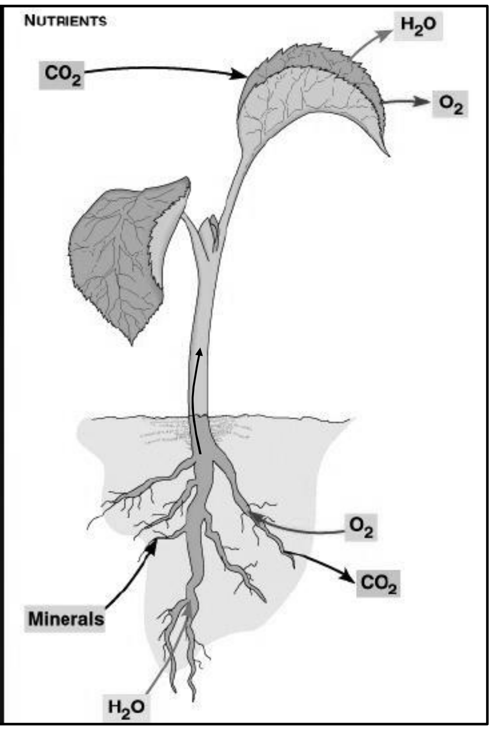
BIOL 695

NUTRIENT UPTAKE AND ASSIMILATION

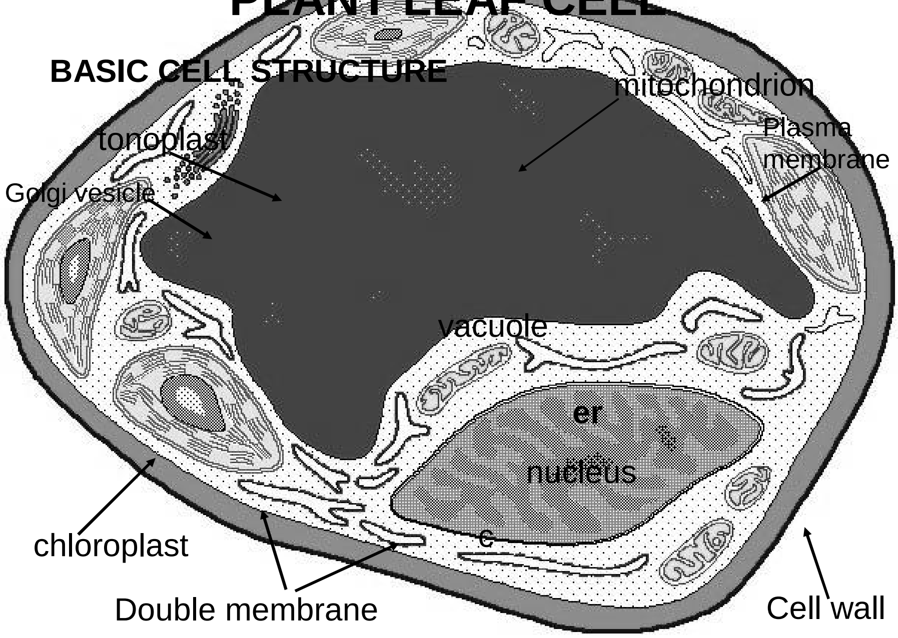
CHAPTER 3: Mengel et al., 5th Ed

Uptake of Nutrients by Plants

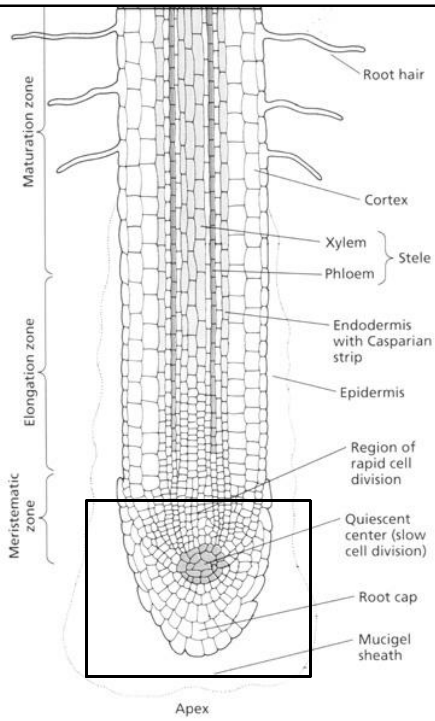


PLANT LEAF CELL

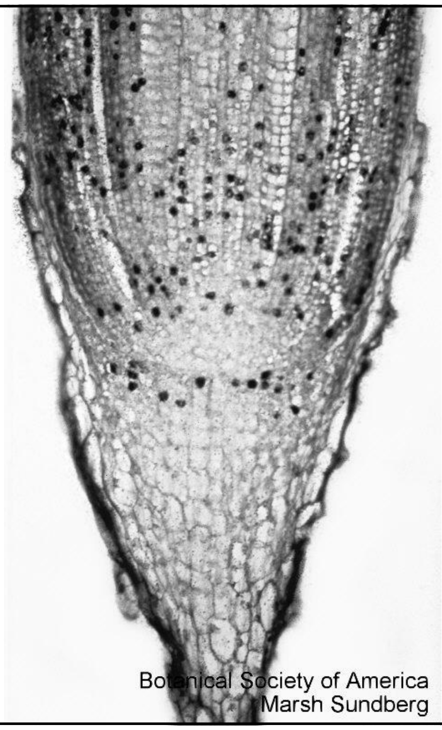
BASIC CELL STRUCTURE



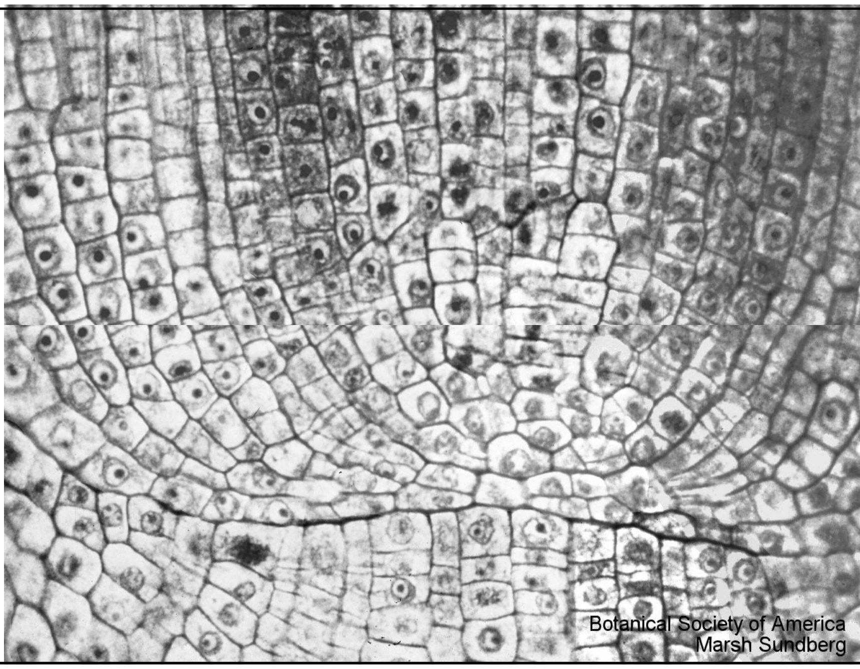
LONGITUDINAL SECTION OF A ROOT



AUTORADIOGRAPH OF A CORN ROOT TIP



CORN ROOT TIP

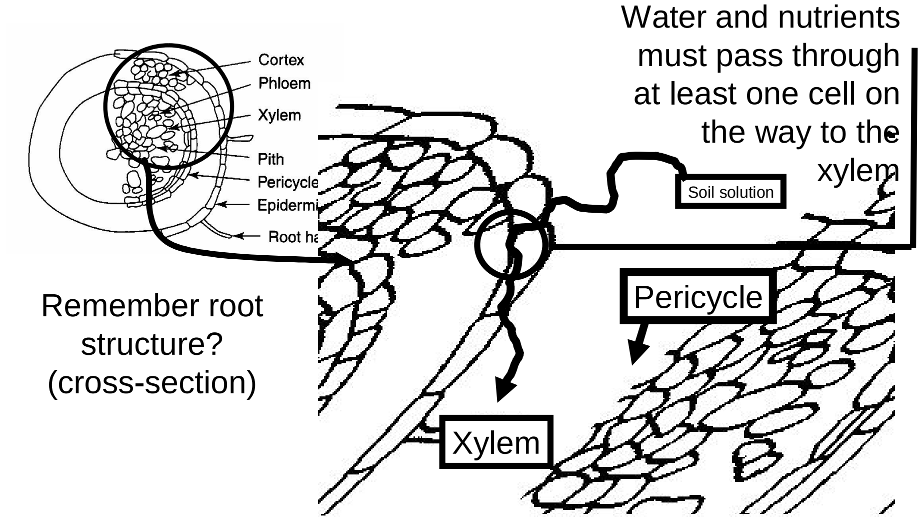


MINERAL UPTAKE BY PLANTS

- **Nutrient ions must be dissolved in soil water ("soil solution") for uptake by plants**
- **They move from "soil solution" to vascular center of plant root passing through at least one cell membrane (the "skin" that hold the cell's liquid contents inside)**
- **This movement, across the membrane, may be passive or active**

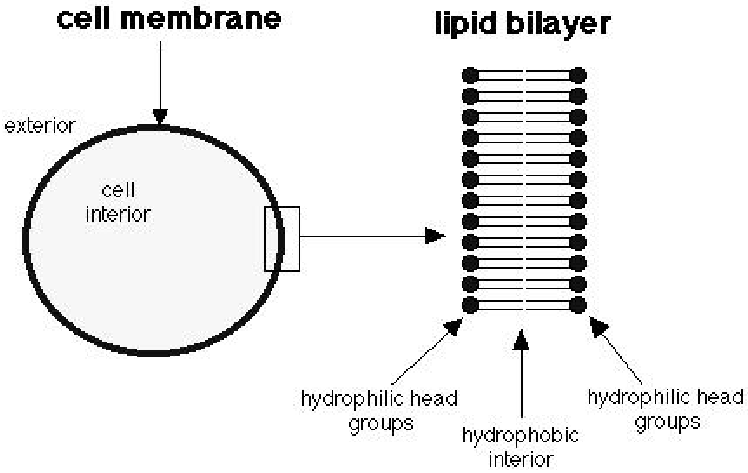
MOVEMENT INTO THE ROOT

Water and nutrients must pass through at least one cell on the way to the xylem

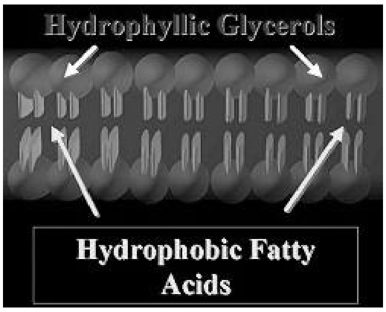


Remember root structure? (cross-section)

CELL MEMBRANES

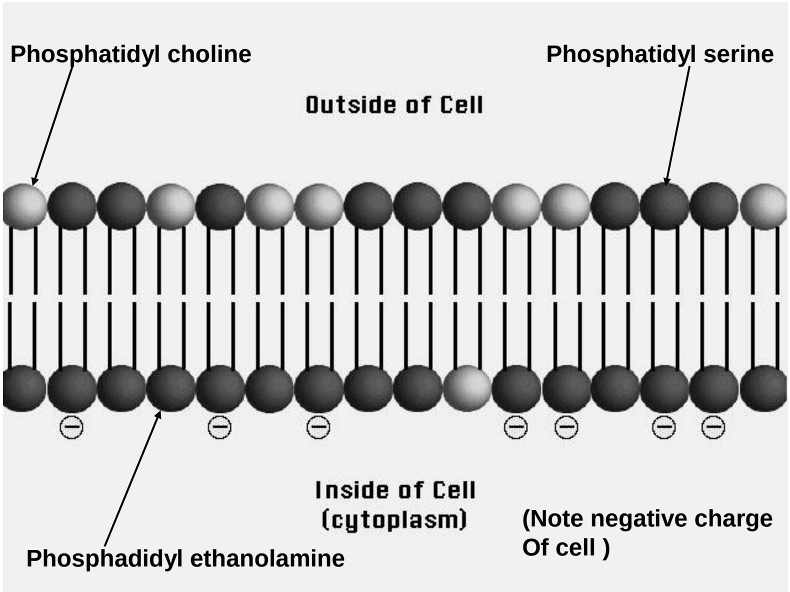


CELL MEMBRANES



- Phospholipids are the fundamental components of membranes.
