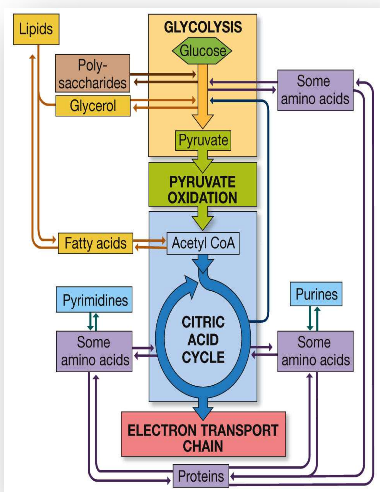
General Biology II (101-HTK)
Cellular Respiration & Fermentation Concepts and Learning Outcomes

Topic	Concept	Learning Outcomes
Biological redox reactions	1. Cells use redox reactions to extract free energy from reduced chemical compounds (fuel) in nutrients. 2. For most cells, the most common chemical fuel is glucose. The extraction of usable energy from glucose involves metabolic pathways that result in the oxidation of glucose and the capture of energy to make ATP.	1. Name the type of chemical reaction cells use in order to extract free energy from chemical compounds in nutrients 2. Identify the chemical fuel used by most cells and the type of reaction that results in the extraction of usable energy from this compound
Overview of glucose oxidation and the release of chemical energy	3. Energy from glucose is harvested by 3 different metabolic pathways: glycolysis, cellular (aerobic) respiration (involving O_2), and fermentation (in the absence of O_2). 4. In aerobic respiration, the highly reduced glucose is oxidized to form CO_2, and O_2 is reduced to form H_2O: $C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O$ + free energy 5. In fermentation, glucose is partially oxidized, releasing less energy than aerobic respiration and resulting in the formation of ethanol or lactic acid. 6. In biological redox reactions, electron carriers (eg, NAD) are involved in the transfer of e^- from reduced compounds to the final e^- acceptor.	3. Name the 3 different metabolic pathways by which free energy from glucose is captured to drive the endergonic formation of ATP 4. Write a summary reaction for aerobic respiration that shows which reactant becomes oxidized and which becomes reduced 5. Outline the main differences between aerobic respiration and fermentation in terms of O_2 requirement, end products, and level of free energy release 6. Identify the role of electron carriers in biological redox reactions
Glycolysis	7. Glycolysis occurs in the cytoplasm and can be divided into 2 stages: energy-investing reactions that use ATP and energy-harvesting reactions that produce ATP. 8. In the energy-investing reactions of glycolysis, a	7. Indicate where in the cell glycolysis occurs and write a summary reaction for each of the 2 stages of glycolysis 8. Outline the changes in free energy that occurs in the glycolytic pathway

	glucose molecule is split into 2 3-carbon compounds (glyceraldehydes-3-phosphate or G3P): glucose + 2 ATP → 2 G3P + 2 ADP + 2 Pi 9. In the energy-harvesting reactions of glycolysis, G3P is oxidized into pyruvate: 2 G3P + 2 NAD^+ + 4 ADP + 4 Pi → 2 pyruvate + 2 NADH + 2 H^+ + 4 ATP. 10. ATP is formed by substrate-level phosphorylation, in which a phosphate group is transferred to ADP from a phosphorylated intermediate compound.	
Pyruvate oxidation	11. Pyruvate oxidation occurs on the plasma membrane of prokaryotic cells and in the mitochondrial matrix of eukaryotic cells. 12. In eukaryotic cells, pyruvate is actively transported from the cytoplasm into the mitochondrial matrix where it undergoes decarboxylation, oxidation, and conversion into acetyl-coenzyme A (acetyl-CoA) by the enzyme complex pyruvate dehydrogenase: 2 pyruvate + 2 NAD^+ + 2 CoA → 2 acetyl-CoA + 2 NADH + 2 H^+ + 2 CO_2.	9. Contrast the site of pyruvate oxidation in prokaryotic and eukaryotic cells 10. Write a summary reaction of pyruvate oxidation and name the enzyme complex responsible for this reaction 11. Outline the change in free energy that occurs during pyruvate oxidation
Citric acid cycle	13. The citric acid cycle, *aka* Krebs cycle or tricarboxylic acid (TCA) cycle occurs in the cytoplasm of prokaryotic cells and in the mitochondrial matrix of eukaryotic cells. 14. The starting reaction of the citric acid cycle is the reaction of acetyl-CoA with oxaloacetate to yield citric acid (citrate). 15. In a series of 8 enzyme-catalyzed reactions, citrate is oxidized, NAD and FAD (electron carriers) are reduced, and oxaloacetate is regenerated. 16. The citric acid cycle completes the oxidation of glucose to CO_2.	12. Contrast the site of the citric acid cycle in prokaryotic and eukaryotic cells 13. Outline the process of the citric acid cycle by providing the starting point of the cycle and the intermediate reactions that lead to the regeneration of oxaloacetate 14. Outline the change in free energy that occurs during the citric acid cycle
Oxidative phosphorylation	17. Most ATP production occurs by oxidative phosphorylation, which occurs on the inner membrane of mitochondria (eukaryotic cells) or	15. Define chemiosmosis and explain how a gradient of protons is established across the inner mitochondrial membrane 16. Describe the process by which the proton motive force drives

	the cytoplasmic side of the plasma membrane (prokaryotic cells). 18. NADH and FADH2 are oxidized by the electron transport (respiratory) chain whereby O_2 is the final electron acceptor. 19. In oxidative phosphorylation, electron transport is coupled to ATP synthesis by a process known as chemiosmosis.	ATP synthesis in chemiosmosis 17. Add up the energy captured (as ATP, NADH, and FADH2) in each of the stages of aerobic respiration of glucose(glycolysis, pyruvate oxidation, citric acid cycle, and respiratory chain) 18. Explain why reoxidation of NADH is crucial for the continuation of the citric acid cycle
Fermentation	20. Fermentation enables cells to keep producing ATP by glycolysis in the absence of O_2 through the regeneration of NAD^+. 21. In fermentation, pyruvate is reduced to lactic acid (lactic acid fermentation; in muscles, yeast, and some bacteria) or alcohol and CO_2 (alcohol fermentation; in yeast and some bacteria).	19. Define fermentation and compare and contrast lactic acid and alcohol fermentation 20. Compare and contrast aerobic respiration and fermentation; include the mechanisms of ATP formation, the final electron acceptors, the end products, and efficiency of transferring the energy in glucose to ATP
Interrelation of metabolic pathways	22. Cells use many kinds of organic molecules (carbohydrates, lipids, proteins, etc) as fuel for aerobic respiration. 23. Cells use intermediate metabolites of aerobic respiration and ATP for biosynthesis of many kinds of organic molecules 	21. Outline how metabolic and catabolic pathways are interrelated and give examples of catabolic and anabolic interconversions

Metabolic homeostasis	24. Cells regulate metabolic pathways (catabolism and anabolism) by feedback inhibition or stimulation of key enzymes (allosteric regulation).	22. Describe the allosteric regulation of glycolysis and citric acid cycle by giving the examples of phosphofructokinase and isocitrate dehydrogenase