Color Key: Light-Dependent Reaction

= Light Energy = Chlorophyll-b = Carotenoids = ATP = $NADPH + H^+$

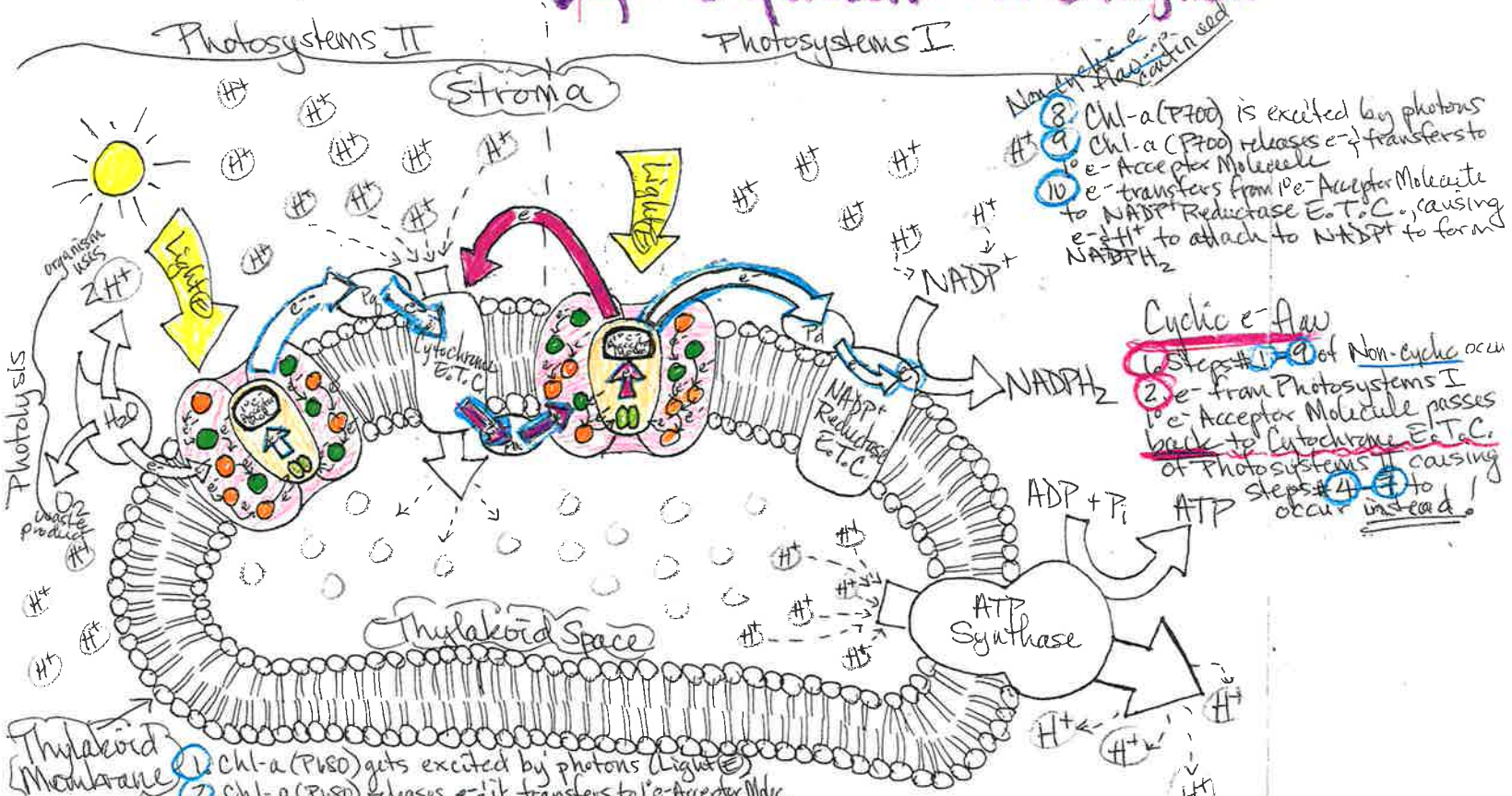
= Chlorophyll-a (P680) = Chlorophyll-a (P700) = $H^+$

= 1° Electron Acceptor Molecule in Photosystem

= Reaction Center of Photosystem = Light Harvesting Complex of Photosystem

Le Light Dependent Rxn Diagram

# L4 Light Dependent Rxn Diagram




Non-cyclic e- flow
8. Chl-a(P700) is excited by photons
9. Chl-a(P700) releases e- & transfers to 1° e- Acceptor Molecule
10. e- transfers from 1°e- Acceptor Molecule to NADP+ Reductase E.T.C., causing e- & $H^+$ to attach to NADP+ to form $NADPH_2$

Cyclic e- flow
1. Steps #1-9 of Non-cyclic occur
2. e- from Photosystems I 1° e- Acceptor Molecule passes back to Cytochrome E.T.C. of Photosystems II causing steps #4-7 to occur instead!

