Marine Science Lesson Enhancements
based on **Grade 11 & 12 curriculum** in
Physics, Chemistry & Biology

Biodiversity

Algae

Ocean Explorer

Module 12

Bayworld Centre for Research & Education

Overview

1 - Algae classification

2 - Photosynthesis and chlorophyll

3 - Light-dependent Reactions - First stage of Photosynthesis

4 - Calvin Cycle - Second stage of Photosynthesis

5 - Harmful algal blooms

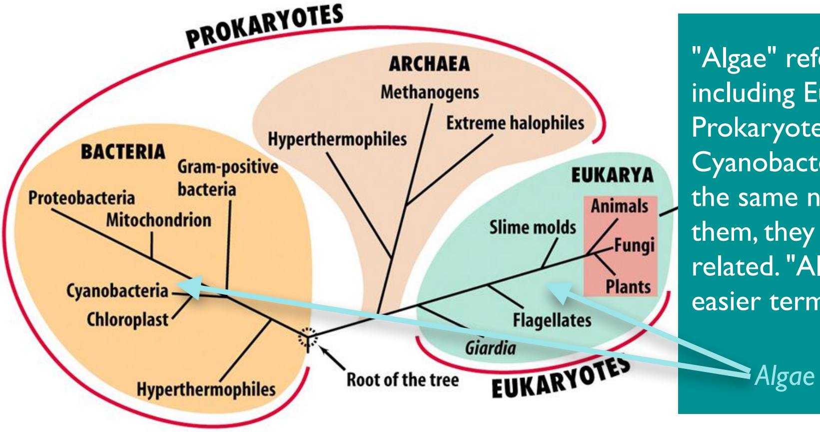
6 - Anaerobic respiration

7 - Activity : Grow algae !

Eucaryotes *are organisms which cells contain a nucleus.* **Procaryotes** *are single-cell organisms without a nucleus*

1 - Algae classification

Many unicellular organisms populate our oceans and our lands. In fact, unicellulars are the most abundant life form on Earth. Algae are a very special group of plant like organisms and most of them are also unicellular.



"Algae" refers to a large group including Eukaryotes but also Prokaryotes such as Cyanobacterias. Even if we use the same name "Algae" for all of them, they are not closely related. "Algae" is simply an easier terminology to use.

What are Algae ?

Algae can be called "primitive plants" for the following reasons :

- No root system, only sometimes attachment structures (Holdfasts)
- Produces spores (not seeds)
- Can have sexual and asexual reproduction
- Non-vascular (do not possess and internal transport system)

Algae can be very diverse, from small single cell organisms to huge kelp lines of 70m long ! But all of them contain pigments such as chlorophylls a, b, c or d (green) and even brown, blue or red to absorb light.

Classification of Algae

As previously said, Algae belong to different groups within the phylogenetic classification. We will divide them into 2 groups : the Prokaryote species and the Eukaryote species.

Prokaryotes :

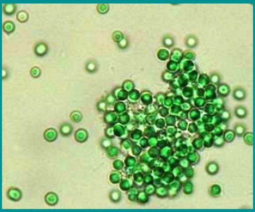
- *Cyanobacteria*

Eukaryotes :

- *Pyrrophyta, Chrysophyta, Euglenophyta*
- *Rhodophyta*
- *Phaeophyta*
- *Chlorophyta*

Cyanobacteria (Cyanophyta)

- Blue-green unicellulars, sometimes grouped in long chains
- Marine or terrestrial

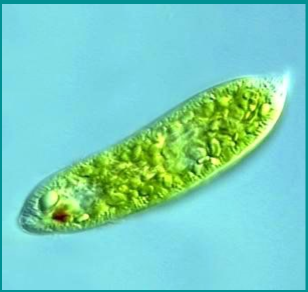


Pyrrophyta (dinoflagellata)**, Chrysophyta, Euglenophyta**

- Marine and freshwater phytoplankton
- Photosynthetic unicellulars. Have both plantlike and animal-like characteristics
- 1000 different species