- Hydrophilic regions form interface with water-rich cytoplasm and cell wall
- Hydrophobic regions combine to form center of membrane

CELL MEMBRANES



FLUID MEMBRANE MODEL

- Protein matrix - electrostatic binding
  - 2 phospholipid layers
    - hydrophilic charged heads
      - toward membranes *
- Protein channels
  - hydrophilic pores
    - polar solutes move through

FLUID MEMBRANE MODEL - 2

- Membranes also composed of polar lipids.
  - Phospholipids *
  - Glucolipids
  - Sulfolipids
- Long chain fatty acids are the hydrophobic tails oriented inwardly
- Variation in length & degree of unsaturation influence the melting point. *

FLUID MEMBRANE MODEL - 3

- Higher degree of unsaturation in plants evolved in colder climates.
- How does this relate to membrane fluidity?
- Wheat root: more polyunsaturates when temperature dips from 25 to 10^{o}C
- Pecans in colder climate have more polyunsaturates in cells
- Beta sistosterol has structural role in membranes.

MOVEMENT INTO THE ROOT

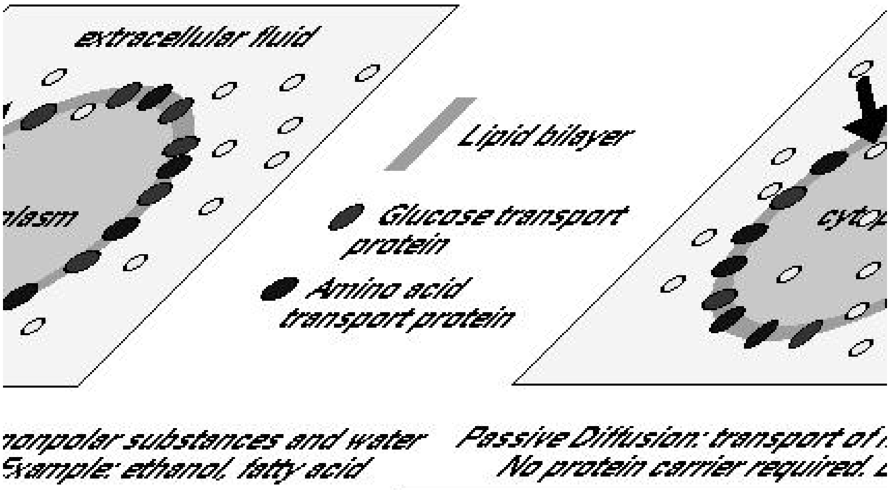
Passive mineral uptake

- Diffusion - movement across a membrane from side of higher concentration of ion to side of lower concentration of ion (with the gradient)