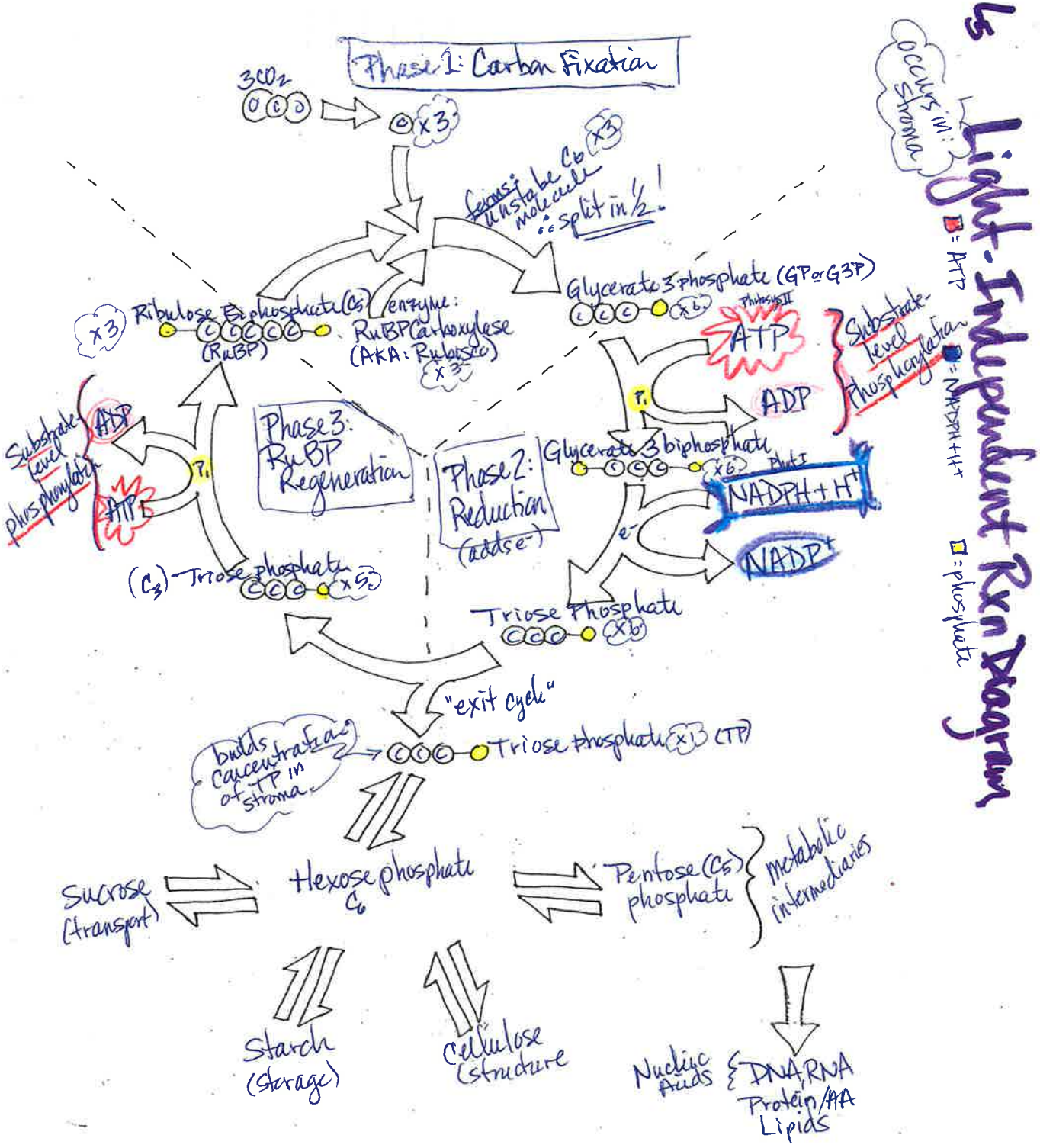
Thylakoid Membrane
1. Chl-a(P680) gets excited by photons (Light)
2. Chl-a(P680) releases e- & it transfers to 1° e-Acceptor Molec.
3. e- transfers from 1° e- Acceptor Molecule → Cytochrome E.T.C.
4. Cytochrome E.T.C. pumps $H^+$ from stroma to Thylakoid space
5. Electrochemical gradient (Proton gradient) forms
6. $H^+$ exit through ATP Synthase to Stroma causing phosphorylation of ADP → ATP
7. Chl-a(P680) stabilized by e- from $H_2O$ causing Photolysis

RH

30':

# Photosynthesis Details

summary/reflection


Light-Independent Rxn Diagram
Occurs in: Stroma
= ATP
= NADPH+H+
= phosphate
Phase 1: Carbon Fixation
3CO2
x3
Ribulose Biphosphate (C5) (RuBP)
enzyme: RuBP Carboxylase (AKA: Rubisco)
Unstable C6 molecule ∴ split in ½!
Glycerate 3-phosphate (GP or G3P)
ATP
ADP
Substrate-level Phosphorylation
Phase 3: RuBP Regeneration
Phase 2: Reduction (adds e-)
Glycerate 3 biphosphate
NADPH+H+
NADP+
(C3) Triose phosphate
Triose Phosphate
"exit cycle"
builds concentration of TP in stroma
Triose phosphate (TP)
Sucrose (transport)
Hexose phosphate C6
Pentose (C5) phosphate
metabolic intermediates
Starch (Storage)
Cellulose (structure)
Nucleic Acids
DNA, RNA
Protein/AA
Lipids