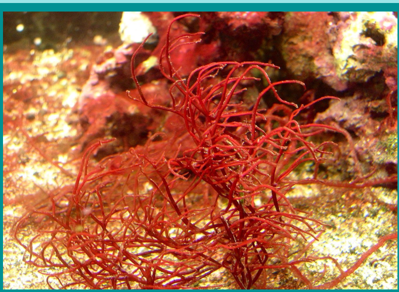
Pyrrophyta

Chrysophyta

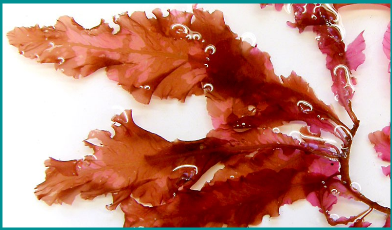


Euglenophyta

Rhodophyta



- Red algae. Contains chlorophyll a and c (green) as well as phycobilins (red)
- Cells coated with carageenan, used in cosmetics, gelatine capsules and cheese
- Marine, often found at a depth of 200m
- 4000 different species



Phaeophyta

- Brown algae
- Multicellular, often large. Can grow up to 100m long !
- Marine
- 1500 different species

Kelp

Chlorophyta

- Green algae. Possess chlorophyll a and b pigments (green) as well as carotenoids (orange)
- Cell walls made of cellulose
- Marine, freshwater and terrestrial
- Thought to be the origin of terrestrial plants
- 7000 different species

2 - Photosynthesis and chlorophyll

Info +

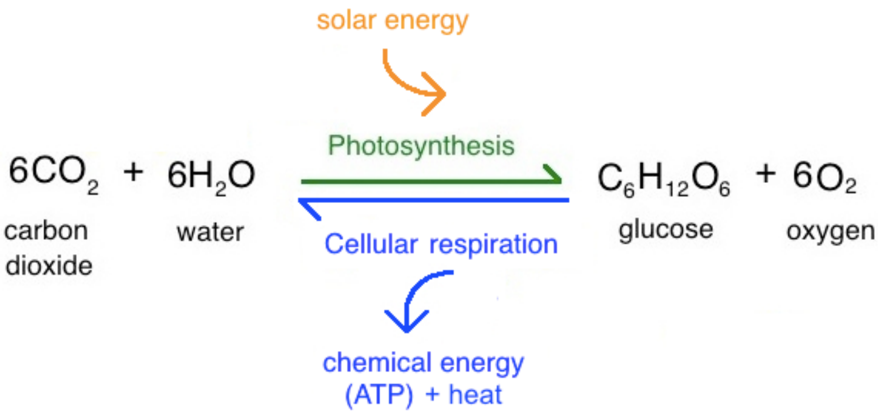
ATP *(Adenosine triphosphate), is the energy currency of life. ATP is a high-energy molecule found in every cell. Its job is to store and supply the cell with needed energy.*

Like plants, algae contain pigments, such as chlorophylls, that are used for a chemical reaction called photosynthesis. This reaction is the only way for a plant to acquire glucose and thus to obtain the materials to build itself. As animals, we do not need photosynthesis to grow because we acquire our energy and building blocs from our food. But both algae and plants need this reaction in order to grow.

What is photosynthesis ?

It is the process by which plants and some other organisms such as algae use the energy from sunlight to produce glucose from carbon dioxide and water. This glucose can be converted into pyruvate which releases adenosine triphosphate (ATP) by cellular respiration. Oxygen is also formed.

