**Photosynthesis Notes 2019**

**Concept: Photosynthesis converts light energy to the chemical energy of food**

All life needs a constant input of energy

-Heterotrophs (Animals) get their energy from “eating others”. They eat food = other organisms = organic molecules and make energy through respiration. Consumers.

C6H12O6 + 6O2 🡪 6CO2 + 6H20 + ATP

-Autotrophs (Plants) produce their own energy (from “self”). They convert energy of sunlight to build \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ molecules (CHO) from CO2 and make energy & synthesize sugars through photosynthesis. Producers.

6CO2 + 6H20 + light energy 🡪 C6H12O6 + 6O2

Plants need to: collect light energy and transform it into chemical energy and store light energy in a stable form to be moved around the plant or stored. It needs to get building block atoms from the environment

C,H,O,N,P,K,S,Mg. They produce all organic molecules needed for growth including carbohydrates, proteins, lipids, nucleic acids

Obtaining raw materials: sunlight collected from leaves = solar collectors, CO2 collected from \_\_\_\_\_\_\_\_\_\_\_\_\_ = gas exchange, H2O uptake from roots, nutrients such as N, P, K, S, Mg, Fe… uptake from roots.

Plant Structure

Chloroplasts have double membrane (outer and inner). Inside the chloroplast is a fluid-filled interior called the \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_. There are stacks of disc like structures (thylakoids). Each stack is grana. Each Thylakoid has a membrane which contains chlorophyll molecules, electron transport chains, ATP synthase, and H+ gradient built up within thylakoid sac

Photosynthesis Overview:

-Light reactions also known as light-dependent reactions or energy conversion reactions. They convert solar energy to chemical energy (ATP & NADPH)

-Calvin cycle also known as light-independent reactions or sugar building reactions. They use chemical energy (ATP & NADPH) to reduce CO2 & synthesize C6H12O6

Light reactions: use Electron Transport Chain like in cellular respiration, use proteins in organelle membrane, use electron acceptors (\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_), use proton (H+) gradient across inner membrane, and use ATP synthase enzyme to build ATP.

The ATP that “Jack” built:

Photosynthesis uses Sunlight to: move the electrons, which runs the pump, that pumps the protons, that builds the gradient, that drives the flow of protons through ATP synthase, that bonds Pi to ADP, that generates ATP…..that evolution built.

**Concept: The light reactions convert solar energy to the chemical energy of ATP and NADPH**

Pigments of Photosynthesis:

Chlorophylls & other pigments are embedded in thylakoid membrane and arranged in a “\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_” which is a collection of molecules

Light: Absorption Spectra

Photosynthesis gets energy by \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ wavelengths of light. One pigment is chlorophyll a. It absorbs best in red & blue wavelengths & least in green. Other accessory pigments with different structures absorb light of different wavelengths. They include chlorophyll b, carotenoids, xanthophylls

2 Photosystems of photosynthesis: Each is a collection of chlorophyll molecules that act as light-gathering molecules.

-Photosystem II uses chlorophyll a P680 = absorbs 680nm (wavelength \_\_\_\_\_\_\_\_\_\_ light)

-Photosystem I uses chlorophyll b P700 = absorbs 700nm (wavelength red light)

ETC of Photosynthesis:

Sun strikes the thylakoid membranes which raises electrons to a higher energy state. Excited electrons pass from chlorophyll to the primary electron acceptor. H20 is broken down into oxygen and hydrogen atoms. Electrons from hydrogen are used to replace excited electrons in the pigment. These electrons are used to provide energy that pumps hydrogen protons across a membrane and create a H+ gradient. Those H+ are used to make ATP with an ATP synthase enzyme in the membrane. The ATP is used in the Calvin Cycle to build carbohydrates. The electrons used to pump H+ in photosystem II now are reenergized with sunlight. They move across the proteins in photosystem I. These electrons then move to the primary acceptor to then be combined with hydrogen protons and reduce NADP+ to NADPH. NADPH is used in the Calvin Cycle.

How do they know oxygen produced comes from water? Scientists added a radioactive tracer O18. Found that the oxygen gas produced was from water.

Noncyclic Photophosphorylation: Light reactions elevate electrons in 2 photosystems PSII and PSI that produces ATP and NADPH.

Cyclic Photophosphorylation: If PS I can’t pass electron to NADP…it cycles back to PS II & makes more ATP, but no NADPH. Calvin cycle uses more \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ than NADPH

Where did the energy come from?

Where did the electrons come from?

Where did the H2O come from?

Where did the O2 come from?

Where did the O2 go?

Where did the H+ come from?

Where did the ATP come from?

What will the ATP be used for?

Where did the NADPH come from?

What will the NADPH be used for?

**Concept: The Calvin cycle uses the chemical energy of ATP and NADPH to convert CO2 to sugar**

The Calvin Cycle: Life from Air!

Plants need to produce all \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ molecules necessary for growth including carbohydrates, lipids, proteins, nucleic acids. They need to store chemical energy (ATP) produced from light reactions in a more stable form and that can be moved around plant or saved for a rainy day.

Building Stuff: Want to make C6H12O6 How? From what? What raw materials are available?

From CO2 🡪 C6H12O6

-CO2 has very little chemical energy as it is fully oxidized

-C6H12O6 contains a lot of chemical energy when highly reduced

-Synthesis = endergonic process (put in a lot of energy)

-Reduction of CO2 🡪 C6H12O6 proceeds in many small uphill steps each catalyzed by a specific enzyme and using energy stored in ATP & NADPH

Calvin Cycle occurs in the \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ of the chloroplast and it needs the products of light reactions, ATP and NADPH.

