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CONCEPT: INTRODUCTION TO ENERGY

●**Energy**: the ability to perform _____.

□ In Biology, **work** is a *transfer of energy* that causes an overall _____.

Potential vs. Kinetic Energy

1) _____ **Energy**: _____ energy that is available to do *work*.

2) _____ **Energy:** energy of _____.

EXAMPLE: Potential vs. Kinetic Energy.

Energy Types	Examples
Potential Energy (Storage)	Gravitational Energy _____ Energy (stored in chemical bonds)
Kinetic Energy (Motion)	_____ Objects Muscle Contractions

PRACTICE: Which of the following is an example of potential energy?

a) Water rushing over a water fall.

b) A glucose molecule.

c) A spring being released and expanding rapidly.

d) An ant foraging (moving around) for food.

PRACTICE: Which of the following is NOT a form of kinetic energy?

a) When the temperature of a substance rises causing the molecules of that substance to move faster.

b) When a hockey puck slides across the ice after being hit by a player.

c) When glucose molecules are broken down to create energy for cellular work.

d) When the molecules of the air vibrate transmitting soundwaves.

CONCEPT: INTRODUCTION TO ENERGY

Thermodynamics: System vs. Surroundings

●**Thermodynamics**: the study of _____ transfers between bodies of matter.

- □ _____: the specific portion of matter being studied.
- □ _____: everything else outside of the system.
- □ **Biological Systems** transfer both _____ & _____ with the surroundings.

EXAMPLE: Biological Systems.

PRACTICE: Why are the principles of thermodynamics important for the study of biology?

a) The principles of thermodynamics govern the chemical processes in all biological organisms.
b) The principles of thermodynamics govern how an organism exchanges energy with their environment.
c) The principles of thermodynamics govern how all life on Earth exchanges energy.
d) All of the above.

PRACTICE: Which of the following is NOT an example of a biological system?

a) A human eating a cheeseburger.
b) A coral reef where energy and mass both enter and exit.
c) The digestive system of an organism absorbing food energy and discarding food waste.
d) The universe where the amount of energy and mass is constant.

CONCEPT: LAWS OF THERMODYNAMICS

First Law of Thermodynamics

●"Energy _____ be *transferred* and *transformed*, but it _____ be *created* or *destroyed*."

□ AKA: The Principle of _____ of Energy.

□ The TOTAL amount of *energy* in the universe does _____ change.

EXAMPLE: First Law of Thermodynamics.

PRACTICE: Which of the following statements describes the first law of thermodynamics?

a) Energy cannot be created or destroyed.
b) Energy cannot be transferred or transformed.
c) Also called The Principle of Creation of Energy.
d) Energy can be destroyed.

Entropy

●A measure of _____, or randomness; the greater the disorder, the _____ the entropy.

●The "natural tendency" of reactions is to move the Universe toward a state of _____ entropy (disorder).

□ Reactions can decrease entropy of a system with an _____ *input*.

EAMPLE: Low vs High Entropy Systems.

CONCEPT: LAWS OF THERMODYNAMICS

PRACTICE: Which of the following images has less entropy?

a) Image A has less entropy.

b) Image B has less entropy.

Second Law of Thermodynamics

●2nd law: 100% efficient energy conversion is *impossible* since _____ energy is lost, increasing *universal entropy*.

□ **Heat**: form of _____ *energy* that is transferred between two objects with different *temperatures.*

EXAMPLE: Second Law of Thermodynamics.

PRACTICE: When chemical, transport, or mechanical work is done by an organism, what happens to the heat generated?

a) It is used to power yet more cellular work in the surroundings.

b) It is captured to store energy as more heat in the system.

c) It is used to generate ADP.

d) It is lost to the environment.

PRACTICE: Which of the following statements is true regarding how energy moves up the food chain?

a) All of the energy is not transferred from producer to consumer because some of the energy is destroyed.

b) All of the energy is transfer from producer to consumer.

c) All of the energy is not transferred from producer to consume because some of the energy is lost as heat.

d) None of the above.