R5

30's

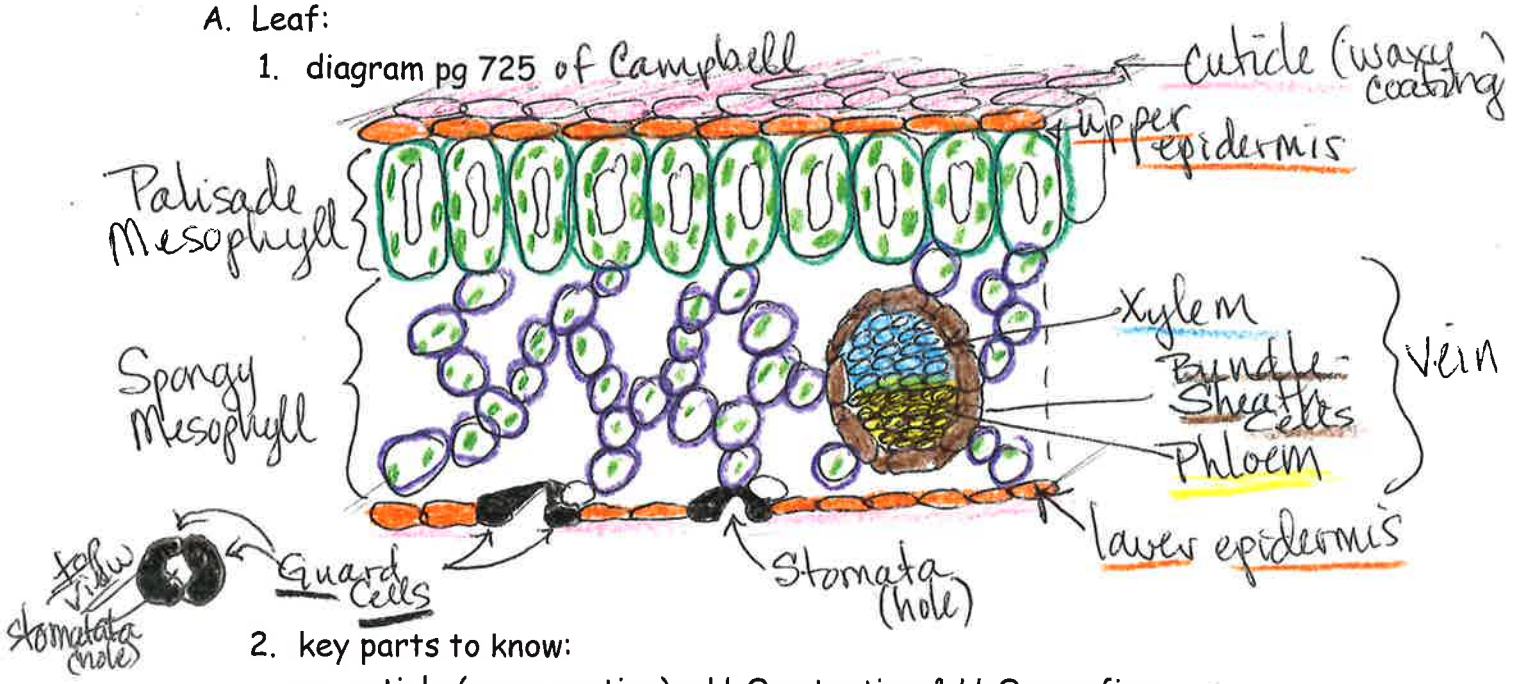
# Photosynthesis Details

# Photosynthesis Details

I. Organisms that perform photosynthesis:
   A. Plants... what we will be talking about
   B. Others... pg 187
      1. some protists (Euglenids) & some bacteria (Cyanobacteria)

II. Light:
   A. Acts as a wave & a particle
      1. Wave... electromagnetic E (AKA Electromagnetic radiation)
      2. Particle... photon
   B. Electromagnetic spectrum
      1. ranges from short gamma waves to long radio waves
      2. only a small band (380nm-725mm) is visible light

III. Site of photosynthesis:
   A. Leaf:
      1. diagram pg 725 of Campbell




      2. key parts to know:
         a. cuticle (waxy coating) = $H_2O$ retention & $H_2O$ proofing
         b. epidermis = surface cells
         c. vein (xylem & phloem) = transport $H_2O$ (X) & sugars (P)
         d. mesophyll = middle tissues
            1) Palisade mesophyll = main photosynthetic cells
            2) Spongy mesophyll = main gas exchange cells
         e. stoma = holes for gas exchange (singular: stomata)
         f. guard cells = regulate size of stoma
         g. bundle-sheath cells = surround veins

   B. photosynthetic portion:
      1. Mesophyll:
         a. spongy mesophyll
         b. palisade mesophyll (columnar cells)
            1) mesophyll cell

a) chloroplast
① Thylakoid (membrane sac) = site of Light-Dependent Rxns (Photosystems II & I)
Ⓐ Thylakoid space (inside)
Ⓑ Thylakoid membrane
Ⓒ Grana (stacks of thylakoid sacs)
② Stroma (~~dense~~ viscous fluid w/enzymes) = site of Light-Independent Rxns (Calvin Cycle)

