appearance of carbon dioxide (CO₂) 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

$$\text{mg CO}_2 \text{ produced} \times 0.68 = \text{mg sugar consumed}$$

- E.g. Onions held at 30C (respiration = 35 mg CO₂/kg-hr) will lose 1.72% dry wt. per month (30 d)



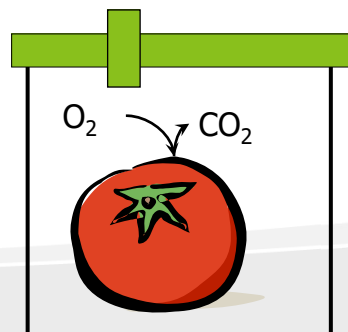
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Measuring Gas Exchange

Static System

– Tissue is placed in a sealed container and the loss of O₂ or increase of CO₂ are measured

- Measure over brief periods so that CO₂ does not accumulate above 0.2% (can inhibit respiration)

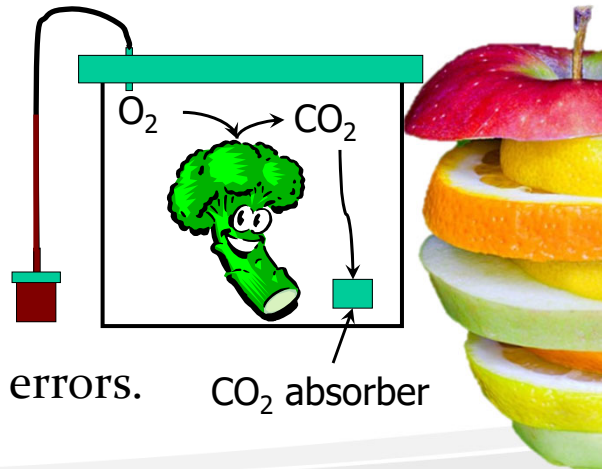


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Measuring Gas Exchange

• Static System

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

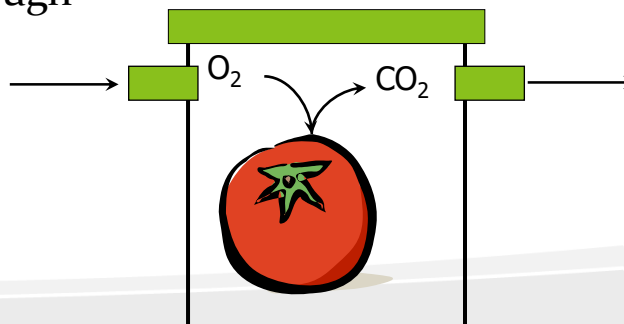


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Measuring Gas Exchange

• Flow-Through System

- Tissue is placed in a container and a flow of known gasses (often air) are passed through

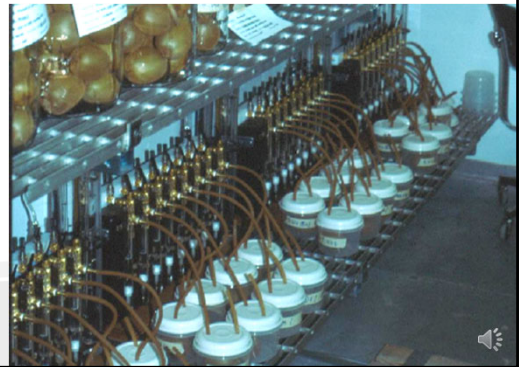


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Measuring Gas Exchange

- **Flow-Through System**

- O₂ uptake and CO₂ 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
- However, it is 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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