Feb 7 – Photosynthesis I: Overview and "big picture" concepts

Photosynthesis – The process by which photoautotrophs use light energy from the sun to construct sugars (esp. glucose) from carbon dioxide and water.

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

You need to have a death grip on this equation!! If you need to stop and think about it on exams…well…you're just not prepared!!

Note that this is the "opposite" of cellular respiration (reaction arrow is reversed). Plants also conduct cellular respiration! This is a fundamentally important concept that is foundational to this lecture.

Carbon fixation: the process by which **autotrophs** remove C atoms from atmospheric CO_2 and incorporate the C atoms into molecules in their tissues (initially glucose). Photosynthesis is a type of carbon fixation (and by far the most common, accounting for >99% of C fixation on Earth).

Autotrophs and Heterotrophs

Autotroph ("auto:*self* + trophic*:nutrition")***:** An organism that makes its own food through carbon fixation (e.g., by photosynthesis) and can sustain itself without eating other organisms. Also known as a "producer" in ecosystems.

Heterotroph: ("hetero:*another* + trophic*:nutrition")*: An organism that cannot make its own food (i.e., can not perform carbon fixation) and must eat other organisms. Also known as a "consumer" in ecosystems. Heterotrophs include:

- All animals (in a few rare exceptions chloroplasts are retained from prey algae/plants)
- All fungi
- Many protists
- A small number of plants that are parasitic and steal C from other plants (crazy!)

Photoautotrophs – autotrophic organisms that make sugars via photosynthesis. Conducted by:

1) plants (the focus of this course…)
2) autotrophic protists (especially algae, we'll study these later…)
3) autotrophic bacteria (we won't spend much time on bacteria…but some are photosynthetic. Of special note are cyanobacteria, which we will discuss later, because they are the evolutionary ancestor of chloroplasts in Eukaryotic photoautotrophs. More later in the class…this is an interesting story.)

<u>Plant structure and photosynthesis</u>:
We will focus on terrestrial plants here, which are photoautotrophic eukaryotes.

Carbon in the atmosphere exists as CO_2, which diffuses into plants through pores in their leaves called **stomata** (singular = stoma). Stomata are opened and closed with **guard cells**, which swell to close via osmosis. (We will explore leaf structure in detail immediately after Midterm I).

Chloroplasts are the membrane-bound organelles where photosynthesis takes place. We will explore this in great detail in out next lecture. Chloroplasts are green because they contain the pigment **chlorophyll**.

Chlorophyll: green pigment in thylakoid membrane (more next lecture) that absorbs light energy and initiates photosynthesis. Chlorophyll is what makes plants green. Plants do not absorb green – they reflect it. Thus, the energy in green light is not absorbed. If plants absorbed green also, they would harvest more total energy and appear black…why don't they…? Chlorophyll contains Mg – hence Mg in CHOPKNS Ca Fe Mg. Mg deficiency can cause chlorosis - a condition in which leaves to lose their green color and turn a pale yellow (other causes too!).

Pigment: a molecule or material that reflects and absorbs specific wavelengths of light (colors).

Accessory pigments: additional light absorbing pigments other than chlorophyll. They protect cells and absorb other wavelengths of light, thereby enhancing the energy gathering ability of plants. These include anthocyanins (reddish hues) and carotenoids (orange hues), and they are partially responsible for the brilliant colors of autumn leaves on deciduous plants (as chlorophyll is resorbed by the plant or breaks down). *(Video: BBC's <u>Life</u>, "Plants" episode; (34:48-37:02))*

Because plants remove CO_2 from the atmosphere, they directly influence atmospheric [CO_2] on scales both small and large.

> *Note: the square brackets "[ ]" are chemical shorthand for 'concentration'. So, "[CO_2]" reads as 'carbon dioxide concentration'. Furthermore, we will use the abbreviation ATM for 'atmosphere' or 'atmospheric'. For example, ATM [CO_2] reads as 'atmospheric carbon dioxide concentrations'.*

Note that the chemical equations for photosynthesis and cellular respiration and the reverse of each other (that is to say, the reactants of one reaction are the products of the other, and vice versa …if you don't know what I am talking about take the time now to write out the balanced chemical equations…)

This has interesting consequences for ATM [CO_2] and how it fluctuates through time. We discussed two series of observations made by the scientist Charles David Keeling:
1) 24-hr patterns in forests in Big Sur, CA
2) Annual patterns measured at Mauna Loa in Hawaii

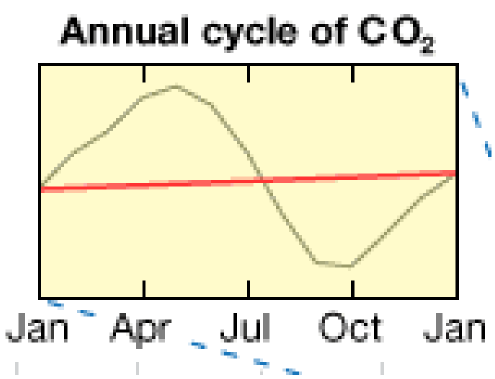
In each case, we related what was happening to the chemically balancing influences of photosynthesis and cellular respiration. Brutal lecture to miss…especially before a midterm!!