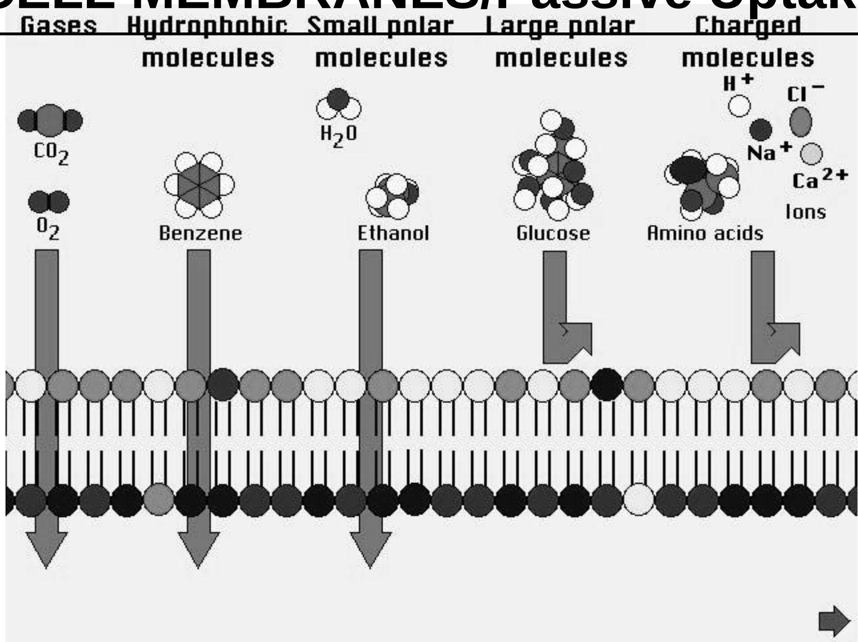
PASSIVE TRANSPORT

- High conc // membrane // Low conc
  > Free en. // diffuse down // < chem pt
- Membrane either
  - lipid phase with carrier
  - across aqueous pores

PASSIVE ION UPTAKE



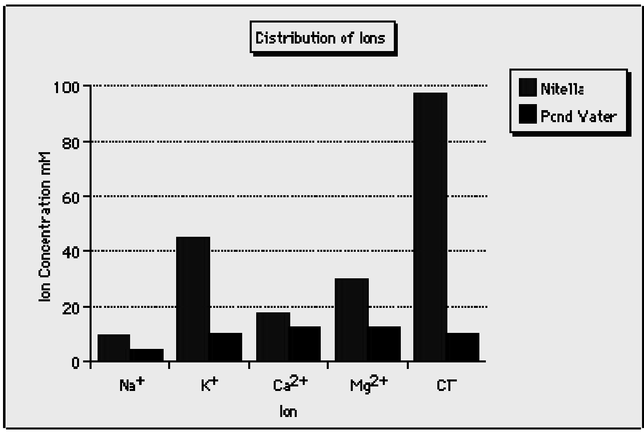
CELL MEMBRANES/Passive Uptake



MOVEMENT INTO THE ROOT

- Active transport of minerals
  - Occurs across the membrane against a concentration gradient
  - Requires energy to "pump" ions into the cell

EARLY EVIDENCE OF SELECTIVE ION UPTAKE



(HOAGLAND, 1948)

ACTIVE TRANSPORT

- **Transport uphill against energy gradient. (Pump in membrane)**
  - **Chemical Potential Gradient**
    - **- Conc of ions on either side of membrane**
  - **Electrical Potential Gradient**
    - **- Differential of milivolts across membrane**

ELECTROPOTENTIALS

- **Nernst equation**

$$E\,(mv) = \frac{RT}{zF} \ln \frac{[K^+_o]}{[K^+_i]}$$

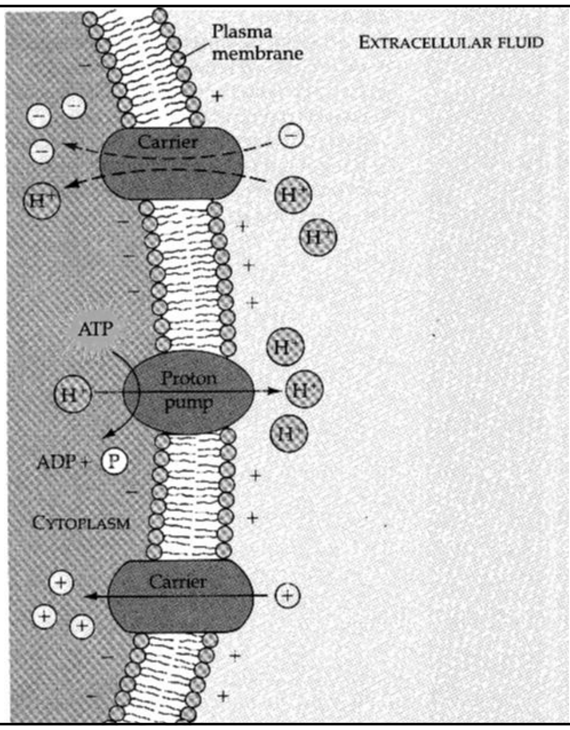
$$E\,(mv) = -59 \log \frac{\text{conc. inside (vacuole)}}{\text{conc. outside (external sol.)}}$$

ELECTROPOTENTIALS, cont'd

- K^+ in equilibrium if conc. in vacuole is 10 times > than in external solution.
- Cl- in equilib if conc in vacuole is 10 times < than in external solution.
- Divalent ions are 100 times or more different between vacuole and external solution

MOVEMENT INTO THE ROOT

Active Absorption



Two Classes of ATP Driven Proton Pumps

- Plasma membrane H^+-ATPase
  - Stimulated by monovalent cations
    - $K^+ > NH_4^+ > Na^+$
    - Insensitive to anions
- Tonoplast H^+-ATPase
  - Insensitive to monovalent cations
  - Stimulated by anions

Two Classes of ATP Driven Proton Pumps, con't

- These 2 classes of proton pumps present in all vacuolated cells
- Plasma membrane H^+-ATPase
  - Light dependent in leaves
  - May be resp - light stimulated K up
- Main driving force -
  - H^+-ATPase Fig. 3.10

COMPETITION BETWEEN IONS

- Comp between ^{42}K and K
- Comp between K^+ and Rb^+
- Ca $^{2+}$ does not comp with K^+
- NH_4^+ comp with K^+ but not reverse
  - Conversion to NH_3 leaves H^+ comp K^+
- Mg^{2+} binding weak
  - Replaced by Ca^{2+} and Mn^{2+}

ANION COMPETITION

- Cl^- can reduce excessive NO_3^- accumulation in spinach, barley
- In saline soils, Cl^- may impair N nutrition by reducing NO_3^- uptake

ROLE OF pH IN COMPETITION

- Low pH decreases K^+ uptake
  - Direct comp between H^+ and K^+
    - Large # H^+ & red'n efficiency of H^+-efflux pump
- At pH <4 & abs of Ca^2 redn root K^+
  - Addn of Ca stopped K loss. WHY?
- pH 7 to 4 decreases uptake of NH_4^+
  - Increases uptake of $NO3^-$

ION SYNGERISM

- Ca^{2+} stimulation of K^+ uptake
  - Increases with decreasing pH
  - Because
    - - Ca counteracts the high H^+ conc on K^+ uptake
- Stimulation less at higher pH
  - Ca^{2+} begins to inhibit K^+ - WHY?