CONCEPT: CHEMICAL REACTIONS

- **Chemical reactions** consist of the *making* and/or *breaking* of _____ *bonds* leading to changes in matter.
  - □ **Reactants**: the _____ material in a *chemical reaction.*
  - □ **Products**: the _____ material in a *chemical reaction.*

EXAMPLE: Chemical Reaction.

Types of Chemical Reactions

- *Chemical Reactions* are categorized into 2 groups based on _____ requirement:
  1. _____**dergonic Reactions**: requires an *input* of energy (energy **EN**ters the reaction).
  2. _____**ergonic Reactions**: releases energy (energy **EX**its the reaction).

EXAMPLE: Endergonic vs Exergonic Reactions.

PRACTICE: Which of the following statements is true for all exergonic reactions?

a) The products have more total energy than the reactants.

b) The reaction proceeds with a net loss of free energy.

c) The reaction goes only in a forward direction: all reactants will be converted to products.

d) A net input of energy from the surroundings is required for the reactions to proceed.

CONCEPT: ATP

●*Recall:* **Adenosine Triphosphate** (_____): a _____ energy molecule used to "*power*" cellular activities.

●There are 3 primary components of an ATP molecule:

1 Chain of ____ phosphate groups 2 _____ sugar 3 _____ nitrogenous base.

●**ATP Hydrolysis:** process of breaking bonds between _____ *groups* generating *chemical energy* & ADP.

□ Sometimes ADP can be hydrolyzed to form AMP.

EXAMPLE: ATP structure & hydrolysis.

PRACTICE: Which of the following statements is true?

a) ADP contains more potential energy than ATP.

b) Following hydrolysis, ATP can give off one phosphate group and usable energy, whereas ADP cannot.

c) The energy produced by ATP comes from the breaking of the bond between two phosphate groups.

d) AMP and ADP contain the same amount of potential energy.

PRACTICE: Which of the following is the most correct interpretation of the figure?

a) Energy from food sources can be used directly for performing cellular work.

b) ADP + P_i are a set of molecules that store energy.

c) ATP is a molecule that acts as an intermediary to store energy for cellular work.

d) Pi acts as a shuttle molecule to move energy from ATP to ADP.

CONCEPT: ATP

Energy Coupling

●When energy released by an _____ *reaction* is used to power/drive an *endergonic* reaction.

□ *ATP* _____ is coupled to *endergonic* reactions to provide the energy input they need to proceed.

EXAMPLE: Energy Coupling.

PRACTICE: How does ATP participate in energy-coupling reactions?

a) Hydrolysis of ATP fuels endergonic reactions.
b) Hydrolysis of ADP fuels endergonic reactions.
c) Synthesis of ATP fuels exergonic reactions.
d) Synthesis of ADP fuels exergonic reactions.

Phosphorylation

●The transfer of a *phosphate group* from _____ to another molecule to provide *energy*.

●Phosphorylation by ATP hydrolysis can have a wide _____ of effects:

1 _____ a target molecule to react.

2 Changes the _____ of a target protein.

CONCEPT: ENZYMES

●**Enzyme**: molecule that catalyzes (or "_____-_____") a *chemical reaction* _____ being consumed.

□ **Substrates**: the reactants of a chemical reaction that is *catalyzed* by an enzyme.

EXAMPLE: Non-Enzymatic vs. Enzymatic Reaction.

Functions of Enzymes

●*Enzymes* have a variety of functions in living cells including:

1 Building _____ ; 2 Copying _____ ; 3 _____ food.

PRACTICE: Which of the following are examples of the functions of enzymes?

a) A lactase enzyme breaking down lactose sugar in the small intestine.

b) A DNA polymerase enzyme synthesizing new strands of DNA.

c) A lipase enzyme breaking down fats (lipids) in the small intestine.

d) A helicase enzyme unraveling DNA so it can be replicated.

e) All of the above.