IV. Pigments involved in photosynthesis:
A. Pigment dfn:
1. molecules that absorb sections of the visible light spectrum (absorbs photons... electromagnetic energy)
2. light that is not absorbed is reflected or transmitted
B. Types of pigments:
1. Chlorophyll-a: main photosynthetic pigment
a. 2 types:
1) P680... absorbs the most E at 680nm light
2) P700... absorbs the most E at 700nm light
b. blue-green in color
c. absorbs: violet-blue & red light
d. occurs in: Reaction Center of Photosystem protein
2. Chlorophyll-b: accessory photosynthetic pigment
a. yellow-green in color
b. absorbs: violet, blue & red light
c. occurs in: Light Harvesting Complex of Photosystem protein
3. Carotenoids: accessory photosynthetic pigment
a. yellow & orange in color
b. absorbs: violet & blue light
c. occurs in: Light Harvesting Complex of Photosystem protein
d. ... also acts as photoprotection (antioxidants & sunscreen)

V. Light-Dependent Reactions:
A. A.K.A.: Photosystems II & I
B. Photosystems... the "thing"
1. protein complex imbedded in Thylakoid membrane
2. structure (parts):
a. Light Harvesting Complex:
1) pigments (Chl-b & Carotenoids) bound to proteins
2) encircle the Reaction Center
3) general process that occurs there:
a) pigments collect photons, transfer E between pigments (by transferring e-), transfer E to Reaction Center (by transferring e-)
b. Reaction Center:

1) Chlorophyll-a (P680 & P700) and 1° e- Acceptor Molecule bound to a protein
2) surrounded by the Light Harvesting Complex
3) general process that occurs there:
a) Chlorophyll-a receives (E) (in the form of an e-), gets "excited", releases e-, transfers e- to 1° e- Acceptor Molecule

C. Photosystems... the process
1. Typical process = Noncyclic e- Flow
a. Photosystems II
1) Chl-a (P680) excited by photons ∴ loses e-
a) Chl-a (P680) needs e- to be stable ∴ takes e- from $H_2O$ (photolysis) ∴ $H_2O$ splits into $H^+$ & $O_2$ gas
2) e- from Chl-a (P680) transfers to 1° e- Acceptor Molecule
3) e- passes to Electron Transport Chain (E.T.C.) AKA Cytochrome T.C.
a) leads to: $H^+$ pumped into thylakoid space from the stroma
4) chemiosmosis occurs
a) (photo)phosphorylation (pg 193) Campbell
① ↑ # $H^+$ in thylakoid space
② creates proton (electrochemical) gradient... A.K.A. membrane potential
③ ATP Synthase allows H+ ions back across the thylakoid membrane into the stroma & (E) generated is used to convert ADP + Pi → ATP

b. Photosystems I:
1) Chl-a (P700) excited by photons & e- from Photosystems II E.T.C. ∴ loses e-
2) e- from Chl-a (P700) transfers to 1° e- Acceptor Molecule
3) e- passes to different E.T.C. which produces NADPH

2. Alternate process = Cyclic e- Flow
a. caused by Photosystems I ONLY (pg 191) Campbell
1) Chl-a (P700) excited by photons & e- from Photosystems II E.T.C. ∴ loses e-
2) e- from Chl-a (P700) transfers to 1° e- Acceptor Molecule
3) e- passes to Photosystems II E.T.C. (Cytochrome) instead
4) ∴ chemosynthesis (chemiosmosis) occurs by (photo)phosphorylation ∴ ATP formed not NADPH

VI. Light-Independent Reactions:
A. A.K.A. Calvin Cycle
B. 3 phases:
1. Carbon Fixation:
a. take off C from CO2
b. attach C to $C_5$ Ribulose Biphosphate (RuBP)

1) uses enzyme: Ribulose Biphosphate Carboxylase (RuBP Carboxylase) AKA: RubisCO

c. forms unstable $C_6$ sugar molecule ∴ splits into two $C_3$ molecules

2. Reduction: (add e-)
   a. Pi from ATP is added to $C_3$ molecules (adds E)
   b. $C_3$ molecule reduced (by adding e- from NADPH)
   c. Produces $C_3$ Glyceraldehyde-3-Phosphate (G3P)... $C_3H_6O_3$ AKA: Triose Phosphate (TP)
      1) one G3P exits Calvin Cycle
      2) G3P used to form:
         a. glucose, starch, cellulose, and even other O. Molec (pg 198) such as DNA, RNA, Proteins & Lipids
3. Regeneration of RuBP:
   a. 5 molecules of G3P are rearranged to form 3 molecules of RuBP
      1) using enzymes & Pi from ATP's

VII. Photorespiration: photosynthesis "oops"
   A. occurs when not enough $CO_2$ to do photosynthesis
   B. typical reason why there's not enough $CO_2$?... partially closed stomata
   C. photorespiration process:
      1. RuBP Carboxylase (enzyme) binds to $O_2$ instead of $CO_2$
      2. ∴ $C_2$ molecules produced instead of unstable $C_6$ molecule
      3. $C_2$ molecules unusable ∴ broken down in mitochondrion or peroxisome ∴ produces $O_2$ (creates vicious cycle w/#1)
      4. End Result:
         a. NO sugar produced & ↓#ATP
         b. ∴ takes E from Calvin Cycle ∴ ↓# glucose (by ≈ 50%)