ION UPTAKE ALONG ROOT

- Higher uptake in apical zone
  - Increase in suberin in older roots
  - Formation of barriers to radial translocation
- Only chance for Ca because lack of phloem mobility of Ca
- Ions react differently - Fe apical
  - Basal roots absorb more P than apical
- Apical cells use more K than basal cells

RADIAL ROOT TRANSPORT -1

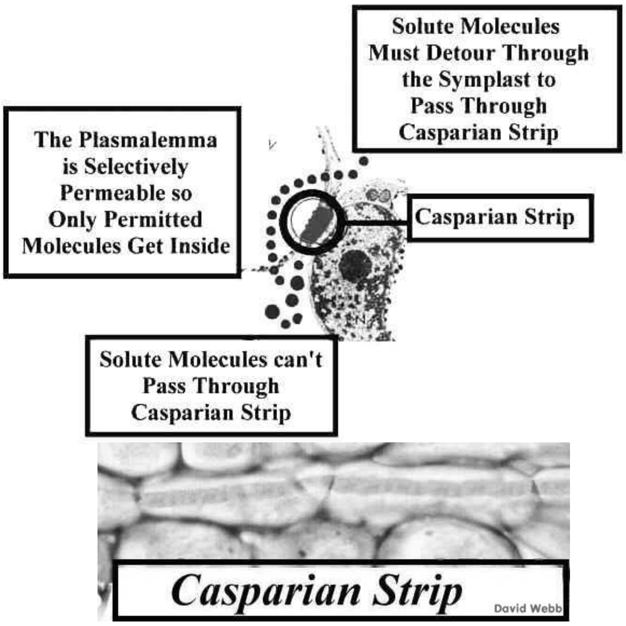
- Apoplastic
  - Ions move through cell walls & intercellular spaces
    - - Exception to termination at Casparian strip
    - (forms in few days old roots)
      - * Apical areas - suberization increases
      - * Basal areas - lateral root development
  - Leaky areas important for Ca, Al, Mg

RADIAL ROOT TRANSPORT - 2

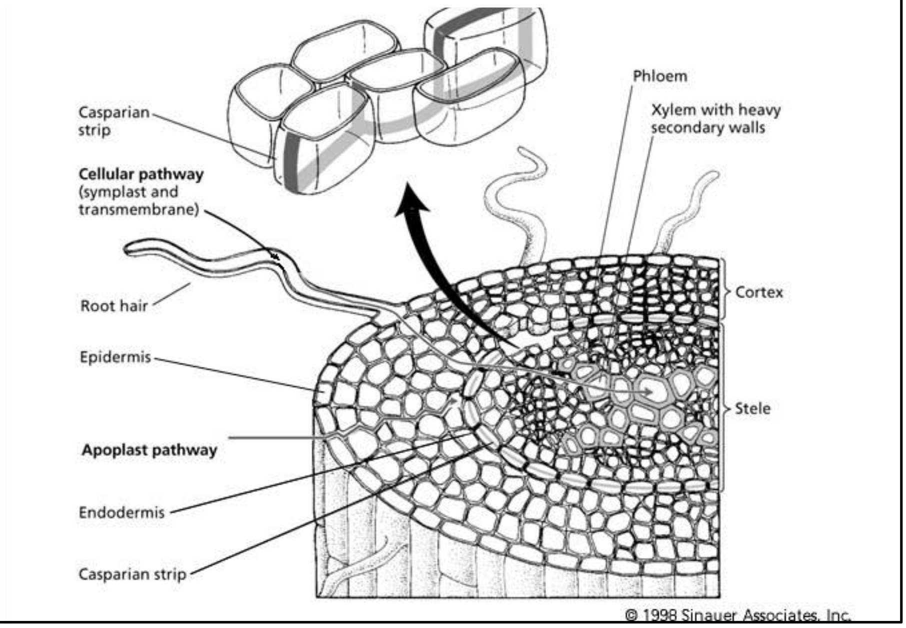
- **Symplastic**
  - **Ions passing from cell to cell thru**
    - **plasmodesmata bypassing vacuole**

