Sustainability, Cellular Respiration, and Photosynthesis

VOCABULARY

Alternative Energy - energy derived from sources that do not use up natural resources or harm the environment.

Carbon emissions - the carbon compounds released as a result of burning fossil fuels

Carbon footprint - the total amount of CO_2 and CH_4 emissions of a defined population.

Coal – fossilized carbon; fossil fuel; largest source of energy for electricity

Electrical energy – energy made available by the flow of electric charge through a conductor

Energy efficiency – the ratio between the output of an energy conversion machine and the input

Fossil fuels – fuels (coal, oil, natural gas) formed by fossilized carbon from once living organisms

Geothermal – of or relating to energy produced by the internal heat of the earth

Geoexchange (geothermal heat pump) – a system that pumps heat from the ground to produce energy

Generator – a machine that converts mechanical energy into electrical energy

Industrial revolution – the rapid development of industry in Britain in the late 18th and 19th centuries, brought about by the introduction of machinery

Kilowatt hour- a unit of energy; 3.6 million joules

Landfill – a dump

Natural gas – naturally occurring flammable gas used as fuel; mostly methane with other hydrocarbons

Non-renewable energy - natural resource which cannot be reproduced, grown, generated, or used on a scale which can sustain its consumption rate

Oil – a viscous liquid derived from petroleum, esp. for use as a fuel or lubricant.

Photovoltaic- Relating to the production of electric current at the junction of two substances exposed to light.

Pollution - The presence in or introduction into the environment of something that has harmful or poisonous effects.

Renewable energy - energy from naturally replenished resources such as sunlight, wind, tides, and geothermal heat.

Solar panels – A panel designed to absorb the sun's rays for generating electricity or heating.

Solar power – power obtained from the energy of the sun's rays (photons)

Sustainability – the capacity to endure

Turbine- a machine with a rotor, driven by the pressure, momentum, or reactive thrust of a moving fluid

Watt – a measure of power; a measure of rate of energy use (J/s)

Wind farm – an area of land with many wind turbines

Wind power – power derived from wind

CHAPTER 8

Concept 1

- Metabolism = totality of an organism's chemical reactions
- Metabolic pathways = a specific molecule goes through a series of steps to arrive at a product, and each step is catalyzed by a specific enzyme
    - Catabolic pathways = complex molecules broken down to simpler ones to make energy available (e.g. cellular respiration), known as "downhill"
    - Anabolic pathways = consume energy to build up complex molecules from simpler ones (e.g. photosynthesis), known as "uphill"
- Energy = capacity to cause change
    - Kinetic energy = motion of objects
    - Thermal energy = kinetic energy associated with movement of atoms and molecules
    - Potential energy = energy that is not kinetic energy
    - Chemical energy = potential energy available for release in bonds
- Thermodynamics = study of transformation of energy
    - First Law: Energy cannot be created or destroyed.
    - Second Law: Every energy transformation increases the entropy of the universe.
        - increasing forms of heat (e.g. producing heat and small useless molecules with lower chemical energy during cellular respiration)
        - energy usually flows into an ecosystem as light and exits in the form of heat

Concept 3

- ATP = adenosine triphosphate and contains a sugar ribose, a nitrogenous base adenine, and a chain of three phosphate groups
- Note that the phosphate bonds are not unusually strong, it's just that ATP and water have high energy in relation to ADP and P
- ATP cycle = process of renewing ATP
- ATP formation is not spontaneous, so it requires energy

Concept 4

- Enzymes speed up metabolic reactions by lowering activation energy barriers
    - Activation energy = amount of energy needed to push a reaction "uphill"
- The reactant an enzyme acts on is called the substrate

        - Enzymes bind to substrates on their active site to form enzyme-substrate complexes
            - Specificity is due to its shape
- Enzyme reaction rate is increased by more substrate up to a certain point; then the rate can be increased by adding more enzyme
    - "Certain point" = when enzyme gets saturated
- Rate also increases with warmer temperatures to a point and generally at pH of 6-8
    - Too high temperature disrupts bonds in enzyme and denatures it
    - Some exceptions to pH exist
- Cofactors: nonprotein helpers for catalytic activity
- Coenzyme: cofactor that is an organic molecule

CHAPTER 9

<u>Concept 1</u>

- Cellular respiration includes both aerobic respiration and anaerobic respiration (e.g. fermentation) but is sometimes synonymous with aerobic respiration only
- Aerobic respiration: organic molecules + oxygen → carbon dioxide + water + energy
    - Specifically: $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + ATP$
- Respiration breaks down molecules in steps because it's inefficient to do it at all at once
    - Hydrogen gets transferred to the coenzyme electron acceptor NAD^+ because it cycles easily between NAD^+ and NADH; electrons eventually make their way to oxygen
- Electron transport chain = bunch of molecules (mostly proteins) in the inner membrane of the mitochondrion where electrons from glucose are shuttled to the high energy end by NAD^+ and then taken and combined with H^+ and O_2 to make water
    - Each "downhill" carrier is more electronegative than the "uphill" carrier preceding it
    - Route = glucose -> NADH -> electron transport chain -> oxygen
- Three stages of cellular respiration: glycolysis, pyruvate oxidation and citric acid cycle, oxidative phosphorylation
- Glycolysis occurs in the cytosol and breaks glucose into two molecules of pyruvate
- Pyruvate gets oxidized into acetyl CoA and enters citric acid cycle where glucose is broken down into carbon dioxide
- Energy released by each step of the electron transport chain is stored in the mitochondria, where it can be converted into ATP through oxidative phosphorylation
    - Substrate-level phosphorylation occurs during reactions of glycolysis and citric acid cycle, when an enzyme transfers a phosphate group from a substrate to ADP
    - Oxidative phosphorylation is when an inorganic phosphate is added