VIII. How do plants deal w/these partially closed stomata?
   A. need to "fix" or take in more $CO_2$ molecules
   B. 2 plant adaptations: (different than $C_3$ plants which is most common plant type)
      1. $C_4$ plant (i.e. corn & sugarcane)
         a. stomata only open part of day
         b. use 2 photosynthetic cells instead of 1:
            1) mesophyll cell (where all part of typical C3 plant photosynthesis occurs)
               a) uses PEP Carboxylase instead of RuBP Carboxylase... *different enzyme=different product*
               b) produces $C_4$ Malate
               c) $C_4$ Malate transported to bundle-sheath cells
            2) bundle-sheath cell
               a) $CO_2$ released from C4 Malate
               b) $CO_2$ enters Calvin Cycle
      2. CAM (Crassulacean Acid Metabolism) plant (i.e. succulents)
         a. stomata closed in day & open at night

what we have been outlining in notes :)

b. $CO_2$ fixed into organic acids (i.e. crassulacean acid) when stomata open
c. organic acids stored in mesophyll cell organelles (vacuole)
d. $CO_2$ released from organic acids during daytime when stomata closed & enters Calvin Cycle

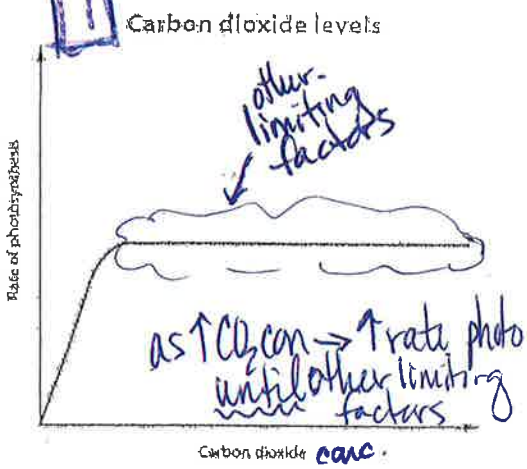
IX. Why is photosynthesis important?... human perspective
A. $O_2$ production
B. $CO_2$ intake $\therefore$ $\downarrow CO_2$... which is a greenhouse gas
C. Food production $\approx$ 160,000,000,000 metric tons of carbohydrates/year!!
D. Coupling with Aerobic Cellular Respiration to cycle materials in ecosystems

3 Limiting factors

# Environmental Effects on Photosynthesis

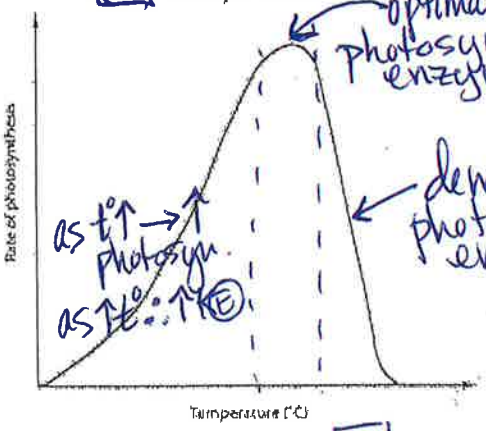
How measure Photosynthesis?
① rate of $CO_2$ consumed? ← use probeware
② rate of $O_2$ produced } ← use probeware
③ $\Delta$ in pH aq. (aquatic) around plant or cyanobacteria ← use color indicator (Bromthymol Blue)

1 Carbon dioxide levels



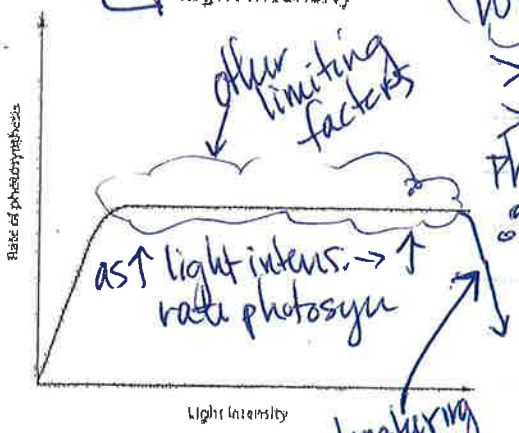

why?
> $CO_2$ ∴ > #C's available for carbon fixation of Calvin Cycle ∴ > rate Calvin cycle ∴ > #GP → TP ∴ > # carbs → other O. macromolecules

2 Temperature




why 1st part of curve?
> t° ∴ > K(E) ∴ > rate of photosynthetic enzyme function (ex. ATP Synthase & RuBP Carboxylase AKA Rubisco) ∴ ↑ rate of both light-dep & light-ind rxn