- **Release of ions into xylem**

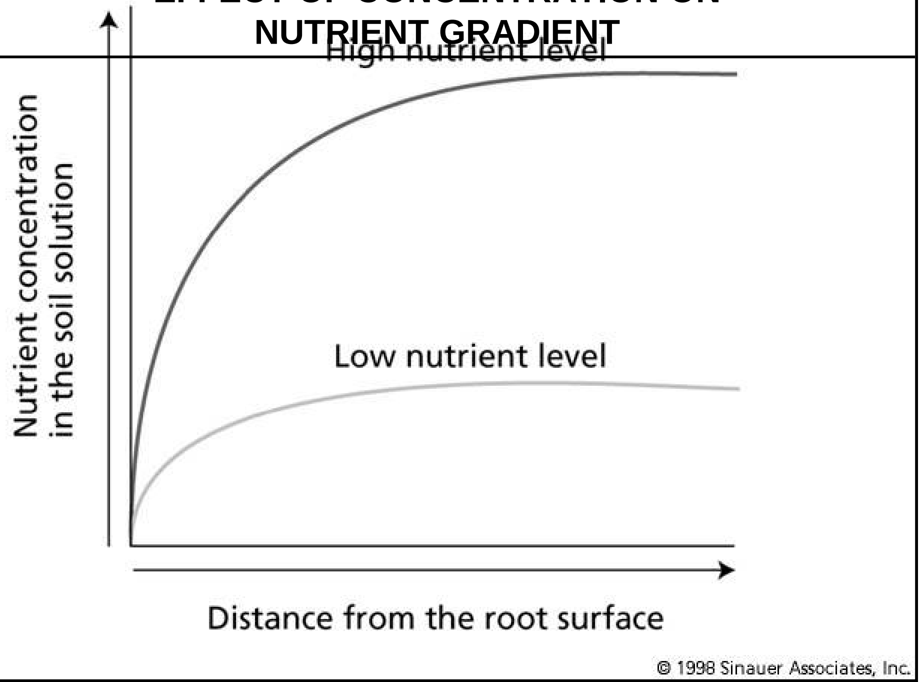
RADIAL ROOT TRANSPORT - 3



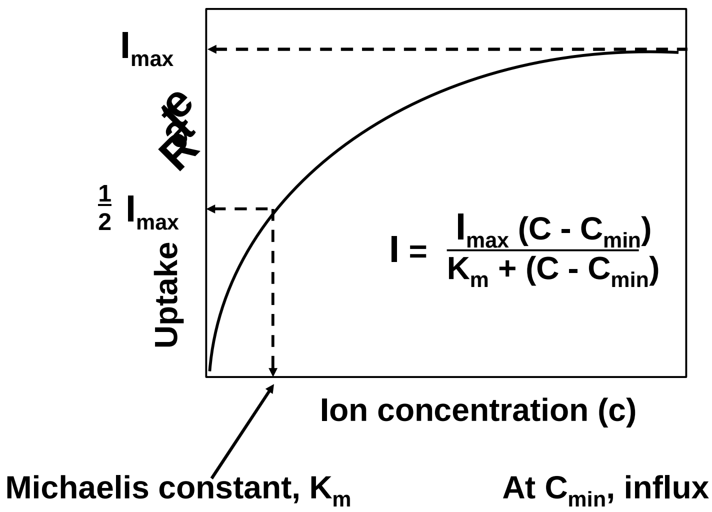
RADIAL ROOT TRANSPORT-4



EFFECT OF CONCENTRATION ON NUTRIENT GRADIENT



UPTAKE RATE AND ION SOLUTION CONCENTRATION

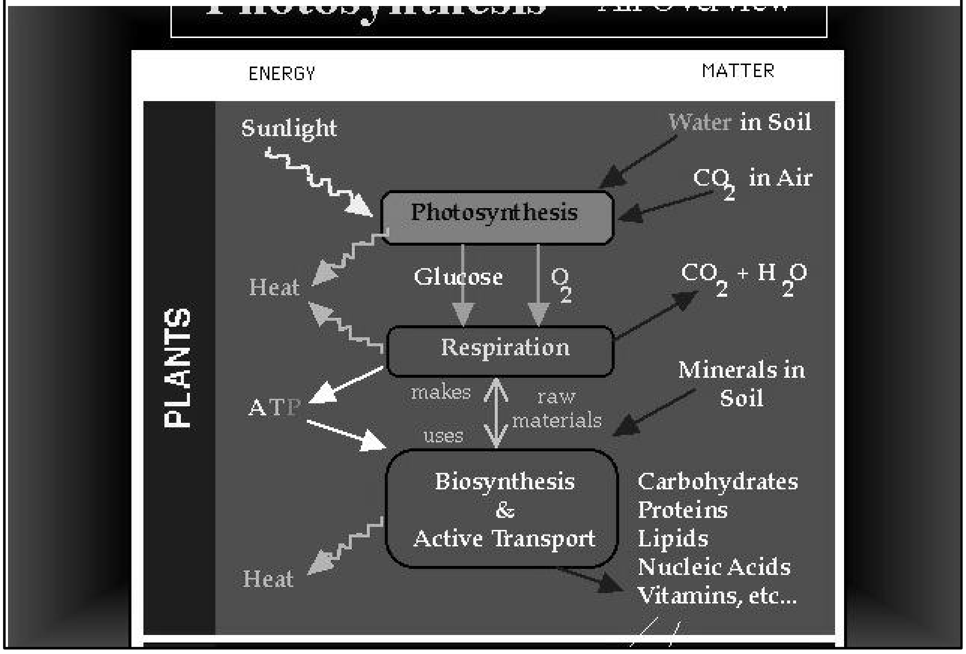


At C_{min}, influx and efflux are equal

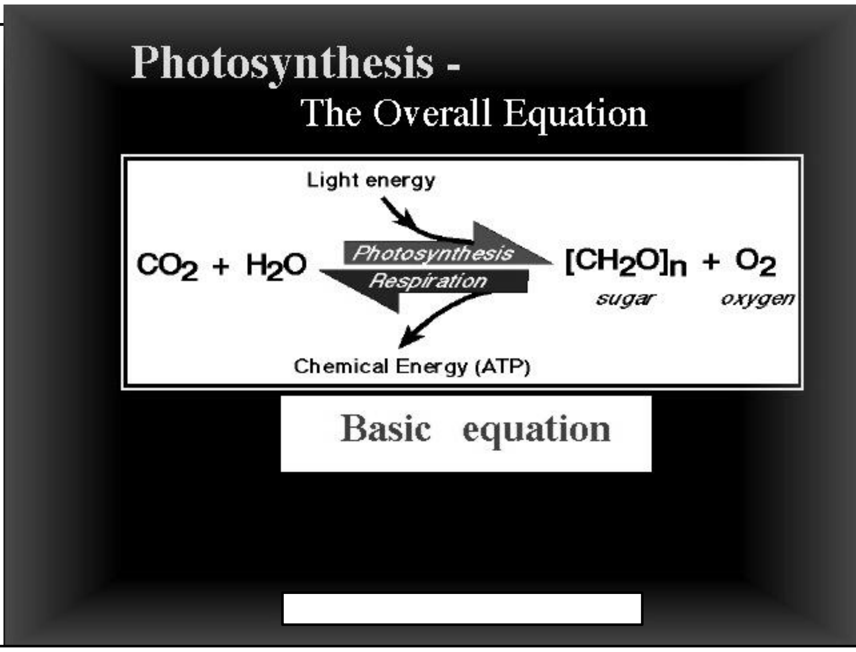
PHOTOSYNTHESIS AND CO_2 ASSIMILATION GENERAL OBSERVATIONS

- Many, many reactions are interrelated
- Excess products from one reaction used in another
  - minimizes potential toxicity (origin of reaction?)
  - product or pH change often initiates reactions
- Note the smooth flow of energy from one reaction to another, even in different cell structures
- Efficient recycling of energy-bearing compounds - these often participate in two sets of reactions; one in each "direction"