<u>Concept 2</u>

- Glycolysis: glucose is split into two three-carbon sugars which are rearranged to form pyruvate
- Two phases: energy investment and energy pay-off
    - Energy investment: expends 2 ATP
    - Energy pay-off: create 4 ATP through substrate-level phosphorylation and NAD^+ is reduced to NADH from electrons released during the oxidation of glucose; glucose becomes 2 pyruvate and 2 H_2O
    - Net yield: 2 ATP, 2 NADH, 2 pyruvate, 2 H_2O
- No CO_2 is released and no O_2 is needed; energy from pyruvate and NADH is released through further steps

Concept 3

- Most of the energy is in the two molecules of pyruvate
- If O_2 is there, pyruvate enters mitochondrion in eukaryotic cells through active transport or stays in cytosol in prokaryote cells where oxidation of glucose is completed
- Pyruvate turns into acetyl coenzyme A (acetyl CoA) which has a high potential energy, and some extracted electrons reduce NAD+ (1 per pyruvate molecule)
- Citric acid cycle: 1 CoA yields 2 CO_2, 3 NADH, 1 ATP (substrate-level phosphorylation), and 1 $FADH_2$
  - NADH and $FADH_2$ bring their electrons to the electron transport chain
- Citric acid cycle + glycolysis: 4 ATP per glucose

Concept 4

- After citric acid cycle, most of the energy from glucose is in NADH or $FADH_2$
- Oxidative phosphorylation uses energy released by the electron transport chain to make ATP
- Electron transport chain = collection of molecules embedded in the inner membrane of the mitochondrion (plasma membrane in prokaryotes)
- Each component becomes reduced when it accepts electrons from its “uphill” neighbor and then back to its original state when it passes it to the “downhill” neighbor
- Steps of the chain for NADH:
  - NADH's electrons go to a flavoprotein
  - Flavoprotein's electrons go to an iron-sulfur protein
  - Iron-sulfur protein’s electrons go to the only molecule that isn’t a protein
  - Electrons pass through a series of cytochromes
  - Finally go to oxygen, which also picks up two H+ ions
- $FADH_2$ joins the party late, at the iron-sulfur protein, which is why it contributes less energy for ATP synthesis
- Note: electron chain does not create any ATP directly; it only releases energy in manageable amounts instead of all at once
- Electron transport and energy release is coupled in chemiosmosis to lead to ATP (process of electron transport + ATP synthesis = oxidative phosphorylation)
  - ATP synthase, the enzyme that makes ATP from ADP, is powered by an H+ gradient on the inner mitochondrial membrane
  - Chemiosmosis: energy stored in the form of H+ gradient to do cellular work
  - Electron transport chain creates the H+ gradient by pumping protons out, and ATP synthase uses the power from some of the H+ ions returning
- Total process generates 36 to 38 ATP

Concept 5

- Oxidative phosphorylation wouldn’t work without oxygen because you need the electronegative atom to pull electrons at the end of the electron chain
- Fermentation is done in the absence of oxygen, and glycolysis is still performed since you always only use NAD+ to oxidize glucose into two molecules of pyruvate
  - Fermentation = extension of glycolysis by continuation of substrate-level phosphorylation
- Fermentation = glycolysis + oxidizing NAD+
  - Since you’d eventually run out of NAD+ as there’s no electron transport chain to oxidize

NADH, you have to oxidize it with pyruvate
    - NAD+ is then reused to oxidize glucose
- Two types of fermentation: alcoholic fermentation and lactic acid fermentation
- Alcoholic fermentation: pyruvate is converted to ethanol
    - Step 1: release carbon dioxide from pyruvate
    - Step 2: use NADH to reduce the 2-carbon compound to ethanol
    - Carried out by many bacteria as well as yeast
- Lactic acid fermentation: pyruvate is converted to lactate with no CO_2 release
    - Carried out by some fungi and bacteria for dairy products and by human muscle cells
- Cellular respiration gets more ATP than fermentation because you get to use pyruvate's energy
- Obligate anaerobes: only carry out fermentation or anaerobic respiration and can't survive in the presence of oxygen
- Facultative anaerobes: can carry out either fermentation or respiration (pyruvate = fork in metabolic road, so either becomes acetyl CoA or lactate)
    - When undergoing fermentation, has to consume glucose at faster rate
    - Muscles cells act like this on a cellular level

