Let’s look at photosynthesis and respiration from a different perspective:

_Nothing in Biology Makes Sense_  
_Except in the Light of Evolution_

Theodosius Dobzhansky  
(1900-1975)

http://people.delphiforums.com/lordorman/light.htm
Etched in our cells is the history of life on earth

Looking at this history can help us understand the transactions of the cell and how they relate to our evolutionary history

Cool Web Sites on the History of Life and the Universe

http://seaborg.nmu.edu/earth/Life.html

http://www.tufts.edu/as/wright_center/cosmic_evolution/

learn more about cyanobacteria
http://www.ucmp.berkeley.edu/bacteria/cyanointro.html
The Oxygen Revolution and Evolution of Eukaryotic Cells

[Diagram showing the evolutionary timeline from sterile Earth to modern cellular life.]

- **Sterile Earth**
- **Prebiotic syntheses** (proteins and RNA made abiotically)
- **RNA**
- **Self-replicating RNAs**
- **Lipoprotein vesicle**
- **Early cellular life** (RNA as coding and catalytic molecule)
- **Proteins assume catalytic functions** (RNA only as coding molecule)
- **Evolution of DNA from RNA**
- **Modern cellular life** (DNA replaces RNA as coding molecule leading to DNA $\rightarrow$ RNA $\rightarrow$ Protein)
Major landmarks in biological evolution. The positions of the stages on the time scale are approximate. Note that for the bulk of Earth’s history, only microbial forms existed.
Photosynthesis requires a hydrogen source and it is though that the first primitive photosynthesizers used hydrogen sulfide (non-oxygenic photosynthesizers)

\[ \text{CO}_2 + \text{hydrogen sulfide} + \text{light energy} \rightarrow \text{Glucose} + \text{sulfur} \]

*hydrogen sulfide released from volcanic eruptions*

[Y axis as redox potential becomes more negative, the free energy level increases]

- **The flow of electrons in a relatively primitive form of photosynthesis observed in present-day green sulfur bacteria.**
- **A single photon of light has sufficient energy to bump an electron from H}_2\text{S to a potential energy state high enough to reduce NADP}^+.**
- **The electron transport components of this photosystem resemble photosystem I in plants and cyanobacteria.**
Eventually other forms arose that were able to extract hydrogen form water (ancestor to cyanobacteria or blue-green algae)

\[ \text{CO}_2 + \text{water} + \text{light energy} \rightarrow \text{Glucose} + ? \]

What is the chemical significance of this switch from \( \text{H}_2\text{S} \) to \( \text{H}_2\text{O} \)?
Above equation becomes

\[ \text{CO}_2 + \text{water} + \text{light energy} \rightarrow \text{Glucose} + \text{O}_2 \]

The arrival of the cyanobacteria (oxygenic prokaryotic photosynthesizers) marked a point of no return in the history of life.

It was one of the most central events in the development of life on earth.

The relationship between changes in atmospheric oxygen and some of the major steps that occurred during the evolution of living organisms. Geological evidence suggests that there was billion year delay between the rise of cyanobacteria (thought to be the first organism to release O\(_2\)) and the time that O\(_2\) levels began to accumulate in the atmosphere. This delay was probably due to the rich supply of ferrous iron in the oceans, which reacted with the released O\(_2\) to form enormous iron deposits.
Oxygen: the Great Destroyer

- After all, these organisms had evolved under anaerobic conditions
- Oxygen was intensely toxic to all life forms existing at the time
- DNA is particularly sensitive to oxidative attack
- Other macromolecules (proteins, lipids, RNA are also sensitive)
- O₂ produces highly reactive compounds (such as O₂⁻) that damage biological macromolecules (by oxidizing them) -- so increasing levels generated intense global stress
- Many organisms were immediately wiped out because of the oxygen toxicity

WHAT SORT OF STRATEGIES Could be USED TO SURVIVE IN THIS ENVIRONMENT?
DETOXIFICATION AND EXPLOITATION

In one of the greatest coups of all time the cyanobacteria invented a metabolic system that required the very substance that had been a deadly poison: aerobic metabolism -- in other words that microcosm adapted.

First primitive heterotroph used ANAEROBIC FERMENTATION to digest these compounds and derive energy.

Glucose $\rightarrow$ ethyl alcohol + CO$_2$ + H$_2$O + 2 ATP

Increase in oxygen in the atmosphere allowed the evolution of cells that respired aerobically.

AEROBIC RESPIRATION
Glucose + O$_2$ $\rightarrow$ CO$_2$ + H$_2$O + 34 ATP

Science 291: 437
Once oxygenic photosynthesis arose, respiration probably developed simultaneously, given the enormous benefit of respiration both as an energy-harvesting strategy and as a sink to mitigate the potentially toxic oxidants.
Plan B: Detoxification

For the chemists: (about reactive oxygen species)
http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/R/ROS.html

Some Reactive Oxygen Species:
O\textsubscript{2}\textsuperscript{-} Superoxide
Hydroxyl radical (OH with unpaired electron)

- the increase in atmospheric oxygen was slow at first and allowed a gradual evolution of protective devices
- The organisms that survived the exposure to O\textsubscript{2} evolved mechanisms to protect themselves from the toxic effects of O\textsubscript{2} (or learned to hide from it)

Enzymatic defenses: superoxide dismutase (SOD)
O\textsubscript{2}\textsuperscript{-} + O\textsubscript{2}\textsuperscript{-} + 2H\textsuperscript{+} \rightarrow H\textsubscript{2}O\textsubscript{2} + O\textsubscript{2} (superoxide)
(Hydrogen peroxide is metabolized by another enzyme)

Non-enzymatic defenses: compounds (vitamin C, vitamin E and others) that act as antioxidants to neutralize the highly reactive compounds produced by O\textsubscript{2} in biological tissues
• The oxygen they produced accumulated over the milennia to form the kind of oxygen rich atmosphere we know today

• the development of advanced eukaryotic forms did not take place until the level of oxygen in the atmosphere rose to a sufficient level
Other implications of the rising levels of atmospheric O₂

The bozone layer: shielding the rest of the solar system from the Earth’s harmful effects.
Before the ozone layer developed, photosynthetic organisms probably protected themselves from UV by seeking filters such as

(i) developing pigments that absorbed harmful wavelengths
(ii) seeped under sand or other substances that filtered out UV light
(iii) evolved mechanisms to repair DNA damage that are still present in modern-day organisms
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