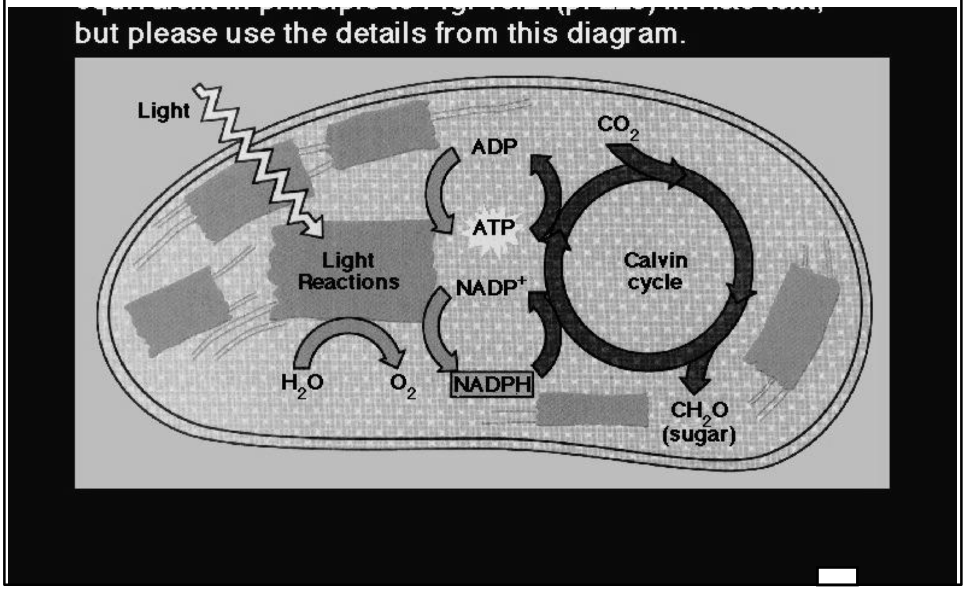
PHOTOSYNTHESIS AND CO_2 ASSIMILATION



PHOTOSYNTHESIS

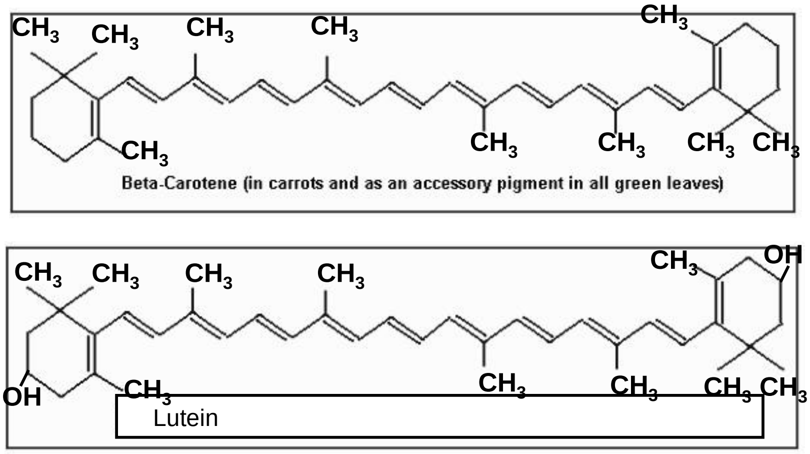


Process I: Photosynthesis | **Process II: CO_2 Assimilation**



LIGHT ABSORPTION & ELECTRON FLOW

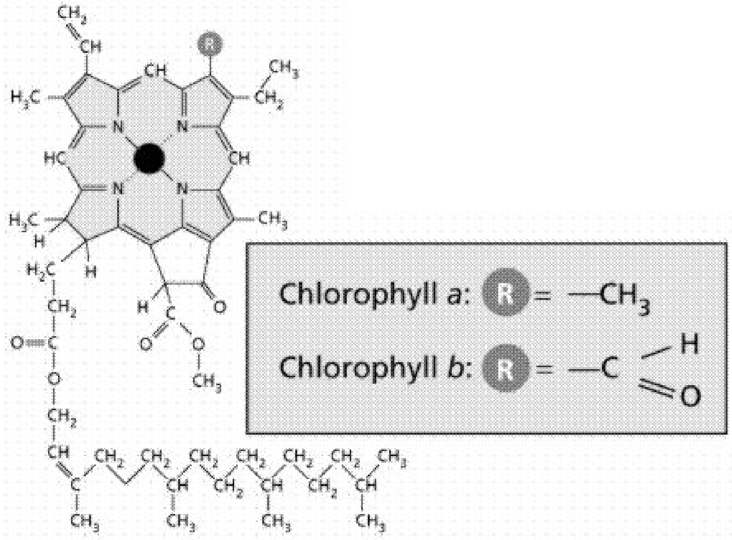
Light absorbing molecules



(Fig 3.16)

LIGHT ABSORPTION & ELECTRON FLOW

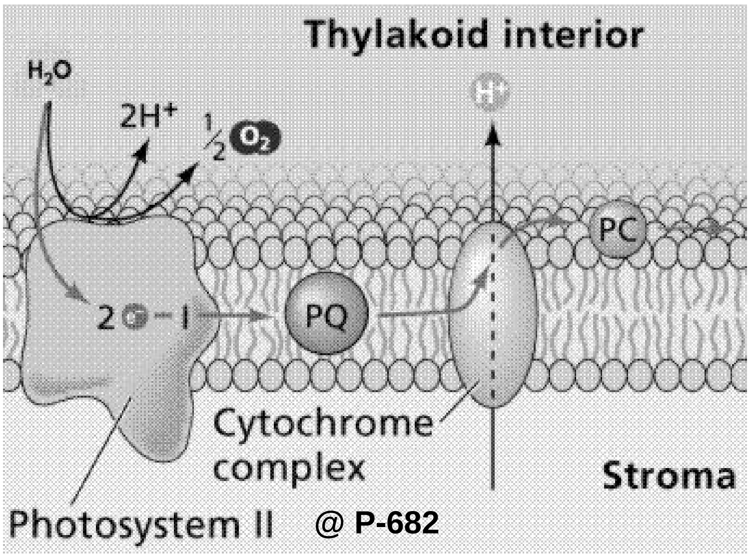
Light absorbing molecules



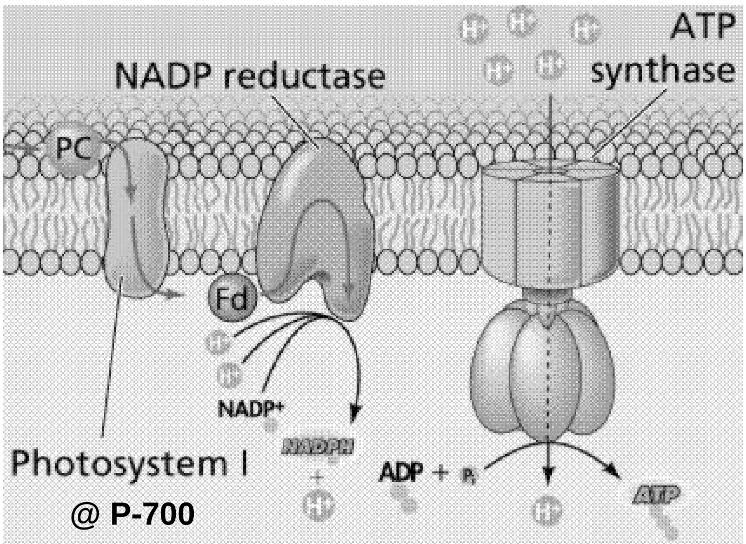
PHOTOPHOSPHORYLATION

- **Photophosphorylation = coupled electron transport and ATP synthesis**
- **Photosystems I and II operate within thyalkoid membrane**
- **ATP synthesis occurs within the thyalkoid membrane**
- **Potential generated also used for cation transport across membrane**
- **Mineral elements involved:**
  - **Mg - chlorophyll**
  - **Fe - ferredoxin - e^- transmitter/donor**
  - **Mn - enzyme complex - photolysis of H_2O**
  - **Cu - plastocyanin - e^- acceptor**