Photosynthesis' reaction is summarised by the equation:



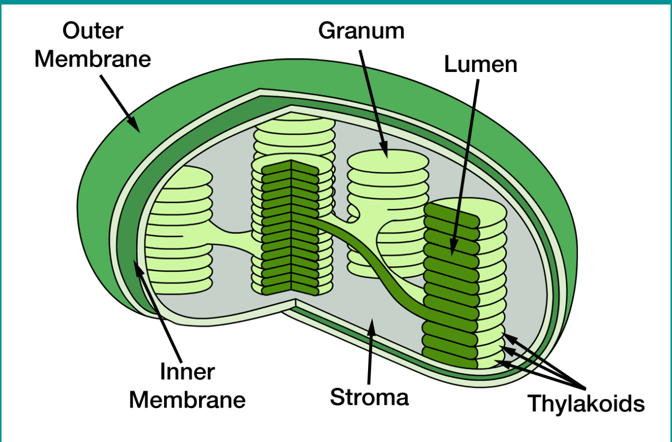
Photosynthesis in plants occurs in two stages. These stages are known as the light-dependent reactions and the Calvin Cycle.

Chlorophyll and photosynthesis

The conversion of usable sunlight energy into chemical energy is associated with the action of the green pigment chlorophyll.

Chlorophyll is a complex molecule. Several modifications of chlorophyll occur among plants and other photosynthetic organisms. All photosynthetic organisms have chlorophyll a. Accessory pigments absorb energy that chlorophyll a does not absorb. Accessory pigments include chlorophyll b (also c, d, and e in algae), xanthophylls, and carotenoids (such as beta-carotene). Chlorophyll a absorbs its energy from the violet-blue and reddish orange-red wavelengths, and little from the intermediate (green-yellow-orange) wavelengths. Carotenoids absorb green and blue.

Chloroplasts

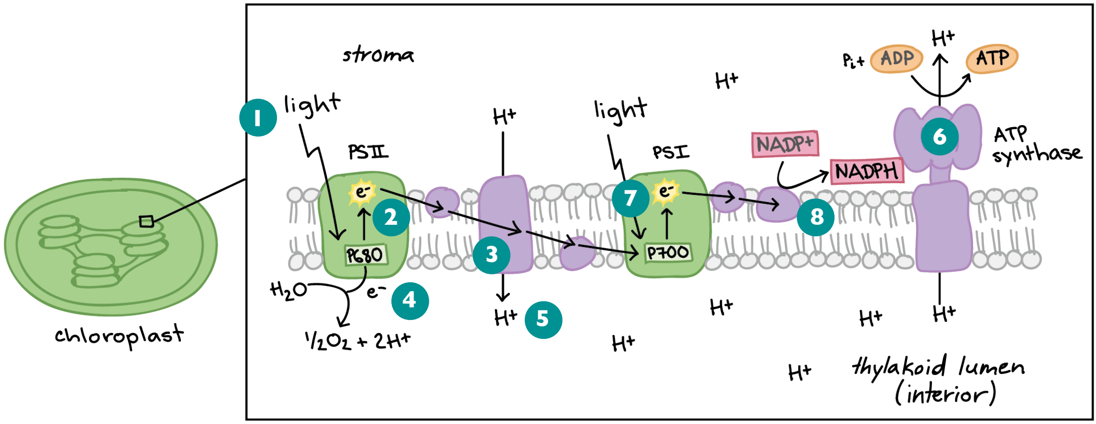


They are the food producers of the cell. The organelles are only found in plant cells and some protists such as algae. Animal cells do not have chloroplasts. Chloroplasts work to convert light energy of the sun into sugars that can be used by cells.

Two membranes contain and protect the inner parts of the chloroplast, the outer and inner membranes. The inner membrane surrounds the **stroma** and the **grana** (stacks of **thylakoids**). One thylakoid stack is called a **granum**.
Chlorophyll molecules sit on the surface of each thylakoid and capture light energy from the Sun. As energy rich molecules are created by the light-dependent reactions, they move to the stroma where carbon (C) can be fixed and sugars are synthesized.

These reactions take place on the thylakoid membrane inside the chloroplast. During this stage light energy is converted to ATP (chemical energy) and NADPH (reducing power).

Light is absorbed by two Photosystems called **Photosystem I** (PSI) and **Photosystem II** (PSII). These protein complexes contain chlorophyll molecules and accessory pigments. The chlorophyll molecules of PSI absorb light with a peak wavelength of 700nm and are called P700 molecules. The chlorophyll molecules of PSII absorb light with a peak wavelength of 680nm and are called P680 molecules.



