First off “for something completely different,” before you forget all about biochemistry . . .

* We’re going to have a short, in-class ‘think-piece!’
* Here’s the premise: An unmanned space probe lands on a far-distant planet around a far-distant star. It ‘thinks’ that it found a new life form there. But it’s not carbon based — it seems to be silicon based!

http://aliens.wikia.com/wiki/
Category:Alternative_Forms_of_Life
And see diatoms and horsetails on our planet!
Based on this list of facts about silicon chemistry:

Silicon is similar to carbon in many ways, having many similar chemical properties; however, it...

- Is much larger than carbon and doesn't easily form double and triple bonds.
- Silicon-hydrogen compounds are highly reactive in water; silicon-oxygen polymers (silicones) are more stable; but not near as much so as carbon based compounds.
- Silicon-based compounds are more stable in sulfuric acid rich environments.
- Silicon dioxide, a constituent of sand, and completely insoluble at all temperatures at which water is liquid, ...

Would be the waste product of aerobic respiration (based on oxygen), if metabolism there worked at all like it does here on earth. Excretion of solid sand from the life form could be problematic.

Ammonia-based biochemistry versus water-based may get around some of the problems of silicon dioxide. However, ammonia has several other complications, one of which is it is quite combustible in an oxidizing environment.

If this new life form really is alive and really is based on silicon:

Tell me whether this planet’s atmosphere could have air that we could breathe.

Give me a paragraph or so about why you think so.

You need to finish this in class and give it to me as you leave. Be sure to put your name, the date, and the class number and section at the top of the page.
Now photosynthesis, oh yeah . . .
because it’s darn important!
All (actually MOST) of life ultimately depends on it. The sun provides most of the energy for most of life. And not just plants . . .
About half the earth's atmospheric oxygen is produced by phytoplankton in the ocean!

Phytoplankton are photosynthetic organisms of all sorts, one-celled and multicellular, from many divisions of life that collectively form the base of the marine food chain.

Here's when many of them first appeared over the lifetime of the earth. It made a huge difference!

from http://bionumbers.hms.harvard.edu/default.aspx
Life before photosynthesis

Before photosynthesis, most organisms had to be heterotrophs.

Heterotrophs – organisms that obtain carbon by consuming preexisting organic molecules. Versus...

Autotrophs – organisms that make their own organic compounds from inorganic compounds (in the case of photosynthesis, water and CO$_2$), but don’t forget chemosynthetic critters like those hydrogen sulfide metabolizing deep-see hydrothermal vent bacteria.

The rise of photosynthesis radically altered the Earth:

- It decreased CO$_2$, lowered global temperature, and added oxygen gas to atmosphere, eventually reaching the present day 20% level.
This graphic of the timeline is from your text.

Before plants, these guys did it all, now terrestrial plants of all sorts do half the work.

* Let’s see what photosynthesis is.
Photosynthesis is the... Process by which plants, algae, and many microorganisms harness solar energy and convert it into chemical energy. With few exceptions, all life on this planet ultimately depends on photosynthesis.
How’s it work?

* Specialized pigment molecules in plants capture the sun’s energy.
* Special enzymes use that energy to build glucose (C₆H₁₂O₆) from carbon dioxide (CO₂).
* Plants use water in the process, releasing oxygen gas (O₂); nice.

Light energy

$$6\text{CO}_2 + 6\text{H}_2\text{O} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2$$
It’s another redox reaction.

* Redox (reduction-oxidation) – here electrons are moved from H\textsubscript{2}O to CO\textsubscript{2}.

* The energy comes from the sun.

* Plants use the glucose for many things: about half is used for the plant’s own cellular respiration, and the rest to manufacture other compounds such as amino acids, cellulose for cell walls, and the excess is stored as starch or sucrose.
Sunlight as an energy source:

* Electromagnetic spectrum – range of all possible frequencies of radiation. It . . .
* Consists of photons – discrete packets of kinetic energy.
* Shorter wavelengths have more energy.
* Sunlight has:
  1) Ultraviolet (UV) – short wavelength, high energy;
  2) Visible – perceived by humans, powers photosynthesis; and . . .
  3) Infrared (IR) – long wavelength, low energy, heat.
The electromagnetic spectrum

Short wavelength / High energy

Gamma rays
X-rays
Ultraviolet radiation
Near-infrared radiation
Infrared radiation
Microwaves
Radio waves

Visible light

Wavelength in nanometers

Violet
Indigo
Blue
Green
Yellow
Orange
Red

475 nm
750 nm

Portion of spectrum that reaches Earth's surface

Long wavelength / Low energy

Thursday, January 27, 2011
It happens in the chloroplast.