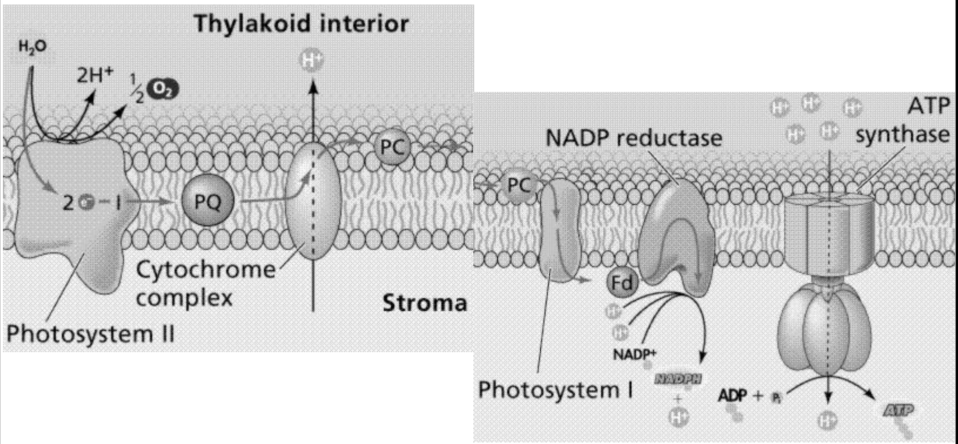
PHOTOSYSTEM II



PHOTOSYSTEM I



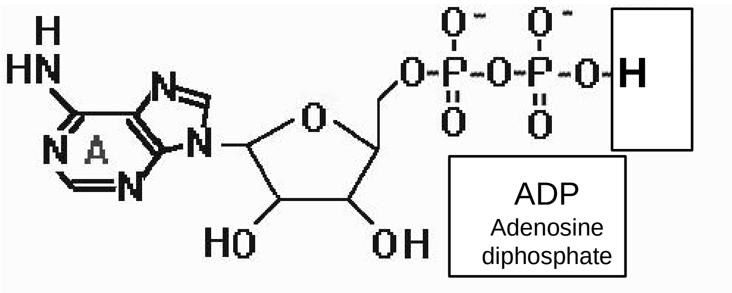
PHOTOSYSTEMS I AND II

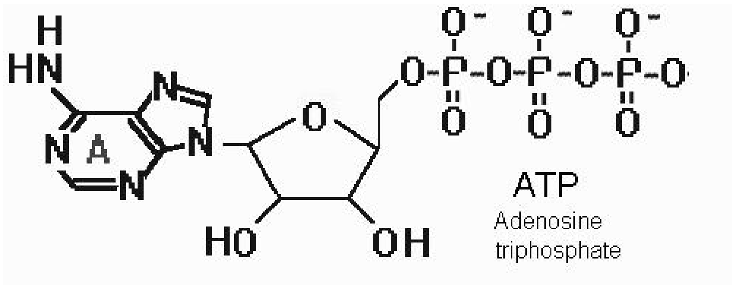


Photosys II @ P-682

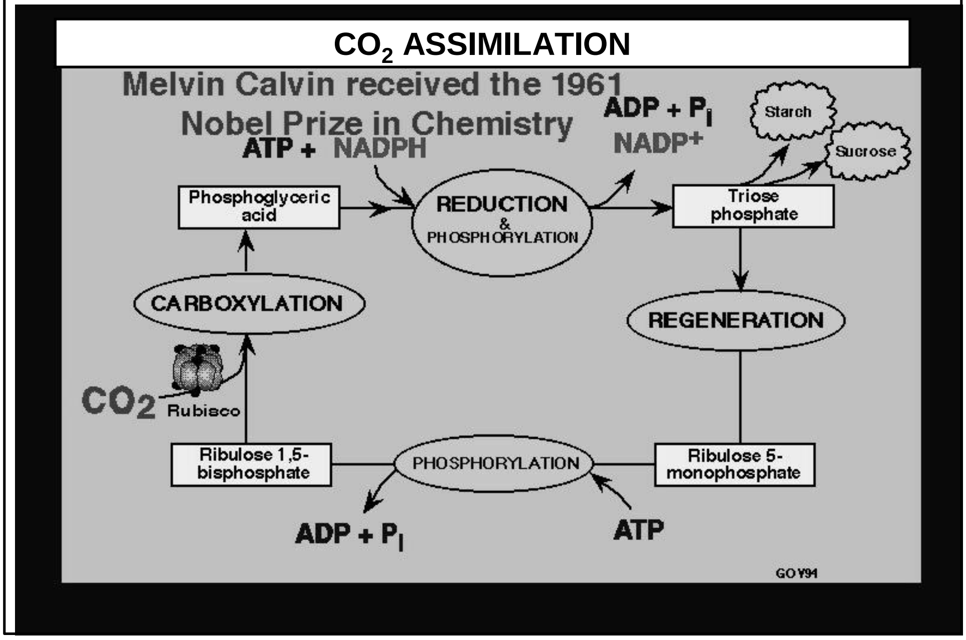
Photosys I @ P-700

ENERGY PROVIDER - ATP

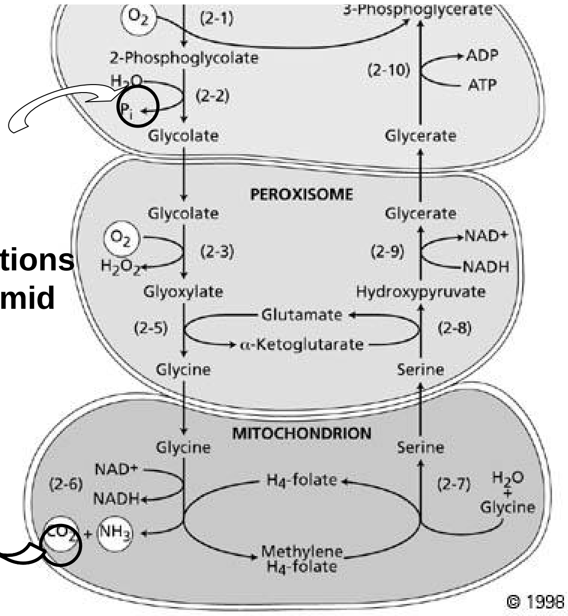




ESSENTIAL COMPONENTS OF THE CALVIN CYCLE

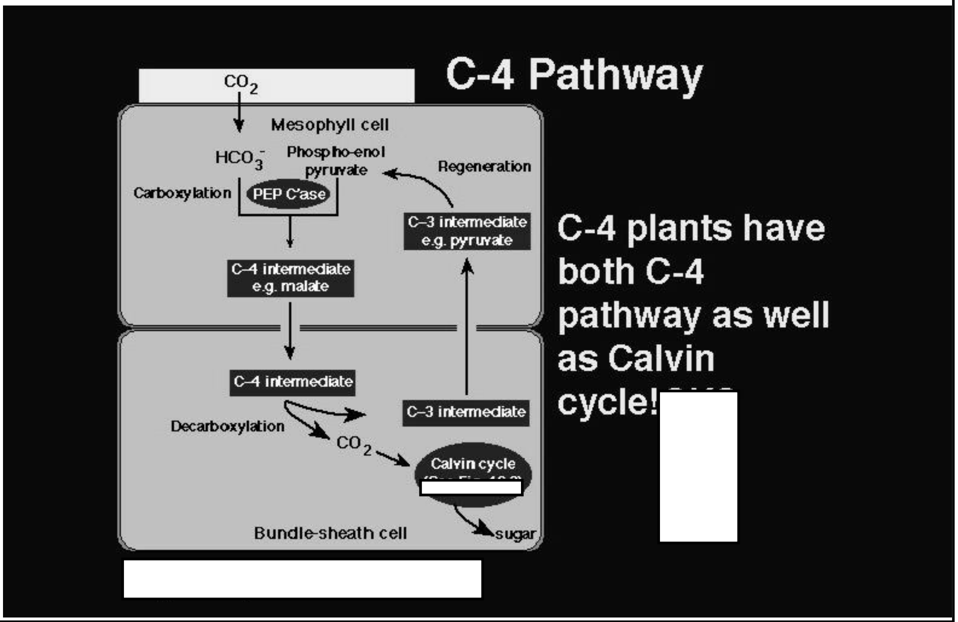


PHOTORESPIRATION & GLYCOLLATE PATHWAY



Unique reactions
In each plasmid

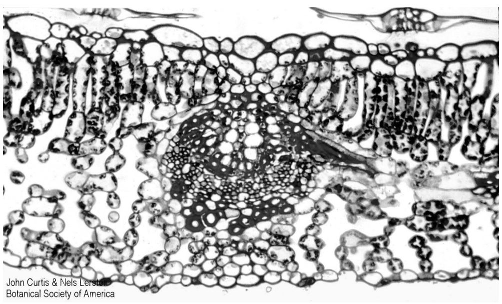
THE C-4 PATHWAY

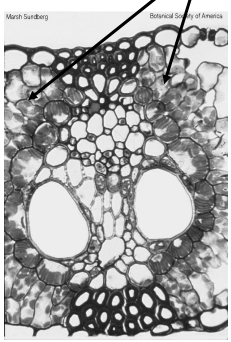


THE C-4 PATHWAY

- **Produces sugar and starches**
- **Operates in mesophyll cells that surround**
  - **vascular bundle: "produce & pump"**