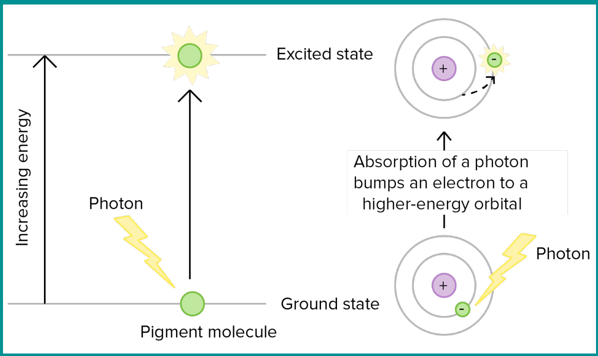
The light dependent reactions begin in PSII.

1. A **photon** of light is absorbed by a P680 chlorophyll molecule in the light harvesting complex of PSII.
2. An **electron** (e^-) in the chlorophyll molecules becomes excited as a result of a higher level of energy. The excited electron becomes unstable and is released.
3. The electron is transported in a chain of protein complexes and mobile carriers called an **electron transport chain** (ETC).

4. The electrons lost from PSII are replaced by splitting water with light in a process called **Photolysis**. Water is split into electrons (e^-), hydrogen ions (H^+ protons) and oxygen (O_2). The hydrogen ions and oxygen are released into the thylakoid lumen. Oxygen is later released into the atmosphere as a by-product of photosynthesis.
5. While the electrons pass through the ETC, hydrogen ions (H^+ protons) from the stroma are also transferred and released into the thylakoid lumen. This results in a higher concentration of H^+ in the lumen.
6. As a result, H^+ are transferred to **ATP synthase** and provide the energy needed for combining ADP and Pi to produce ATP.
7. The electrons then move from PSII to PSI. They again receive energy, but this time from light absorbed by P700 chlorophyll molecules.
8. They are then transported to NADP reductase, which is the final electron acceptor. At this point the electrons and a hydrogen ion are combined with NADP+ to produce NADPH.

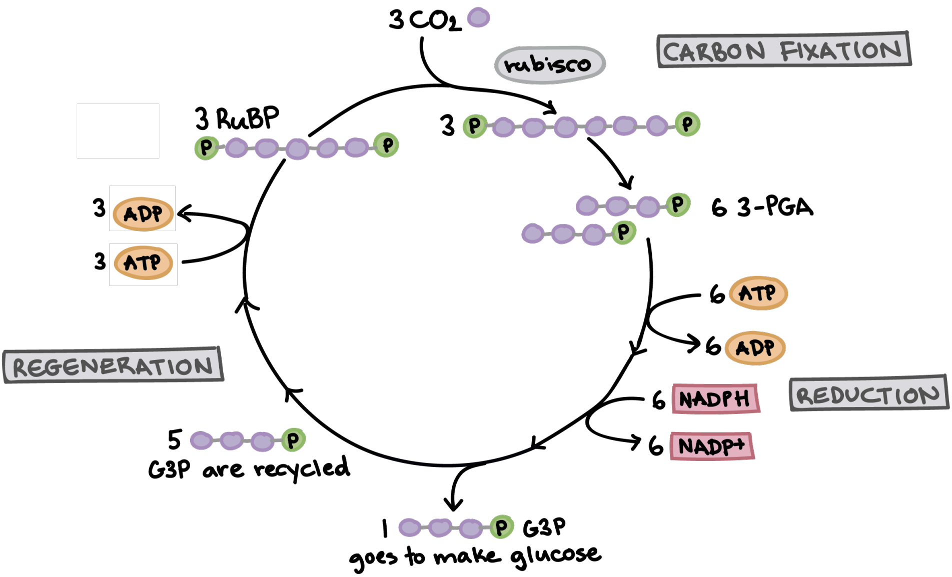
What does it mean for a pigment to absorb light ?