* Chloroplast – organelle of photosynthesis, and the product of primordial endosymbiotic events.
* Two outside membranes enclose the stroma.
* Stroma – is gelatinous with enzymes, ribosomes, DNA, and grana.
* Grana – a stack of thylakoids.
* Thylakoids – are membranes studded with photosynthetic pigments enclosing the thylakoid space.
Let's look.
Special pigments are required to absorb sunlight.

- **Pigments** —
  - **Chlorophyll a:**
    - Most abundant photosynthetic pigment in plants, algae, and cyanobacteria.
  - **Accessory pigments:**
    - Chlorophyll b and . . .
    - Carotenoids.
- **Only absorbed light is photosynthetically active:**
  - The pigments absorb red and blue, but . . .
  - Reflect green. That’s why plants look green!
  - Accessory pigments extend the range of wavelengths used.
# The pigments:

<table>
<thead>
<tr>
<th>Pigment</th>
<th>Color</th>
<th>Organisms</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Major pigment</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chlorophyll (a)</td>
<td>Blue-green</td>
<td>Plants, algae, cyanobacteria</td>
</tr>
<tr>
<td><strong>Accessory pigments</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chlorophyll (b)</td>
<td>Yellow-green</td>
<td>Plants, green algae</td>
</tr>
<tr>
<td>Carotenoids</td>
<td>Red, orange,</td>
<td>Plants, algae, bacteria,</td>
</tr>
<tr>
<td>(carotenes and</td>
<td>yellow</td>
<td>archaea</td>
</tr>
<tr>
<td>xanthophylls)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The chlorophyll a molecule – the transfer of energy from sunlight to molecule, occurs in the head. It is anchored in the thylakoid membrane by the hydrophobic tail.
Different pigments have different absorbance maximums.
There are two stages to photosynthesis:

* The light reactions —
  * Occur in thylakoid membranes; and . . .
  * Convert solar energy to chemical energy.
  * The energy from captured photons is used to make ATP (stores energy) and NADPH (carries electrons).

* The carbon reactions —
  * ATP and NADPH is used to reduce CO₂ to glucose.
  * It occurs in the stroma, and . . .
  * Does not require light – light-independent reactions!
Where things are going on:
In turn, the light reactions:

- **Photosystem** – is a complex unit with chlorophyll a (around 300) and other pigment molecules (around 50), and many proteins, all anchored in the thylakoid membrane. It has a...

- **Reaction center** – the one chlorophyll a molecule per photosystem and its associated proteins that actually use the light energy, and...

- **Antenna pigments** – all the other pigments that capture energy and funnel it to the reaction center.

- This organization enhances efficiency.

- There are two types of photosystems, I and II, and they are connected by an electron transport chain.
Here's what number II looks like:

Photosystem II: the first player –

http://www.rcsb.org/pdb/cgi/explore.cgi?pdbld=3BZ2
Photosystem II produces ATP.

- II Functions first, but was named II because it was discovered second. Confusing, eh?
- Pigment molecules absorb light energy, and . . .
- Transfer it to the reaction center. This . . .
- Excites a pair of electrons. Which are . . .
- Ejected and grabbed by the first protein in the electron transport chain linking the two photosystems.
- Lost electrons are replaced by splitting water into oxygen and protons (H⁺ ions).
- Oxygen gas is the waste product. Nice.
The light reactions:
And here’s another example of chemiosmotic phosphorylation.

* As electrons pass along the electron transport chain, the energy they lose drives the transport of protons from the stroma into the thylakoid space. This causes the ... 

* Proton concentration to increase, and sets up a chemiosmotic gradient.

* Then our friend from last time, ATP synthase, uses that gradient to produce ATP.

* It’s like a dam generating electricity.
Phosphorylation adds P to ADP — powered by the active transport of protons across the membrane.
Here's an overview animation:

In plants, photosynthesis occurs in specialized organelles called chloroplasts. The internal membranes of chloroplasts are organized into sacs called thylakoids.

http://www.valdosta.edu/~stthompson/animations/Chapter05/photosyn_electron_transport_and_atp_syn.swf
Photosystem I produces NADPH.

