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UNIT 1: METABOLIC PROCESSES

A. Photosynthetic Organisms

Chlorophyll

- photosynthesis takes place in plants, algae, some protests, and cyanobacteria
- all of these organisms contain the major photosynthetic pigment **chlorophyll a** (blue-green)
- the structure of chlorophyll is seen on p. 139, Figure 2
- chlorophyll contains a **porphyrin ring system** and a long hydrophobic tail, called a **phytol chain**
- the porphyrin ring possesses a system of rings that have alternating double and single bonds, and a magnesium atom at the centre of the system
- the delocalized electrons in the ring system absorb the sunlight energy, get exited to high energy levels, and begin the photosynthetic process
- the difference between chlorophyll a and chlorophyll b is a functional group – chlorophyll a has a methyl group (-CH_3), and chlorophyll b has an aldehyde group (-CHO) in the same position
- this minute difference in functional group chemistry results in each pigment absorbing slightly different types of light

Cyanobacteria – Prokaryotic Autotrophs

- these organisms are often referred to as blue-green algae
- they make up the largest group of photosynthesizing prokaryotes
- they live in water – oceans, freshwater lakes, rivers, and on land – on rocks, and in soil
- cyanobacteria are known to cause cyanobacterial blooms (see Figure 4, p. 140) – a discolouring of water that is toxic to fish, birds, humans, and other mammals
- dense blooms of cyanobacterium *Microcystis aeruginosa* produce a toxin called microcystin – which can cause headaches, vomiting, diarrhea, and itchy skin in humans, and even death in small animals (see Figure 4 (b), p. 140)
- cyanobacterial blooms develop in water that is rich in nitrates and phosphates runoff from farms and industry – basically, the over fertilization of the water results in an overgrowth of cyanobacteria
- on rocks, cyanobacteria associate with fungi, in a symbiotic, mutual relationship, to produce lichens – *Flavopunctelia soredica*
- lichen are responsible for breaking down rock and making soil – they help the inorganic minerals from the rock nourish soil for plant growth (see Figure 5, p. 140)
- cyanobacteria were probably the first organisms to photosynthesize – they are responsible for infusing the O_2 into the atmosphere, an paving the way for heterotrophic life on Earth
- the endosymbiotic theory proposes that it was an ancestral cyanobacterial life form that was engulfed by an ancestral eukaryotic cell
- the relationship was probably mutually beneficial -- the cyanobacterium benefited by being protected from a harsh external environment, and the eukaryotic host cell benefited by obtaining food molecules produced by the engulfed cyanobacteria

- unlike plants, cyanobacteria contain **chlorophyll d** – photosynthetic pigments called phycobilins
- cyanobacteria do not have membrane-bound organelles, therefore the pigments in cyanobacteria are embedded in infoldings of the cell membrane – possible evidence as to how membrane bound organelles developed in evolution

Eukaryotic Autotrophs: Algae, Photosynthetic Protists, and Plants

- in eukaryotic autotrophs, the phytol chain of the chlorophyll molecule functions to anchor the molecule in the thylakoid membrane of the thylakoid sacs found in the chloroplasts, and the porphyrin ring system is exposed above the thylakoid membrane
- Figure 1(a), (b), and (c), p. 138, shows an example of each type of eukaryotic autotroph that may exist
- the chlorophyll molecule absorbs all bands of light except green, giving leaves, stems, and unripened fruit its characteristic green colour
- the overall process of photosynthesis is summarized as: $6CO_2\ (g) + 6H_2O\ (l) + \text{light energy} \rightarrow C_6H_{12}O_6\ (aq) + 6O_2\ (g)$
- however, since a variety of simple sugars can be made by this process, an empirical formula is written to represent the process: $CO_2\ (g) + H_2O\ (l) + \text{light energy} \rightarrow [CH_2O]\ (aq) + O_2\ (g)$

Leaves: The Photosynthetic Organs of Plants

- leaves are the primary organ of photosynthesis for plants
- despite the variety of modifications that exist in leaf structure physiology (Figure 7 (a) and (b), p. 141), all leaf designs maximize the surface area exposed to sunlight and limit the distance that gases, such as CO_2, need to travel to reach the chloroplasts
- the basic design of leaf structure is seen in Figure 9, p. 142

Leaf Part	**Function**
cuticle	waxy, water-resistant covering on the surface of leaves that prevents water loss and protects the interior of the cell from harmful, excessive radiation
epidermis layer	allows light to pass through to the mesophyll cells and is an additional layer of protection for interior tissues
palisade mesophyll	elongated cells stacked close together in a “column”-like arrangement, that possess a lot of chloroplasts, thus undergo the bulk of the leaf’s photosynthesis
spongy mesophyll	spaced out cells that are located below the palisade cells and allow air spaces for the collection of CO_2 and O_2 gases
guard cells	two cells that border the stomatal openings – they swell up with water to open, and lose water to close the opening
stomata	allow transpiration to occur microscopic openings in the epidermal layer of leaves to regulate gas exchange of CO_2 and O_2