When a pigment absorbs a photon of light, it becomes excited, meaning that it has extra energy and is no longer in its normal state. At a subatomic level, excitation is when an electron is bumped into a higher-energy orbital that lies further from the nucleus.
Only a photon with just the right amount of energy to bump an electron between orbitals can excite a pigment. In fact, this is why different pigments absorb different wavelengths of light : the "energy gaps" between the orbitals are different in each pigment, meaning that photons of different wavelengths are needed in each case to provide an energy boost that matches the gap.



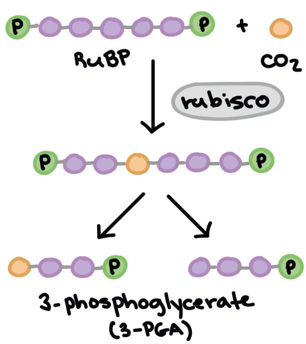
An excited pigment is unstable, and it has various "options" available for becoming more stable. For instance, it may transfer either its extra energy or its excited electron to a neighbouring molecule.

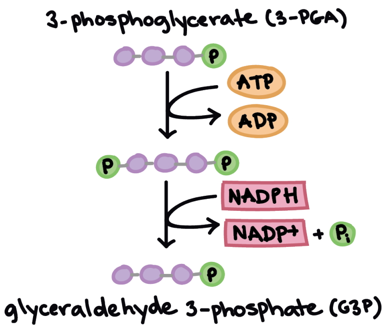
These reactions occur in the stroma of the chloroplast. The Calvin cycle reactions can be divided into three main stages : carbon fixation, reduction, and regeneration of the starting molecule.



1 - Carbon fixation.

A CO_2 molecule combines with a five-carbon acceptor molecule, ribulose-1,5-bisphosphate (**RuBP**). This step makes a six-carbon compound that splits into two molecules of a three-carbon compound, 3-phosphoglyceric acid (3-PGA). This reaction is catalyzed by the enzyme RuBP carboxylase/oxygenase, or **rubisco**.





2 - Reduction

In the second stage, ATP and NADPH are used to convert the 3-PGA molecules into molecules of a three-carbon sugar, glyceraldehyde-3-phosphate (**G3P**). This stage gets its name because NADPH donates electrons to, or reduces, a three-carbon intermediate to make G3P.

3 - Regeneration

Some G3P molecules go to make glucose, while others must be recycled to regenerate the RuBP acceptor. Regeneration requires ATP and involves a complex network of reactions.

In order for one G3P to exit the cycle (and go towards glucose synthesis), three CO_2 molecules must enter the cycle, providing three new atoms of fixed carbon. When three CO_2 molecules enter the cycle, six G3P molecules are made. One exits the cycle and is used to make glucose, while the other five must be recycled to regenerate three molecules of the RuBP acceptor.

No light - no reaction !

Although the steps of the Calvin cycle don't require light, the process only occurs when light is available (daytime). Why ? Because it's a waste of energy as there is no electron flow without light. The enzymes that power the Calvin cycle are therefore regulated to be light dependent even though the chemical reactions themselves don't require photons.

At night, plants convert starch into sucrose and release it into the phloem. These reactions are also known as "dark reactions."

5 - Harmful algal blooms

Under the right conditions, Harmful Algal Blooms (HABs) can develop. Excess run-off caused by rural, urban and natural environments can wash nutrients such as phosphorus, nitrogen and potassium into water. Nutrients, warm temperatures and sunlight cause the algae to grow large and dense along the shorelines.

Info +

Not all algal blooms are harmful. Most blooms, in fact, are beneficial because the tiny plants are food for animals in the ocean. In fact, they are the major source of energy that fuels the ocean food web.

What colour is the water during a HAB ?

An algal bloom becomes visible to the naked eye and can be green, blue-green, red, or brown, depending on the type of algae. Not all of them are life-threatening but some can release dangerous toxines that can provoque serious illness and, in some cases, death. Red tides are often dangerous.