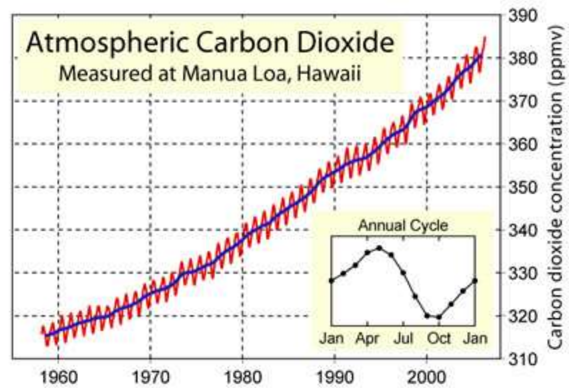
Carbon cycle, seasonal CO_2 cycling, ATM CO_2, and climate change

Carbon cycle: The biogeochemical cycle by which carbon is exchanged among the atmosphere, land, and bodies of water (e.g., oceans, lakes, and rivers).

Seasonal cycling of CO_2 in the atmosphere.

In the northern hemisphere, CO_2 levels rise in the fall as days shorten and trees/plants photosynthesize much less. Furthermore, deciduous trees drop leaves that are consumed (decomposed) by bacteria and fungi – and the cellular respiration of these organisms re-releases CO_2 into the atmosphere (ATM). As summer approaches, cellular respiration of decomposing plant material slows/ceases (most of it has been completely decomposed) and photosynthesis resumes. This causes CO_2 levels to fall in the atmosphere (ATM). There is a time lag between these events and measurable changes of CO_2 in the ATM, such that the annual pattern looks like (left-hand figure):





Long term atmospheric rises in [CO_2]

Atmospheric concentrations of CO_2 have been steadily increasing since the 1800's. We know that this is caused by humans through two activities: 1) deforestation, and 2) burning of fossil fuels.

Deforestation: In a forest of large trees, there is a tremendous number of C atoms bonded to each other and other atoms in biomolecules – and ALL that carbon ultimately arrived there through fixation of CO_2 from the atmosphere!!

Think about what happens to all those C atoms when a forest is burned to make way for agriculture, or chopped down for toilet paper or your notebook…where does that carbon end up??!! Well, if you keep your notebook for life, then some of the C atoms remain locked up in the cellulose molecules in the paper. More realistically however, you will unceremoniously burn the notebook! Or, perhaps you will dispose of it in a landfill (but perhaps you'll recycle it…?) where ultimately bacteria and fungi will digest the paper and break down the sugars via cellular respiration. So, unless timber products are stored forever or recycled, the C atoms go right back into the atmosphere where they likely exist in molecules of CO_2, either due to burning (e.g., the bonfire you will make with your notebook) or cellular respiration of dead plant tissue by heterotrophs (e.g., bacteria and fungi in the landfill where your notebook comes to rest). Recycling helps limit CO_2 release to some extent, but lots of energy is spent to power recycling operations…so the process releases CO_2 into the atmosphere even if all the C atoms in your notebook are recycled.

Fossil fuels: hydrocarbons such as coal, oil and natural gas, sourced from the remains of prehistoric organisms (mostly plants and algae).

When these fuels are burned, the energy released can be harnessed to produce electricity, power vehicles, heat homes, cook food, etc…

The energy contained in fossil fuels can ultimately be traced to the sun. That is because fossil fuels are literally the buried remains of prehistoric organisms (mostly photoautotrophs such as plants and algae).

When we humans burn fossil fuels, we are literally "digging up" (or "drilling up", as the case may be…) the energy that prehistoric plants converted from sunlight to sugar molecules (via photosynthesis) and that was buried as those organisms died. **[**By the way, many fossil fuels deposits originate from organisms that lived and died during the Carboniferous period (~360-300 million years ago) – and it is these deposits that are the target of coal mining operations. We'll discuss the Carboniferous in more detail later this semester…some really cool plants were around back then.

Therefore, burning fossil fuels releases CO_2 that was removed from the atmosphere millions of years ago!!! Not surprisingly, C fixation by currently existing terrestrial plants and marine (ocean dwelling) cyanobacteria and protists cannot "keep up" with current rates of CO_2 emission via fossil fuel burning. Therefore [CO_2] in the atmosphere (ATM) have risen sharply since the industrial revolution (mid 1800's).

So what if ATM [CO_2] is increasing?

One of the consequences of increased ATM [CO_2] is global warming – we discussed this in lecture and you should understand the term "greenhouse gas" and associated concepts.

The consequences of global warming? They are many…and complicated – we'll discuss them later in the semester.

Video: (http://www.youtube.com/watch?v=W0F-RmOswOs)- polar bear / GW video

Photosynthesis: "Big picture" concepts:

1) Photoautotrophs are responsible for all (nearly!!) carbon fixation on Earth (and are therefore known as producers. Conversely, the heterotrophs dependent upon producers for sugars are known as consumers.)

   So, every C atom in the biomolecules in your body (you big consumer…) was at some point removed from the atmosphere and converted to sugar by a plant (or was removed by algae in the ocean – we'll get to that later). These sugar molecules were either converted into other biomolecules in the plant, or were consumed directly by you or a chain of consumers that lead ultimately to you!

Q: What is the fate of these sugars in the plant itself?

- Used immediately as energy by the plant (~50%)
- Stored for later use as energy (stored as the polysaccharide **starch**)
- Converted into the structural polysaccharide **cellulose** or other biomolecules

2) Because the construction of sugars via photosynthesis is driven by energy in sunlight, the **sun is the ultimate source of energy for all living organisms** (with a few exceptions)!!

3) Finally, photosynthesis is the mechanisms by which CO_2 concentrations in the atmosphere are regulated. This is evident in the daily and seasonal CO_2 trends that we examined. Loss and burning of large plant communities (forests) and burning of fossil fuels (remnants of ancient forests) are the leading causes of global warming. At its roots, global warming is very much a botany issue…

Next lecture, we examine the chemistry of this process: bring your "game face"…