CONCEPT: ENZYMES

Environmental Factors Affecting Enzyme Activity

●**Enzyme Activity:** a *measure* of the amount of _____ an enzyme can produce in a certain amount of time.

●Many *environmental* factors affect an enzyme's activity:

1 _____ 2 _____ 3 _____ of reactants.

●*Recall*: Several environmental factors (ex. high temp. or acidity) can cause a protein or enzyme to _____.

□ *Denatured* enzymes *lose their shape* & would therefore have _____ activity.

EXAMPLE: Certain species of bacteria are able to perform metabolic reactions (involving enzymes) in hot springs because**:**

a) They are able to maintain a lower internal temperature.

b) High temperatures make catalysis unnecessary.

c) Their enzymes have high optimal temperatures.

d) Their enzymes are completely insensitive to temperature.

PRACTICE: Which characteristics are likely associated with an enzyme isolated from a human stomach where conditions are strongly acidic.

a) An enzyme that functions properly at 70 degrees Fahrenheit and at a neutral pH.

b) An enzyme that functions properly at 98 degrees Fahrenheit and at an acidic pH.

c) An enzyme that functions properly at 98 degrees Fahrenheit and at a neutral pH.

d) An enzyme that functions properly at 70 degrees Fahrenheit and at an acidic pH.

CONCEPT: ENZYME ACTIVATION ENERGY

●**Activation Energy** (_____): the *difference* in energy between the *reactants* & the *transition state* of a reaction.

- □ E_A is the minimum amount of *energy* required to _____ a chemical reaction.
- □ The *higher* the E_A, the _____ the reaction.
- □ **Transition State**: a temporary state of _____ energy in a reaction.

Enzymes Lower E_A

●Enzymes *catalyze* chemical reactions by _____ their *activation energy* barrier (or *transition state* energy).

- □ Reactions occur much _____ in the presence of an enzyme.

EXAMPLE: Reaction coordinate for enzymatic catalysis.

PRACTICE: Which of the following statements is TRUE regarding an enzyme's function?

a) It is generally increased if the structure or conformation of an enzyme is altered.

b) It is independent of factors such as pH and temperature.

c) It increases the rate of chemical reactions by lowering activation energy barriers.

CONCEPT: ENZYME BINDING FACTORS

Enzyme-Substrate Complex

●A substrate binds an enzyme at the *active site*, forming the ***Enzyme-Substrate*** _____ (_____).

□ **Active Site**: specific region of an enzyme that _____ *substrates*.

□ After catalysis, _____ are released from the *active site* but the enzyme is *unchanged*.

EXAMPLE: Substrate binding forms the ES-complex.

Cofactors

●Some enzymes require _____: *non-protein* substances required for catalysis to occur (ex. metal ions).

□ Cofactors are NOT consumed in the reaction.

□ **Coenzyme**: an *organic molecule* cofactor derived from *vitamins*.

EXAMPLE: Cofactors can assist in substrate binding.

PRACTICE: The organic non-protein components that aid in enzyme catalysis are called:

a) Reactants. b) Cofactors. c) Coenzymes. d) Substrates. e) Products.

CONCEPT: ENZYME INHIBITION

●**Enzyme Inhibitors**: compounds that interfere with & selectively _____ the catalysis of specific enzymes.

1 **Competitive Inhibitors:** *compete* with the substrate for a position in the free enzyme's _____ site.

□ Can only bind when the active site is _____.

2 **Noncompetitive Inhibitor:** *does not compete* with the substrate & binds at an _____ *site* on the enzyme.

□ *Allosteric site*: an alternative site for inhibitor binding that is _____ in the *active site*.

EXAMPLE: Competitive Inhibition vs. Noncompetitive Inhibition.