3 Light intensity

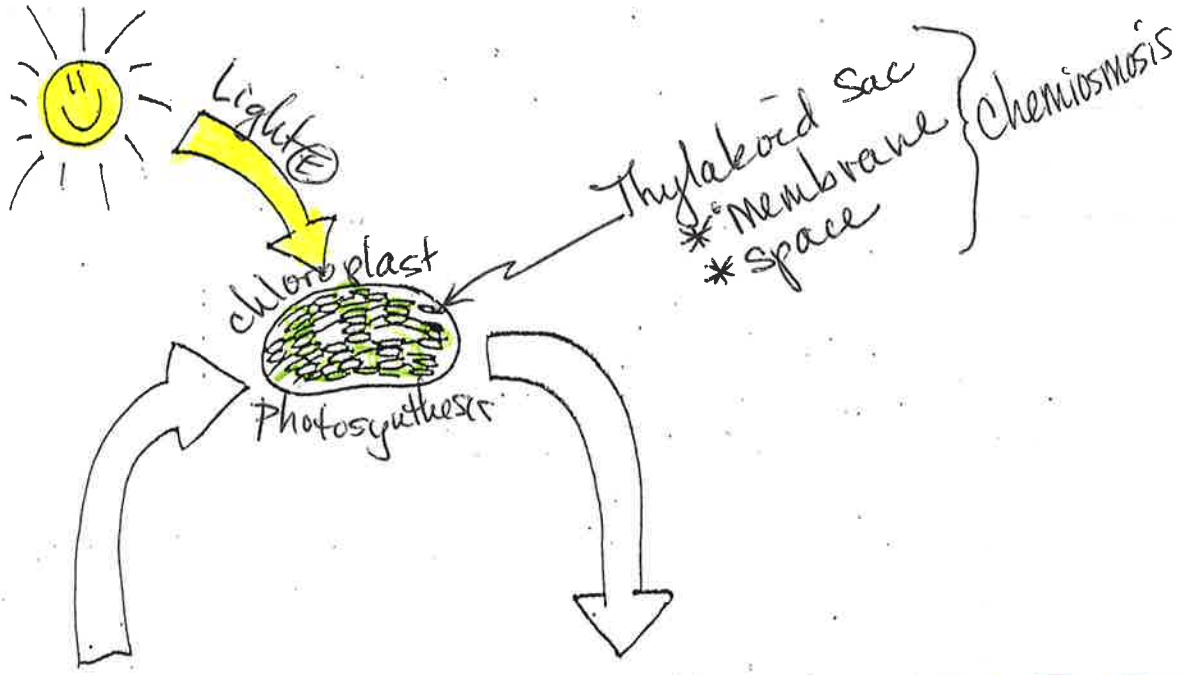



why?
> light intensity ∴ > photoactivation of Phot II & I Protein Complexes ∴ > prod ATP & $NADPH+H^+$ & $O_2$ (photolysis) ∴ > rate Calvin Cycle (Light-independent rxn) ∴ > prod G3P & TP ∴ > level O. macromolecules produced by organism

# R1 Cycling of Molecules in Ecosystems "Global Balance"

OVERALL Equation for Photosynthesis

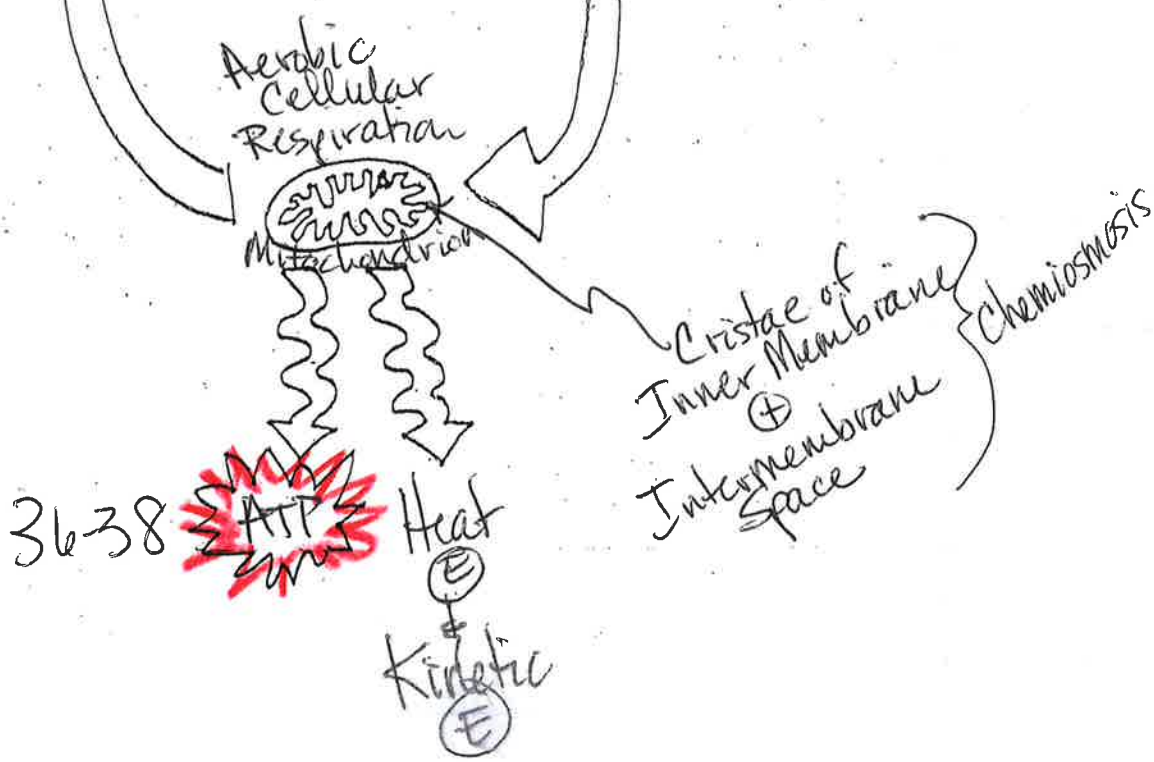
$6CO_2 + 6H_2O + \text{Light} \rightarrow C_6H_{12}O_6 + 6O_2$




