The Basis of Life – Energy Acquisition and Utilization

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Autotrophs

- Organisms acquire energy by two general methods: by light or by chemical oxidation to create energy-rich organic compounds, beginning with energy-poor carbon dioxide (CO_2).
- Autotrophs provide energy for the other organisms, the hetertrophs.
- Heterotrophs are organisms that acquire their energy by the controlled breakdown of pre-existing organic molecules, or food. Human beings, like most other animals, fungi, protists (single-celled organisms such as protozoans or simple alga), and bacteria, are heterotrophs.
- Chemoautotrophs use inorganic materials (ammonia [NH_3], methane [CH_4], or hydrogen sulphide [H_2S]) combined with oxygen to generate their energy.
- Indeed, at least five metabolic pathways entirely different from each other have evolved to use CO_2.
- Only some bacteria are capable of obtaining energy this way by oxidizing , i.e., “burning,” inorganic chemicals.

Photoautotrophs

- Photoautotrophs, such as plants, use pigments to absorb light photons, and the resulting energy is used to split water (H_2O) into oxygen and hydrogen (“light” reaction”).
- The hydrogen from water is then combined with carbon dioxide (CO_2) in “dark reactions” inside the chlorophyll grana through a long and complicated process to produce two three-carbon compounds, which are ultimately used to produce a six-carbon sugar.
- This releases oxygen gas (O_2), which is disposed of as “waste” back into the atmosphere.

- **$6\ CO_2 + 6\ H_2O$ + light and chlorophyll → $C_6H_{12}O_6$ (sugar) + $6\ O_2$**

Heterotrophs

- Animals must breathe in atmospheric or dissolved oxygen to survive. They combine oxygen chemically with hydrogen atoms that they remove from their food—that is, from organic materials such as sugar, protein, and fat.
- They release water as a waste product from oxygen respiration.

Carbon Dioxide

- In addition to energy, all forms of life as we know it require carbon sources.
- All autotrophic organisms (chemosynthetic and photosynthetic bacteria, algae, and plants) derive this essential element from carbon dioxide.
- Heterotrophs use preformed organic food compounds as their source of carbon.

The Photosynthetic Pathway

- Plants use the sun's energy to drive a complex set of chemical reactions to transform CO_2 into a solid form (carbohydrates).
- Sunlight that touches a plant can be trapped (absorbed), bounced back (reflected) or pass through untouched (transmitted).
- Only absorbed light is utilized and put to work inside a plant, and for light to be trapped, it has to be absorbed by a pigment.
- Two groups of pigments exist: the green chlorophylls and the orange carotenoids. The colour of a pigment is actually the light that is not absorbed, but is rather the light that is reflected or transmitted.
- Chlorophyll traps red and blue light wavelengths and doesn't absorb green light well.
- Carotenoids trap blue-green and violet region wavelengths and reflect red and orange wavelengths.

Flower Colour

- Red flowers thus absorb every colour but red, which is reflected back to our eyes.
- Other flowers, whether yellow, blue, green, purple, etc., absorb all the other colours except the one we see.
- White flowers don't absorb any visible wavelengths but reflect them all back to our eyes.
- A pure black flower would absorb all light and look like a black hole, leaving nothing for us to see, so the reality is that "black" flowers reflect back some red, blue or purple wavelengths.

Oxygen Toxicity

- The primitive Earth had no atmospheric oxygen, which is a lethal, corrosive molecule, and all primitive life was anaerobic, requiring low oxygen levels to survive.
- As molecular oxygen gradually accumulated in the atmosphere, a catastrophic extinction of anaerobic life-forms occurred, with these organisms now being confined to underwater or underground habitats with low oxygen levels.
- Today's terrestrial organisms, plant and animal, are now not only adapted to the presence of oxygen but also use oxygen to break down carbohydrates and other compounds efficiently.
- A primitive, ancient enzyme, with the acronym RuBisCo, that creates sugars still exists in all plants today, and actually comprises about 30-50% of the total protein in leaves.