Step 1: Carbon fixation

A five-carbon sugar molecule called ribulose bisphosphate, or RuBP, is the acceptor that binds CO2 dissolved in the stroma. This process, called CO2 fixation, is catalyzed by the enzyme RuBP carboxylase, forming an unstable six-carbon molecule. This molecule quickly breaks down to give two molecules of the three-carbon 3-phosphoglycerate (3PG), also called phosphoglyceric acid (PGA).

Step 2: Reduction

The two 3PG molecules are converted into glyceraldehyde 3-phosphate (G3P, a.k.a. phosphoglyceraldehyde, PGAL) molecules, a three-carbon sugar phosphate, by adding a high-energy phosphate group from ATP, then breaking the phosphate bond and adding hydrogen from NADH + H+.

Step 3: Regeneration of RuBP (ribulose biphosphate)

Three turns of the cycle, using three molecules of CO2, produces six molecules of G3P. However, only one of the six molecules exits the cycle as an output, while the remaining five enter a complex process that regenerates more RuBP to continue the cycle. Two molecules of G3P, produced by a total of six turns of the cycle, combine to form one molecule of glucose.

Glyceraldehyde-3-P is end product of Calvin cycle. It is an energy rich 3 carbon sugar “C3 photosynthesis”

G3P is an important intermediate

G3P 🡪🡪 glucose 🡪carbohydrates

🡪🡪 lipids 🡪🡪phospholipids, fats, waxes

🡪🡪 amino acids 🡪🡪 proteins

🡪🡪 nucleic acids 🡪🡪 DNA, RNA

RuBisCo

Enzyme which fixes \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ from air

-ribulose bisphosphate carboxylase

-the most important enzyme in the world!

-it makes life out of air!

-definitely the most abundant enzyme

Accounting

The accounting is complicated

3 turns of Calvin cycle = 1 G3P

3 CO2 🡪1 G3P (3C)

6 turns of Calvin cycle = 1 C6H12O6 (6C)

6 CO2 🡪 1 C6H12O6 (6C)

18 ATP + 12 NADPH 🡪 1 C6H12O6

any ATP left over from light reactions will be used elsewhere by the cell

**Concept: Alternative mechanisms of carbon fixation have evolved in hot, arid climates**

Photosynthesis: Variations on the Theme

C3 Plants

Controlling water loss from leaves (transpiration)

-On hot or dry days, the stomates close to conserve \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

guard cells surround the stomata. When plant gains H2O = stomates open. When plants lose H2O = stomates close. No CO2 uptake when they are closed.

When stomates close….

Closed stomates lead to…

-O2 build up 🡪 from light reactions

-CO2 is depleted 🡪 in Calvin cycle

-causes problems in Calvin Cycle

Photorespiration

Oxidation of RuBP

-throws a short circuit of Calvin cycle

-loss of carbons to CO2 which can lose 50% of carbons fixed by Calvin cycle

-reduces production of photosynthesis

-no ATP (energy) produced

-no C6H12O6 (food) produced

-if photorespiration could be reduced, plant would become 50% more efficient. This puts strong selection pressure to evolve alternative carbon fixation systems

C3 Plants, photosynthesis the light reactions and the Calvin cycle occur in the same cell. This puts the production of O2 in close proximity to rubisco, leading to photorespiration.

C4 Plants: Separate carbon fixation from the Calvin Cycle.

-Physically separate carbon fixation from Calvin Cycle

-\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ cells to fix carbon vs. where Calvin cycle occurs

-store carbon in \_\_\_\_\_\_\_\_\_\_ compounds

-use a different enzyme to capture CO2 (fix carbon)

-PEP carboxylase

-use different leaf structure

A better way to capture CO2

-1st step before Calvin cycle, fix carbon with enzyme PEP carboxylase. It stores as 4C compound

-Is an adaptation to hot, dry climates which have to close stomates a lot. They have different leaf anatomy. Examples include: sugar cane, corn, other grasses…

-\_\_\_\_\_\_\_\_\_\_ carboxylase enzyme has higher attraction for CO2 than O2 which is better than RuBisCo

-PEP carboxylase fixes CO2 in 4C compounds and regenerates CO2 in inner cells for RuBisCo which keeps O2 away from RuBisCo

CAM (Crassulacean Acid Metabolism) plants

-CAM plants separate the two stages of photosynthesis temporally to reduce photorespiration. This is accomplished by fixing CO2 at night using PEP carboxylase and storing the carbon in organic acids. During the day when CAM plants have their stomata closed to conserve water, the carbon from the organic acids is chemically release and used in the Calvin cycle.

-Adaptation to \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_, dry climates separate carbon fixation from Calvin cycle by TIME

-close stomates during day

-open stomates during night

-at night: open stomates & fix carbon in 4C “storage” compounds

-in day: release CO2 from 4C acids to Calvin cycle which increases concentration of CO2 in cells

-Examples include succulents, some cacti, pineapple

Why the C3 Problem?

Possibly evolutionary baggage

-Rubisco evolved in high CO2 atmosphere

-there wasn’t strong selection against active site of Rubisco accepting both CO2 & O2

Today it makes a difference

-21% O2 vs. 0.03% CO2

-photorespiration can drain away 50% of carbon fixed by Calvin cycle on a hot, dry day

strong selection pressure to evolve better way to fix carbon & minimize photorespiration