$6CO_2 + 6H_2O \quad\quad 6O_2 + C_6H_{12}O_6$

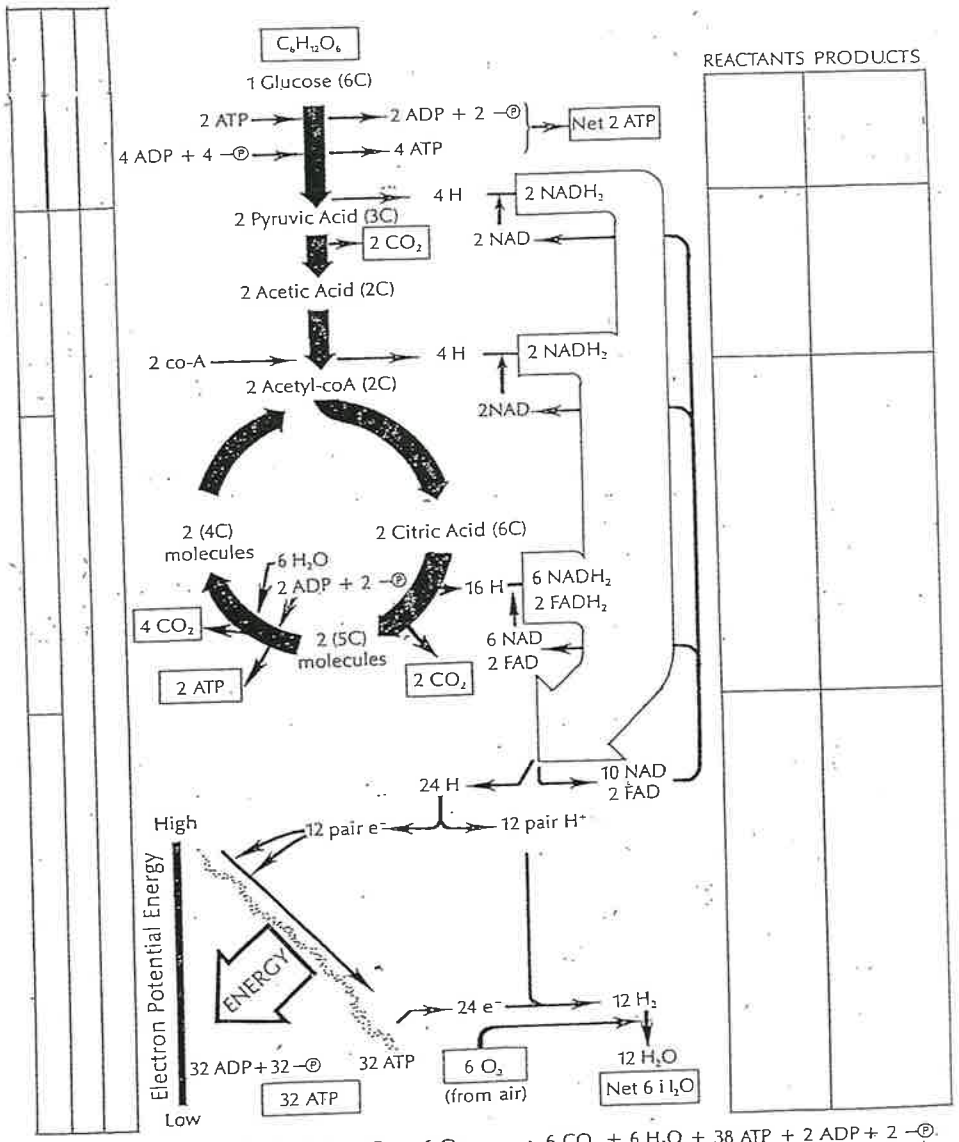
OVERALL Equation for Aerobic C.R.

$6O_2 + C_6H_{12}O_6 \rightarrow 6CO_2 + 6H_2O + 36\text{-}38\ ATP$



Lz Aerobic Cellular Respiration Review

# Aerobic Cellular Respiration Process:



Anaerobic Cellular Respiration: Glycolysis → Lactic Acid Ferm: 2 ATP, 2 Lactate
→ Alcoholic Ferm: 2 ATP, 2 Ethanol, 2 $CO_2$

# (O₂) Aerobic Cellular Respiration Process:

in Mitochondrion

| | Glycolysis (pg 166) | Link RXN (pg 168) | Krebs (Citric Acid) Cycle (pg 168) | Oxidative Phosphorylation (pg 172) |
|---|---|---|---|---|
| | No $O_2$ | $O_2$ | No $O_2$ | $O_2$ is final e⁻ acceptor |
| | Cytosol | Intermembrane Space | Matrix | Cristae (ETC) Matrix & Intermembrane Space (Chemiosmosis) |

$C_6H_{12}O_6$

1 Glucose (6C)

2 ATP → 2 ADP + 2 Ⓟ → Net 2 ATP

4 ADP + 4 Ⓟ → 4 ATP

4 H → 2 $NADH_2$ / $NADH+H^+$

2 Pyruvic Acid (3C) → 2 $CO_2$

2 NAD

2 Acetic Acid (2C)

2 co-A → 4 H → 2 $NADH_2$ / $NADH+H^+$

2 Acetyl-coA (2C)

2NAD

2 (4C) molecules + 6 $H_2O$ + 2 ADP + 2 Ⓟ → 4 $CO_2$ + 2 ATP

2 Citric Acid (6C) → 16 H → 6 $NADH_2$, 2 $FADH_2$

2 (5C) molecules → 2 $CO_2$

6 NAD, 2 FAD

24 $H^+$ → 10 $NAD^+$, 2 FAD

12 pair $e^-$ → 12 pair $H^+$

ETC

produces electrochemical gradient by pumping $H^+$ from matrix into Intermembrane space