Respiration vs Photorespiration

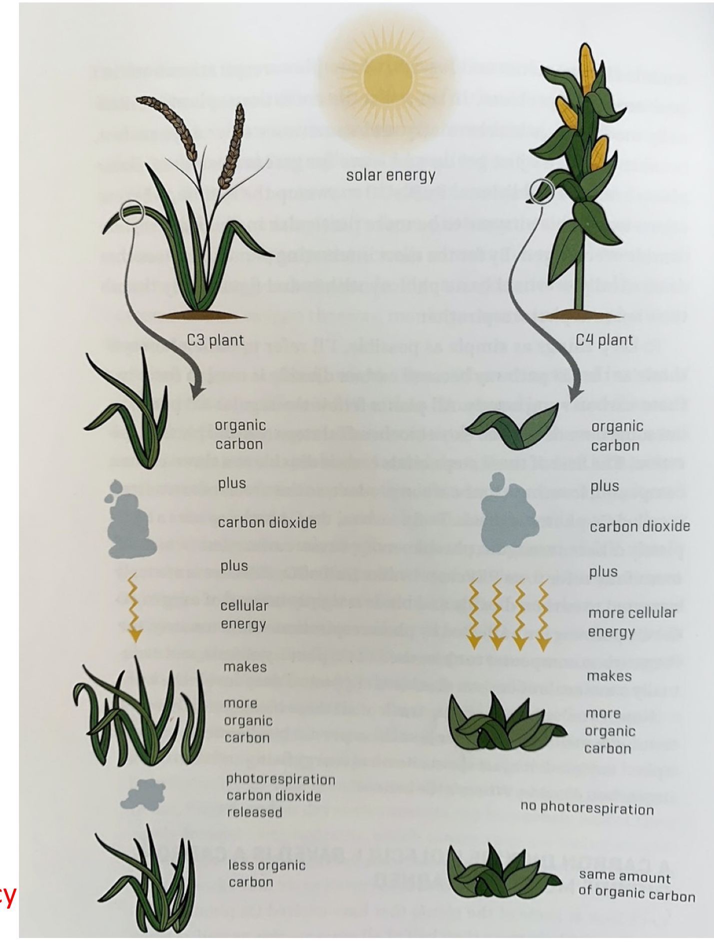
- Respiration is the process by which all living organisms create an energy source from stored food.
- In contrast, plant photorespiration uses up energy and creates useless compounds that have to be reformulated to create food, such as sugars.
- RuBisCo works most efficiently in creating sugars when:

1) CO_2 levels are high,
2) O_2 levels are relatively low,
3) temperatures are moderate and
4) water is plentiful.

- In hot, bright, and/or dry environments, RuBisCo works poorly and photorespiration can be so negative that plants can lose nearly half of their newly formed carbohydrates, and this loss of weight can cause plants to die back, or even die.

C3 vs C4

- C3 is the name given to the basic photosynthesis process described previously, in which 3-carbon precursor compounds are made to make sugar. All plants do this, but some have developed additional extra biochemical steps to avoid photorespiration, called C4, using another enzyme, with the acronym PEPcase.
- PEPcase is strongly attracted to CO_2 and is used to create a 4-carbon compound, which can't be used in phototranspiration.
- However, this new 4- C compound can't easily be used to produce sugar, but at a low O_2 level and low temperature, it can be used by RuBisCo to make a sugar.
- The negative aspect is that it takes almost twice as much energy to make a 4-carbon compound as a 3-carbon compound, but in warm environments like the tropics, because of bright light, the increased energy cost is tolerable to avoid photorespiration.



Unfavourable conditions: too hot and/or dry → → death or dormancy

More energy required

No photorespiration

Survival

C4 Plants

- More than half of all grasses and some herbaceous annuals and perennials, but no conifers, are C4 plants.
- Our lawns go brown in the summer because bluegrass, fescue and our other cool-growing grasses are C3, and so must go dormant in dry summers above about 27° C (80° F). The roots remain alive, but the leaves die back.

- The green “weeds” that we see in hot summer lawns in temperate areas are all C4 plants, photosynthesizing briskly with little interference from the now dormant C3 plants. However, they still need water, so without some minimal water input, they too will go dormant.
- In the fall when temperatures drop and rains return, the extra energy demand in C4 plants become a liability, and C3 plants return in full force and will dominate.
- Tropical grasses like Bermuda grass are C4, which is why they do well in tropical regions and make up lawns there.

Succculents

- The C4 pathway does not work well during the day in perpetually arid environments.
- Desert habitats are characterised by succulent species, such as cacti and euphorbs, which first and foremost must survive drought.
- This is done by storing water in fleshy tissues and reducing water loss by closing their stomata during the day, and only opening them at dusk to allow CO_2 in and O_2 out. Succulents are C4 species, but these compounds when produced are stored overnight in large, water-filled structures called vacuoles.
- When the sun rises, stomata close, and the C4 compounds produced are released into cells where the RuBisCo enzymes begin the C3 pathway in the early morning in what is then a moist, warm, now CO_2 rich environment**.**