PRACTICE: Which of the following statements correctly describes competitive inhibition?

a) A competitive inhibitor binds to the substrate and inhibits it from binding to the active site of the enzyme.
b) A competitive inhibitor binds to a site other than the active site and inhibits the substrate from binding.
c) A competitive inhibitor binds to the active site and degrades the enzyme.
d) A competitive inhibitor binds to the active site of an enzyme and inhibits the substrate to bind.

PRACTICE: How does a noncompetitive inhibitor decrease the rate of an enzyme-catalyzed reaction?

a) By binding to the active site of the enzyme, thus preventing binding of the normal substrate.
b) By binding to an allosteric site, thus changing the shape of the active site of the enzyme.
c) By decreasing the free-energy change of the reaction catalyzed by the enzyme.
d) By binding to the substrate, thus changing its shape so that it no longer binds to the active site of the enzyme.

PRACTICE: Which of the following types of enzyme inhibition is overcome by increasing the substrate concentration?

a) The need for a coenzyme.
b) Noncompetitive inhibition.
c) Competitive inhibition.
d) None of the above.

CONCEPT: INTRODUCTION TO METABOLISM

●**Metabolism:** _____ of an organism's *chemical reactions*.

□ *Metabolic* _____: series of reactions that alters a substrate multiple times before the final product.

EXAMPLE: Metabolic pathways have multiple steps.

Catabolic & Anabolic Pathways

●There are _____ types of *metabolic pathways*:

1 _____**abolic Pathways** (*Catabolism*): *releases* energy by *breaking*-_____ molecules into smaller ones.

2 **Anabolic Pathways** (*Anabolism*): *spends* energy to *build*-_____ larger molecules (like DNA & proteins).

EXAMPLE: Catabolic vs. Anabolic Reactions.

PRACTICE: Which of the following terms specifically describes the metabolic process of breaking down large molecules?

a) Catabolism. b) Metabolism. c) Anabolism. d) Dehydration.

PRACTICE: Which of the following statements is TRUE regarding anabolic pathways?

a) They are used for digesting sugars.

b) They consume energy to build up polymers from monomers.

c) They release energy by breaking down polymers into monomers.

d) They increase the entropy of the organism.

CONCEPT: NEGATIVE & POSITIVE FEEDBACK

Negative Feedback

●When the final product of a *metabolic pathway* _____ an earlier step in the same pathway.

EXAMPLE: Negative Feedback acts like the "red light" to inhibit (-) metabolic pathways.

Positive Feedback

●When the final product of a *metabolic pathway* _____ an earlier step in the same pathway.

EXAMPLE: Positive Feedback acts like the "green light" to further stimulate (+) metabolic pathways.

PRACTICE: _____ is when the product of a biochemical pathway activates the production of itself.

a) Negative feedback inhibition.
b) Positive feedback.
c) Substrate feedback inhibition.
d) Product feedback inhibition.

PRACTICE: Which of the following is TRUE about feedback inhibition?

a) Feedback inhibition has no physiological importance.
b) Multiple products are required for feedback inhibition.
c) Feedback inhibition of a pathway can only be accomplished by the products of that pathway.
d) Feedback inhibition involves products binding to the active site to prevent enzyme activity.

CONCEPT: REDOX REACTIONS

- **Oxidation-Reduction** (_____) **Reaction**: *transfers* _____ (e^-) between molecules.
  - □ **Oxidation:** the process of _____ one or more electrons.
  - □ **Reduction:** the process of _____ one or more electrons (overall charge is reduced).
  - □ Oxidation & reduction reactions always occur _____ (at the same time).

EXAMPLE: Redox Reaction (**LEO** the Lion goes **GER**).

EXAMPLE: Which of the following molecules is oxidized and which is reduced?

a) Molecule A is oxidized ; Molecule B is reduced.
b) Molecule A is reduced ; Molecule B is oxidized.
c) Both Molecule A & Molecule B are reduced.
d) Both Molecule A & Molecule B are oxidized.