Transpiration and Photosynthesis

- transpiration is the loss of water by the plant
- the average-size tree loses up to 200 L of water per day

- even though the stomatal openings account for only 1% to 2% of the entire leaf's surface area, they are extremely efficient at bringing gases into the leaves and allowing gases to exit the leaves
- the stomata are responsible for more than 85% of the water lost by a plant
- the other part of the leaf responsible for water loss is the cuticle layer
- transpiration helps the photosynthetic pathway in two ways:
    - it creates a transpiration pull that helps move water, minerals, and other substances from roots, where they are absorbed, to leaves where they are used
    - it produces an evaporative cooling effect that prevents leaves from heating to temperatures that could inhibit or even denature the enzymes that catalyze the reactions of photosynthesis
- the size of the stomatal openings are regulated by the plant in response to various environmental conditions in an effort to maximize CO_2 intake and limit water loss
- in general, conditions that promote transpiration – such as sunny, warm, dry, windy weather – cause guard cells to reduce the size of the stomatal opening
- stomata open when guard cells are turgid and close when guard cells are flaccid (see Figure 11, p. 143)
- guard cells swell up as water rushes inside them via osmosis, following the diffusion of potassium (K^+) ions across the guard cell's plasma membrane, due to active transport of H^+ ions, through membrane-associated proton pumps, out of the guard cell, which are in turn dependent on availability of ATP
- the specific design of the guard cell – thicker cell walls forming the perimeter, and a series of radial cellulose microfibrils and terminal attachments, causes it to buckle outward and form an opening when they swell up with water (see Figure 11a, p. 143)
- when K^+ ions move out of guard cells, water follows by osmosis, the guard cells sag, and the stomata closes (see Figure 11b, p. 143)
- two factors stimulate stomata to open:
        - as the sun comes out, light energy activates specific receptors in guard cell membranes, which stimulate proton pumps, which in turn pump H^+ ions out of the cells – K^+ ions diffuse into the cells, water follows, the guard cell swells up, and the stomates open
        - as CO_2 is consumed in the mesophyll air spaces, it stimulates osmosis of water into guard cells, which then causes stomates to open as well
- one factor stimulates stomata to close: a decrease in sucrose content of guard cells in the evening (when the sun goes down)

Chloroplasts

- a typical plant cell chloroplast is approximately 3 mm to 8 mm in length and 2 mm to 3 mm in diameter (see Figure 13, p. 144)
- chloroplasts contain two membranes – an outer and inner membrane
- the fluid inside the inner membrane is called the **stroma**
- a system of membrane-bound sacs called **thylakoids** stack on top of one another to form characteristic stacks called **grana**

- there are approximately 60 grana in each chloroplast, each consisting of 30 to 50 thylakoid sacs
- adjacent grana are connected together by **lamellae**
- photosynthesis occurs partly within the stroma and partly within the **thylakoid membrane**
- the thylakoid membrane contains light-gathering pigment molecules and the electron transport chains that are essential to the process of photosynthesis
- the thylakoid system of membranes increases the surface area which ultimately amplifies the efficiency of photosynthesis
- chloroplasts, like mitochondria, contain their own DNA and ribosomes, and they replicate by fission

Homework: 1-9, pp. 145-146.

B. Light Energy and Photosynthetic Pigments

HISTORY of PHOTOSYNTHESIS RESEARCH

- the reaction of photosynthesis can be written as: $12\ H_2O + 6\ CO_2 \rightarrow C_6H_{12}O_6 + 6\ O_2 + 6\ H_2O$
- the original theories of plant photosynthesis suggested that plants received all of the matter that contributed to their growth in size from the soil
- Figure 4, p. 149, illustrates Jean Baptiste Van Helmont's experiment which demonstrated that a willow accumulated more mass than what was lost in the soil it grew in
- Joseph Priestly then discovered (Figure 6, p. 149) that plants were able to replenish the oxygen deficit in a bell jar, suggesting that the oxygen that was liberated by the plant must have been exchanged with another gas present in the air
- it was later found that the gas exchanged was in fact CO_2
- following experiments were done to determine the origins of each of the atoms of the products of photosynthesis
- p. 150 of your text book explains the process that determined the ultimate fate for each photosynthesis reactant atom:
    - the six carbons of CO_2 molecules, all ended up in carbons that made up glucose
    - of the 12 oxygens of the CO_2 molecules, 6 of them end up in glucose, and 6 of them end up in the water that is produced
    - of the 24 hydrogens from the reactant water molecules, 12 of them end up in the glucose, and 12 of them end up in the water that is produced
    - all the 12 oxygens from the reactant water molecules end up becoming the 6 oxygen molecules of gas liberated

OVERVIEW OF PROCESS

- in 1905, F.F. Blackman determined the effects of light intensity, CO_2 concentration, and temperature on photosynthetic rates
- two observations were made from his results:

  - at low light intensities, the rate of photosynthesis could be increased by increasing the light intensity, but not by increasing the temperature
  - at high light intensities, the rate of photosynthesis is increased by increasing the temperature, not by increasing light intensity

- from these results, he concluded that photosynthesis occurs in two distinct parts – an initial light-dependent (photochemical) stage and a second light-independent (biochemical) stage that is primarily affected by heat, not light

- further experiments by Blackman showed that the rate of photosynthesis is sensitive to the concentration of carbon dioxide, but to a certain extent – while controlling the temperature, Blackman subjected plants to air containing different concentrations of carbon dioxide at different light intensities

- he found that at high light intensities increasing the concentration of CO_2 did not increase photosynthetic rates, but a low light intensities, increasing the CO_2 concentration increased the rate at which glucose was produced

- today, we know that photosynthesis is divided into two distinct parts:

  - LIGHT DEPENDENT REACTIONS (Photosystem I and Photosystem II)
    - capturing light energy
    - using captured light energy to make ATP and reduced $NADP^+$ (NADPH) nicotinamide adenine dinucleotide phosphate
  - LIGHT INDEPENDENT REACTIONS (Calvin Cycle)
    - using the free energy of ATP and the reducing power of NADPH to synthesize organic compounds, such as glucose, from CO_2

- Figure 1, p. 147, illustrates an overview of photosynthesis and where each part of the entire process occurs – note the chloroplast structures involved in each process

ELECTROMAGNETIC RADIATION AND THE ABSORPTION SPECTRUM

- only 5% of the solar energy incident on a leaf is transferred to carbohydrates

- solar energy that strikes photosynthetic organisms is called **electromagnetic radiation EM**

- EM travels in rhythmic waves or packets of energy called **photons**

- EM waves are not disturbances of material medium like normal waves – instead, they are disturbances of electrical and magnetic fields

- photons are characterized by wavelength – short wavelength photons have higher energy than long wavelength photons

- Figure 3, p. 148, illustrates the EM spectrum of energy, showing how each kind of EM represents a specific wavelength and frequency

- the wavelengths associated with photosynthesis are those that constitute the visible part of the EM, called white light

- white light consists of the range of wavelengths from 380 nm to 750 nm

- within the visible light band, the bands that influence photosynthetic rates the most are the blue and the red bands of light

- when light strikes a pigment molecule the electrons of that molecule jump to a higher excited state

- the energy released in the fall back down is released as both heat and light

- the amount of light energy absorbed is visible in the fall back down as a distinct colour – a quantified amount of energy of a certain wavelength, gives off the colour that is observed

- for **chlorophyll a** absorbs photons with energies in the blue-violet and red regions of the spectrum and reflect or transmit those with wavelengths between about 500 nm and 600 nm that our eyes see as green light – that is why plants are green!!
- since the majority of photonic energy that is used in photosynthesis consists of blue-violet and red regions of the spectrum, then O_2 production will be at a max when photosynthetic organisms are subjected to these wavelengths of light energy
- Figure 10, p. 151, illustrates the results of a Engelmann's experiment, which support this statement
- the degree of absorption (or transmission) of light energy of any substance can be measured by a device called a **spectrophotometer**
- this device produces an **action spectrum** (see Figure 11, p. 152), which shows peeks of absorption for various wavelengths

THE PIGMENTS OF PHOTOSYNTHESIS

- chlorophyll a is not the only pigment in the thylakoid membranes of photosynthetic organisms – other pigments exist in the membrane that absorb light at different wavelengths and transfer this energy to a chlorophyll a, which then initiates the process
- these other pigments are called **accessory pigments** – **chlorophyll b, carotenoids, and xanthophylls**
- chlorophyll b is almost identical to chlorophyll b – although it only differs in one functional group (see Figure 2, p. 139) it is enough to possess a different action spectrum (see Figure 11, p. 152)
- carotenoids (like b-carotene from vitamin A – Figure 12, p. 152), absorb wavelengths other than the yellow-to-red range (see Figure 14, p. 153), which is why any substance containing carotenoid pigments appear orange – like carrots, persimmons, etc.
- xanthophylls appear yellow since they absorb wavelengths other than those in the 610 nm – 620 nm range
- other pigments called **anthocyanins** also have a minor role in influencing photosynthetic rates in plants
- these are not found in the thylakoid membranes – instead they are in the plant cell vacuoles, and absorb wavelengths of light other than those of the 400 nm to 500 nm (violet-blue) and 680 nm to 750 nm (red) ranges
- the result of having a variety of "helper" pigments is that the plant broadens its range of energy absorption, thereby utilizing more of the spectrum to drive photosynthesis
- however, sometimes too much light can damage chlorophyll – as a defence against this "sunburn", the chlorophyll transfers the extra light energy to carotenoids, providing a light defence mechanism called **photoprotection** – kind of like a "sunscreen" effect

Homework: pp. 154 – 155 (1-11)