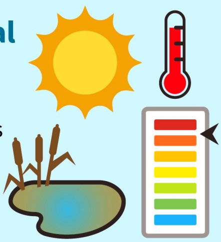
Other impacts from HABs

In addition to health concerns, HABs can cause animal deaths and damage the environment. HABs can deplete oxygen in the water or simply block necessary sunlight from reaching organisms below the surface.

Which conditions increases the chance of HAB ?

Environmental Conditions

- Abundant light
- High temperatures
- High pH levels
- Stagnant water
- Excess nutrients



Climate Change

Climate change is increasing the frequency and severity of blooms due to:

- Increases in water and air temperature
- Increases in droughts and flooding
- Changes in salinity
- Increased amount of CO_2
- Sea level rise and coastal upswelling

Sources of Excess Nutrients

Agriculture: Fertilizer runoff (nitrogen & phosphorus) and animal waste

Industry: Chemical discharge and waste

Urban Life: Sewage and waste runoff

Info +

Anaerobic respiration is not a privilege of plants ! Our own muscles resort to anaerobic respiration when oxygen is not delivered to them fast enough. But for animals, this reaction produces lactic acid instead of alcohol, which then gives us muscle pain after an effort !

Anaerobic respiration is a type of respiration that does not use oxygen. It is used when there is not enough oxygen for aerobic respiration. It takes place in plants and algae cells in the presence of little or no oxygen.

Anaerobic respiration in plant cells and some microorganisms (such as yeast) produces ethanol and carbon dioxide.

$$\text{Glucose} \rightarrow \text{Ethanol} + \text{Carbon dioxide}$$

$$C_6H_{12}O_6 \rightarrow C_2H_5OH + 2CO_2$$

The energy released by anaerobic respiration is considerably less than the energy from aerobic respiration. This is why, given the choice, organisms will rely more on aerobic respiration and the use of oxygen than on anaerobic respiration.

Depending on its type of respiration, an organism can be :

Obligate aerobe – cannot survive without oxygen (Humans)

Obligate anaerobe – cannot survive in the presence of oxygen (Some bacteria and fungi)

Aerotolerant anaerobe – can live in the presence of oxygen, but does not use it to grow (Yeasts)

Facultative aerobe – can use oxygen to grow, but can also perform anaerobic respiration (Plants and algae)

7 - Activity : Grow algae !

You are an engineer given the task to develop a system for removing nutrients from a local stream. The stream is contaminated from rainwater that has picked up nutrients from the fertilizers used at a local golf course. You know that algae can naturally remove the nutrients when they are grown on nutrient-rich waters. You want to find algae species that are native to the area. This activity focuses on finding the right species for the clean-up job.

Material needed

coffee filter

fish tank or large glass container

liquid plant fertilizer

small plastic soda bottle (500 ml)

larger mason jar

spoon

Method

1 - Collect water samples at a local lake or river, fill up the soda bottle.

2 - Filter the water sample through a coffee filter into the larger mason jar.

3 - Fill the fish tank or glass container three-quarters of the way with tap water.

4 - Add 10 ml liquid fertilizer per liter of tap water.

5 - Add an additional 20 ml sample lake or river water per liter of tap water.

6 - Use a spoon to mix the contents in the tank.

7 - Place the container on a window sill or near some artificial lights.

8 - Observe changes in the tank over a few weeks.

Questions

1 - How do the nutrients in wastewater affect algae ?

2 - For the nutrient removal system you are developing, do you think the species that you are growing in the tank are suitable ?

3 - What is in the water collected from the stream or lake ? Why are we taking that water sample and putting it in the tank ?

4 - Why is the water turning green ?

5 - Why is the green colour vanishing from the tank after a few weeks ?

6 - What tools can we use to measure algae growth ?

Algae growth

As any plant, algae need sunlight to perform the photosynthesis reaction and grow. You can carry on with this experiment by designing a colorimetry system which will give you the algae concentration in a solution, or you can try exposing different samples to different light intensity to see what happens !