PRACTICE: Oxidation is the _____, and reduction is the _____.

a) Gain of electrons ; Loss of electrons.
b) Gain of protons ; Loss of protons.
c) Loss of electrons ; Gain of electrons.
d) Gain of oxygen ; Loss of oxygen.

PRACTICE: When glucose donates electrons to NAD^+ creating NADH, the glucose molecule becomes:

a) Hydrolyzed.
b) Oxidized.
c) Neutral.
d) Reduced.

CONCEPT: REDOX REACTIONS

Electron Carriers: NADH & $FADH_2$

●Many biological processes (including *Cellular Respiration*) conduct redox reactions using *electron* _____.

□ Electron carriers such as _____ & _____ each carry/transport _____ electrons.

□ NADH & $FADH_2$ can shuttle electrons to different locations within a cell like an electron "_____" cab.

□ NAD^+ & FAD are the _____ forms of NADH & $FADH_2$, respectively.

EXAMPLE: Formation of NADH and $FADH_2$.

□ *Helpful Memory Tool*: think that NAD____ and FAD____$_2$ are just a little bit "____eavier."

□ During *Cellular Respiration*, electrons carried by NADH & $FADH_2$ go to the *Electron Transport Chain*.

PRACTICE: An electron carrier before it harvests energy from glucose molecules in a series of gradual steps is:

a) Pyruvate. b) AMP. c) ATP. d) NAD^+. e) NADH.

CONCEPT: REDOX REACTIONS

Electron Carrier NADPH

●NADPH is an electron _____ similar to NADH and $FADH_2$ for reduction reactions.

●However, unlike NADH & $FADH_2$, NADPH is used in _____ reactions for biosynthesis.

PRACTICE: NADH is commonly used as an electron carrier during the *breaking down* of complex molecules like glucose in cellular respiration. NADPH is also a common electron carrier. However, NADPH is used to *build* complex molecules like glucose in a process called:

a) Biogenesis.
b) Biocatalysis.
c) Biosynthesis.
d) Metabolism.

PRACTICE: Which electron carrier is *not* matched with its correct function.

a) NADH: Shuttles electrons to regions of the cell which need energy.
b) $FADH_2$: Shuttles electrons to the electron transport chain during cellular respiration.
c) NADPH: Shuttles electrons to photosynthesis where glucose molecules are being made.
d) All of the above electron carriers are matched with their correct function.

CONCEPT: INTRODUCTION TO AEROBIC CELLULAR RESPIRATION

- **Aerobic Cellular Respiration**: the _____ process of *breaking-down* glucose to make lots of _____.
  - □ **Aerobic**: requires the presence of _____ gas (O_2).
  - □ Occurs in multiple stages, *most* of which occur inside of the _____ in *eukaryotes*.
  - □ In *prokaryotes*, which lack mitochondria, most of cellular respiration occurs in the _____.

EXAMPLE: Overall Chemical Equation for Aerobic Cellular Respiration.

Aerobic Cellular Respiration is a Redox Reaction

- The overall chemical equation for *Aerobic Cellular Respiration* is a _____ *reaction*.
  - □ By the end of the process, glucose is _____ while oxygen is _____.

EXAMPLE: Chemical Equation for Aerobic Cellular Respiration.

PRACTICE: Which one of the following molecules is a by-product of cellular respiration?

a) Water. b) Glucose. c) Pyruvate. d) Oxygen. e) ADP.

PRACTICE: Which of the summary statements below describes the results of the following reaction?

$$C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O + \text{Energy}$$

a) $C_6H_{12}O_6$ is oxidized and O_2 is reduced.
b) O_2 is oxidized and H_2O is reduced.
c) CO_2 is reduced and O_2 is oxidized.
d) O_2 is reduced and CO_2 is oxidized.