* Photon energy is passed to the reaction center.
* This ejects electrons to the second electron transport chain.
* Electrons are replaced by those from photosystem II.
* The electron transport chain reduces NADP+ to NADPH. No ATP is produced.
* NADPH is an electron carrier that will reduce CO₂ into glucose in the carbon reactions using the energy of ATP from photosystem II.
The Carbon reactions:

* The Calvin cycle assembles $\text{CO}_2$ into glucose by way of . . .

* Carbon fixation, which is the initial incorporation of carbon from $\text{CO}_2$ into an organic compound.

* The enzyme rubisco catalyzes PGAL synthesis from RuBP. But some of the . . .

* RuBP is regenerated to go back into the cycle.

* ATP and NADPH from the light reactions provide the potential energy and electrons.
1) Carbon fixation:
- CO₂ combines with ribulose biphosphate (RuBP) (5 carbon sugar) to form a 6 carbon product.
- Catalyzed by RuBP carboxylase/oxygenase (rubisco, the most abundant protein on earth, some say).

2) PGAL synthesis:
- 6 carbon product breaks down into two 3-carbon molecules of phosphoglyceric acid (PGA)
- PGA converted into phosphoglyceraldehyde (PGAL)
- PGAL can be used to make more complex molecules like glucose or sucrose. But some is rearranged... so that...

3) RuBP is regenerated.
- This allows the cycle to perpetuate as long as ATP and NADPH are plentiful.
And in animation:
* All plants use the Calvin cycle (C3 pathway) to make glucose.
* C3 plants use only the Calvin cycle.
* About 95% of plant species (e.g. many crops, most trees, etc.) do it this way.
* But it’s not real efficient – less than 10% max, because of . . .
Which is especially a problem in hot, dry conditions.

- Rubisco uses \( \text{O}_2 \) as a substrate (instead of \( \text{CO}_2 \)) starting a process that removes already fixed carbon. Bummer.
- If stomata are kept closed to prevent water loss, \( \text{O}_2 \) builds up and photorespiration increases. Even worse.
So C4 plants, add a new preliminary step and a new cell type to separate carbon fixation from the light reactions.

- **CO₂** combines with a 3 carbon "ferry" to form 4 carbon oxaloacetate in mesophyll cells (this is also where the light reactions occur). This is reduced to malate.
- The malate moves into adjacent bundle sheath cells where the Calvin cycle occurs.
- This two separate compartment process costs 2 ATPs but loses less carbon to photorespiration than C3 plants, especially in hot, dry weather.
- A bonus is significant water savings, because C4 plants can have fewer, smaller stomata.
- About 1% of plants do it this way, including the important crops corn and sugarcane!
CAM plants (crassulacean acid metabolism) – do it a different way. They...

- Only open stomata at night to admit CO\(_2\) and fix carbon as malate. This is stored in a vacuole.
- Then during the day...
- The stored malate moves into the chloroplast in the same cell. And...
- The malate releases the CO\(_2\) to fix it again in Calvin cycle.
- 3-4% of plants do it, e.g.
- Pineapple and cacti.
- Saves water.
### Table 5.2  $C_3$, $C_4$, and CAM Plants Compared

<table>
<thead>
<tr>
<th></th>
<th>$C_3$</th>
<th>$C_4$</th>
<th>CAM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of C atoms in first product of $CO_2$ fixation</td>
<td>3 (PGA)</td>
<td>4 (oxaloacetate)</td>
<td>4 (oxaloacetate)</td>
</tr>
<tr>
<td>How plant avoids photorespiration</td>
<td>—</td>
<td>Light reactions and carbon reactions occur in separate cells.</td>
<td>Light reactions occur during the day, and carbon reactions occur at night</td>
</tr>
<tr>
<td>Limitation of strategy</td>
<td>Carbon and energy losses to photorespiration</td>
<td>ATP cost to transport malate from mesophyll to bundle-sheath cell</td>
<td>Reduced carbon availability (stomata open only at night)</td>
</tr>
<tr>
<td>Habitat</td>
<td>Cool, moist</td>
<td>Hot, dry</td>
<td>Hot, dry</td>
</tr>
<tr>
<td>Species</td>
<td>95%</td>
<td>1%</td>
<td>3–4%</td>
</tr>
</tbody>
</table>
OK, that’s it for now.

* But remember — next time we have our first exam over all of Section I. Don’t sweat details!

* Come talk to me if you don’t understand something.

* And use the Student Success Center!

* Good luck.