ENERGY

$H^+$

Chemiosmosis

32 ADP + 32 Ⓟ → 32 ATP

24 $e^-$ → 12 $H_2$

6 $O_2$ (from air) → 12 $H_2O$

Net 6 $H_2O$

High

Electron Potential Energy

Low

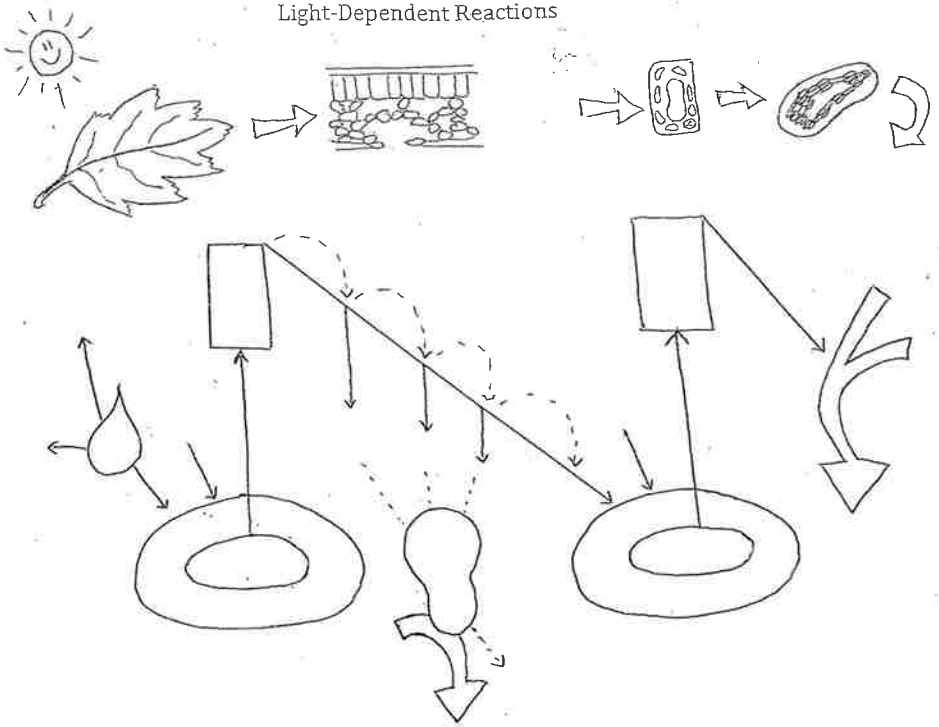
| Inputs (Reactants) | Outputs (Products) |
|---|---|
| $C_6H_{12}O_6$ | $2H_2O$ |
| 2 ATP | 2 $NADH+H^+$ |
| 4 ADP | 2 ADP + 2 Ⓟ |
| 4 Pi | 4 ATP |
| 2 $NAD^+$ | 2 Pyruvate |
| 2 pyruvate | 2 Acetyl CoA |
| 2 Co-A | 2 $NADH+H^+$ |
| 2 $NAD^+$ | 2 $CO_2$ |
| 2 Acetyl-CoA | 2 Co-A |
| 6 $NAD^+$ | 6 $NADH+H^+$ |
| 2 $FAD^+$ | 2 $FADH_2$ |
| 6 $H_2O$ | 6 $CO_2$ |
| 2 ADP | 2 ATP |
| 2 Pi | |
| 10 $NADH+H^+$ | 10 $NAD^+$ |
| 2 $FADH_2$ | 2 $FAD^+$ |
| 6 $H^+$ | 6 $H_2O$ |
| 6 $O_2$ | |
| 32-34 ADP | 32-34 ATP |
| 32-34 Pi | |

$2\,ATP + 38\,ADP + 38\,Ⓟ + C_6H_{12}O_6 + 6\,O_2 \longrightarrow 6\,CO_2 + 6\,H_2O + 38\,ATP + 2\,ADP + 2\,Ⓟ$

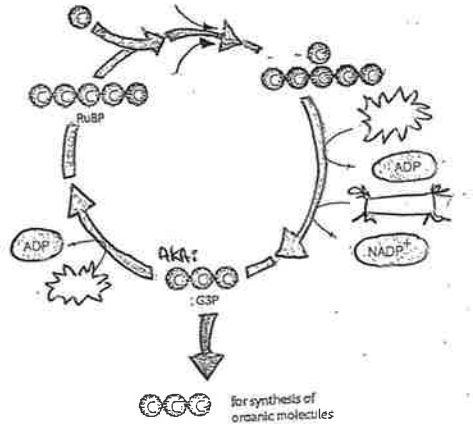
$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + 38ATP$ (36-38) → 686 Kcal/mole of glucose

# Photosynthesis Proces:

Light-Dependent Reactions



Light-Independent Reactions




Photosynthesis Review

# Photosynthesis Process ($C_3$)