CONCEPT: INTRODUCTION TO AEROBIC CELLULAR RESPIRATION

Stages of Aerobic Cellular Respiration

●Aerobic Cellular Respiration includes _____ metabolic pathways/reactions:

Remembering Stages of Aerobic Cellular Respiration

EXAMPLE: Which of the following options lists the stages of aerobic cellular respiration in the correct order?

a) Glycolysis, electron transport chain & chemiosmosis, pyruvate oxidation, and Krebs cycle.

b) Glycolysis, pyruvate oxidation, Krebs cycle, and electron transport chain & chemiosmosis.

c) Pyruvate oxidation, electron transport chain & chemiosmosis, glycolysis, and Krebs cycle.

d) Krebs cycle, electron transport chain & chemiosmosis, pyruvate oxidation, and glycolysis.

CONCEPT: INTRODUCTION TO AEROBIC CELLULAR RESPIRATION

Map of the Lesson on Cellular Respiration

EXAMPLE: Using the map above, which of the following occurs in the absence of oxygen (no oxygen)?

a) Fermentation.

b) Oxidative phosphorylation

c) Aerobic respiration.

d) O_2 serves as the final electron acceptor.

PRACTICE: Based on the map of cellular respiration, why do we need to breathe in oxygen?

a) Oxygen is the final electron acceptor for lactic acid fermentation.

b) Oxygen is the final electron acceptor for alcohol fermentation.

c) Oxygen is the final electron acceptor for aerobic cellular respiration.

d) Oxygen is not important for the purposes of cellular respiration.

CONCEPT: TYPES OF PHOSPHORYLATION

●During *aerobic cellular respiration*, ATP is made via _____ different types of phosphorylation:

1) *Substrate-Level* Phosphorylation & 2) *Oxidative* Phosphorylation.

1) Substrate-Level Phosphorylation

●Uses an _____ & a *substrate* to directly transfer a phosphate group to ADP, creating _____.

□ Used to make a _____ amount of ATP during *Glycolysis* and the *Krebs Cycle*.

EXAMPLE: Substrate-Level Phosphorylation.

2) Oxidative Phosphorylation

●Uses energy from _____ *reactions* in the *Electron Transport Chain* (*ETC*) to phosphorylate ADP.

□ Builds a _____ *concentration gradient*, which is used to make a _____ amount of ATP.

□ **Chemiosmosis**: diffusion of ions across a membrane _____ their concentration gradient (high to low).

EXAMPLE: Oxidative Phosphorylation.

Oxidative Phosphorylation = _____ + Chemiosmosis

CONCEPT: TYPES OF PHOSPHORYLATION

PRACTICE: Substrate-level phosphorylation is utilized to create ATP in which steps of aerobic cellular respiration?

a) Electron Transport Chain and Chemiosmosis.
b) Glycolysis and Pyruvate Oxidation.
c) Pyruvate Oxidation and Krebs cycle.
d) Glycolysis and Krebs cycle.

PRACTICE: Which type of phosphorylation synthesizes ATP using an enzyme that transfers a phosphate group to ADP?

a) Adaptive Phosphorylation.
b) Oxidative Phosphorylation.
c) Substrate-level Phosphorylation.
d) Product-level Phosphorylation.

PRACTICE: The largest amount of ATP made by cellular respiration is created by the process of _____, in the _____ steps of aerobic cellular respiration.

a) Substrate-level phosphorylation; first.
b) Oxidative phosphorylation; first.
c) Oxidative phosphorylation; final.
d) Substrate-level phosphorylation; final.

CONCEPT: GLYCOLYSIS

●**Glycolysis**: 1st step of cellular respiration that *breaks down* _____ into 2 _____ molecules.

□ "Glyco" = _____. □ "Lysis" = to _____.

□ Glucose has _____ **carbon atoms**, all which end up being converted to **CO_2** in the 2nd & 3rd steps of respiration.

□ ONLY step that occurs *outside* mitochondria (in the cell's _____) & does _____ require Oxygen.

Glycolysis occurs _____ mitochondria, in the cell's _____ .