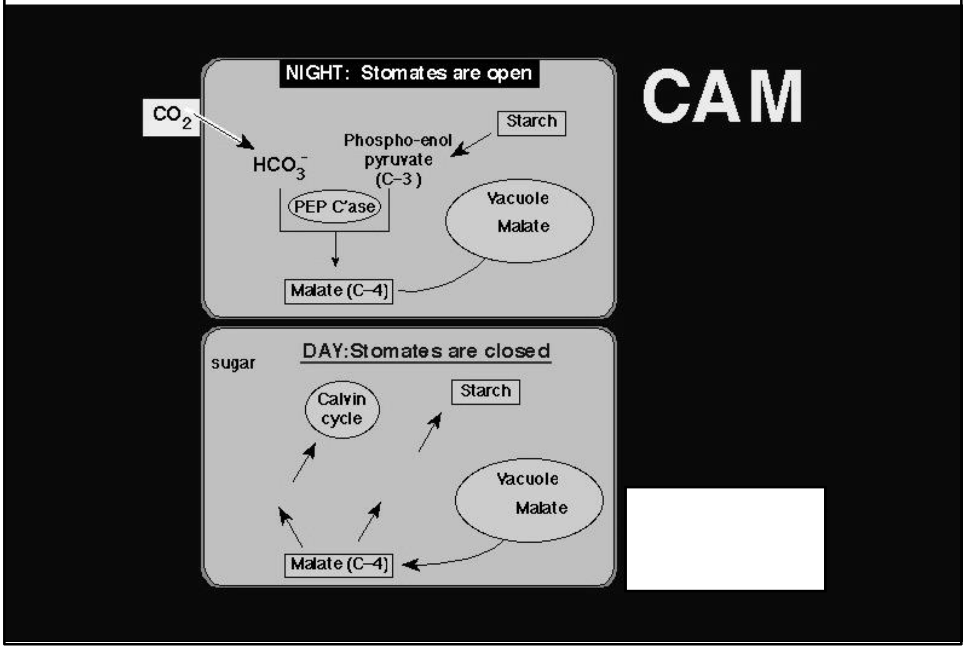
Mesophyll cells





Kranz anatomy: text, Plate 3.1

CRASSULACEAN ACID METABOLISM (CAM)



NITRATE REDUCTION

- NO_3^- is common form available to plants
- Must be reduced to NH_3 before being metabolized
- Two steps:
  - nitrate to nitrite reduction
    - NADH important
  - nitrite to ammonia reduction
    - ferredoxin important

NITRATE REDUCTION

- Mo deficiency causes NO_3^- accumulation
- Mn deficiency has indirect effect; is essential in Photosystem II for ferredoxin production
- Most plant species, NO_3^- reduction in roots & upper parts
- Trees & shrubs, most NO_3^- reduction in roots

NITRATE REDUCTION

$NO_3^- + NAD(P)H + H^+ + 2e^-$

$\rightarrow NO_2^- + NAD(P)^+ + H_2O$

Reductase in cytosol

(Cytoplasm) e

$NO_2^- + 6FD$

$_{ed} + 8H^+ + 6e^-$

$\rightarrow NH_4^+ +$

$6FD_{ox} + 2H_2O$

astids, chloroplasts

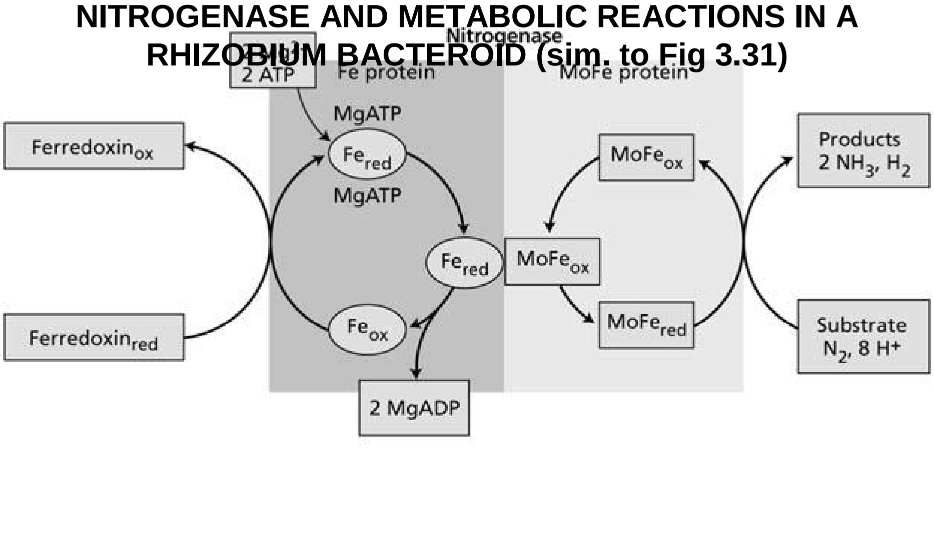
Nitrite Reductase in pl

NITROGEN FIXATION

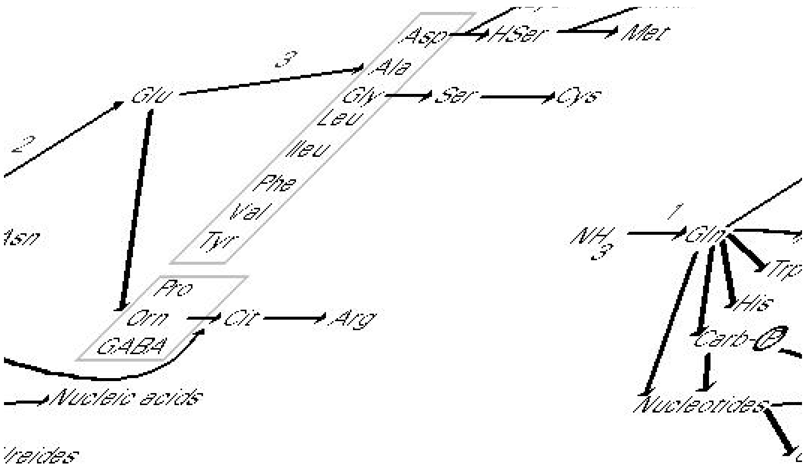
- **Conducted by bacteria**
  - **free-living**
  - **living in symbiosis with higher plant**
- ***Rhizobium* bacteria - legume assoc'n esp. impt.**
  - **bacteroid enveloped in membrane and embedded in host cell**
  - **anaerobic environment in bacteroid**
  - **ATP and ferredoxin important in process**
  - **NH_3 released into cells for utilization**

NITROGEN FIXATION

NITROGENASE AND METABOLIC REACTIONS IN A RHIZOBIUM BACTEROID (sim. to Fig 3.31)

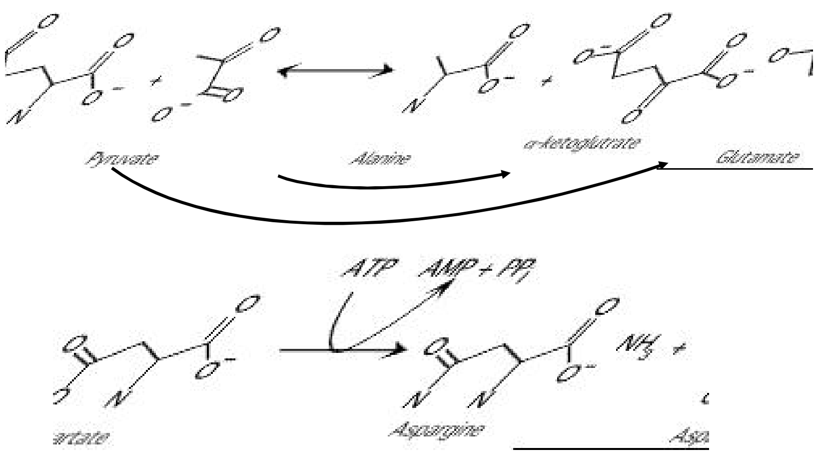


AMMONIA ASSIMILATION



trogen redistribution in Main pathways of ammonia assimilation and n
synthase; 3 = plants. 1 = Glutamine synthetase; 2 = glutamat
glutamine, and aminotransferases. From : Joy KW (1988) Ammoni
2103-2109. asparagine: a carbon - nitrogen interface. Can J Bot 6

AMINO ACIDS AND AMIDES



SULFUR ASSIMILATION