<u>Concept 6</u>

- Glucose is the fuel for cellular respiration but we eat food in the form of fats, proteins, sucrose, and polysaccharides
- Carbohydrates get hydrolyzed into glucose
- Proteins are broken down into amino acids which are used as such, and any extra amino acids become pyruvate or acetyl CoA, releasing NH_3 in the process
- Fats become glycerol and fatty acids (majority of energy here); glycerol becomes an intermediate of glycolysis and fatty acids become acetyl CoA

CHAPTER 10

<u>Concept 1</u>

- Endosymbiont theory: chloroplasts originate from prokaryotic cells living inside ancestors of eukaryotic cells
- All green parts of plants have chloroplasts but leaves are the major sites
    - Found in the mesophyll, the tissue in the interior of the leaf (30-40 chloroplasts per mesophyll cell)
- Carbon dioxide enters and oxygen leaves through stomata
- Chloroplasts contain a dense fluid called stroma with thylakoids suspended inside, which are stacked in columns of grana
    - Chlorophyll is in the thylakoid membrane of the chloroplast
- $6\ CO_2 + 12\ H_2O + \text{light energy} \rightarrow C_6H_{12}O_6 + 6\ O_2 + 6\ H_2O$
    - Taking out the shared waters yields the reverse of the respiration equation
- Photosynthesis: water is split and electrons are transferred along with the H^+ ions from the water to carbon dioxide, reducing it to sugar
    - Unlike respiration where they lose potential energy, spurring ATP production, these electrons gain energy from each step, so the energy comes from light
- Two stages of photosynthesis: light reactions (occurs in thylakoids) and Calvin Cycle (occurs in stroma)

- Light reactions: convert solar energy to chemical energy
    - Splitting water produces electrons, protons (H+), and O_2
    - Light energy drives a pair of electrons and H+ from H_2O to reduce NADP+ to NADPH
    - Uses chemiosmosis to generate ATP = photophosphorylation
    - Net energy products: NADPH and ATP
- On the outside of thylakoids, NADP+ picks up its electrons and ADP picks up its phosphate and then they move to the stroma
- Calvin cycle: produce sugar
    - Incorporates CO_2 from air into organic molecules = carbon fixation
    - Adds electrons to reduce the fixed carbon into a carbohydrate (reducing power comes from NADPH and energy comes from ATP from the light reactions)
    - Also called "dark reactions" or "light-independent" reactions
        - Still occurs in the daylight for most plants because it needs the energy generated by the light reactions

<u>Concept 3</u>

- Calvin cycle is similar to citric acid cycle in that the starting molecule is regenerated
    - Key different: Calvin cycle = anabolic (building up glucose and using ATP) and citric acid cycle = catabolic
- CO_2 enters and leaves in the form of sugar, and NADPH is used as reducing power to give electrons for the formation of sugar
    - Sugar produced isn't glucose but glyceraldehyde 3-phosphate (G3P)
        - G3P = same molecule made in glycolysis by splitting glucose
    - Cycle must take place 3 times to produce one molecule of G3P
- Three stages of Calvin Cycle: Carbon fixation, reduction, regeneration of CO_2 acceptor
- Carbon fixation: attaches each CO_2 to a 5-carbon sugar, RuBP (via rubisco enzyme)
    - Product = three unstable 6-carbon sugars that split into two 3-phosphoglycerates each (2 per CO_2)
- Reduction: for every 3 CO_2, makes six molecules of G3P but only 1 net (due to RuBP used)
    - Each 3-carbon sugar gets a phosphate group from ATP, then gets reduced by NADPH and loses the phosphate group, becoming G3P
- Regeneration: use the other five G3P to make three RuBP by spending 3 molecules of ATP
- To make one G3P, 9 ATP and 6 NADH are used and 1 G3P is made
    - Light reactions regenerate ATP and NADH
    - G3P is used to synthesize glucose and other organic molecules

<u>Concept 4</u>

- Plants need a compromise between photosynthesis and extensive water loss
    - CO_2 enters via stomata but water needs to leave through that; on hot days plants need to close their stomata to prevent loss of water
- C3 plants = those that fix carbon to RuBP with rubisco
    - On hot days, they produce less sugar and fix O_2 instead of CO_2 through photorespiration but it consumes ATP and doesn't make sugar
- Photorespiration is an evolutionary relic from when there was very little O_2 because the inability of rubisco to exclude oxygen wouldn't have mattered

- C4 and CAM have evolved to maximize Calvin cycle and minimize photorespiration
- C4 plants precede the Calvin Cycle by making a 4-carbon product
    - Two types of photosynthetic cells: bundle-sheath and mesophyll (the latter is under the former)
    - Calvin cycle occurs in the bundle-sheath cells but carbon fixation occurs in the mesophyll cells
    - Summary: mesophyll cells pump CO_2 into the bundle sheath to keep the concentration high enough for rubisco to bind with CO_2 instead of O_2
- CAM plants: water-bearing plants
    - Close their stomata during the day and open them at night (takes in CO_2 at night and carries out photosynthesis during day)
    - Carbon fixation happens at night (four-carbon molecules like C4) and Calvin cycle happens during the day