PRACTICE: Where does the first stage of aerobic cellular respiration take place within a cell?

a) Mitochondrial matrix.
b) Inner mitochondrial membrane.
c) Intermembrane space.
d) Cytoplasm.

Phases of Glycolysis

●Glycolysis consists of a series _____ reactions, which can be grouped into _____ phases:

1) **Energy Investment Phase**: requires an _____ of energy by *using* _____ ATP molecules.

□ **Glyceraldehyde-3-Phosphate (_____):** the intermediate molecule between the two phases.

2) **Energy Harvest Phase**: _____ energy by *forming* _____ NADH & _____ ATP molecules.

□ *Net* products from 1 single glucose molecule = ____ pyruvate, ____ NADH, & ____ ATP molecules.

□ 2 pyruvates transported to the _____ *matrix* for the next step of *cellular respiration*.

EXAMPLE: Phases of Glycolysis.

CONCEPT: GLYCOLYSIS

Remembering Phases of Glycolysis

EXAMPLE: There is an energy investment step needed to get glycolysis started, requiring the use of _____ ATPs.

a) Two. b) Four. c) Three. d) One. E) Five.

PRACTICE: Starting with one molecule of glucose, glycolysis results in the net production of which of the following sets of energy-containing products?

a) 2 NAD^+, 2 pyruvate, and 2 ATP.
b) 2 NADH, 2 pyruvate, and 2 ATP.
c) 4 NADH, 2 pyruvate, and 4 ATP.
d) 6 CO_2, 2 pyruvate, and 2 ATP.

PRACTICE: Which of the following is a result of glycolysis?

a) A net gain of four ATP per one glucose molecule.
b) Conversion of FAD to $FADH_2$.
c) Conversion of one glucose molecule to two pyruvate molecules.
d) Conversion of NADH to NAD^+.

CONCEPT: ENTNER-DOUDOROFF-PATHWAY

- *Recall:* Glycolysis has ____ phases: 1) Energy *investment* phase & 2) Energy *harvest* phase.
  - □ Some bacteria (NOT eukaryotes) use an *alternative* pathway for glycolysis energy _____ phase.
- **Entner-Doudoroff Pathway (EDP):** alternative glycolysis pathway producing several molecules including **NAD___H.**
  - □ Only invests 1 ATP molecule to produce ____ **G3P** for the energy harvest phase.
  - □ Since *only* 1 **G3P** is made, the energy harvest phase only produces _____ the amount of NADH & ATP
  - □ Unlike normal glycolysis, **EDP** produces _____ by the reduction of $NADP^+$.

PRACTICE: The Entner-Doudoroff Pathway:

a) Converts glucose to pyruvate.
b) Can operate aerobically or anaerobically.
c) Is an alternative process to the glycolytic pathway.
d) All the above are correct.

PRACTICE: The Entner-Doudoroff pathway leads to the formation of:

a) ATP.
b) Pyruvate.
c) NADH.
d) NADPH.
e) All of the above.

CONCEPT: PENTOSE PHOSPHATE PATHWAY

- **Pentose Phosphate Pathway (PPP):** glycolysis _____ producing CO_2, NADPH & precursors for biosynthesis.
  - □ Can occur in BOTH *prokaryotes* & *eukaryotes* (Ex. red blood cells).
  - □ Does _____ produce any ATP
  - □ Generates important **Precursor Metabolites** (intermediate molecules for *anabolic pathways*).

PRACTICE: Which of the following is NOT a function of the pentose phosphate pathway?

a) Provides reducing power in the form of NADPH.

b) Produces precursor metabolites for nucleic acid and protein synthesis.

c) Generates ATP for anabolic pathways.

d) Produces precursor metabolites for glycolysis.

CONCEPT: PENTOSE PHOSPHATE PATHWAY

PRACTICE Glycolysis and the pentose phosphate pathway can both be used to create:

a) Glucose.
b) G3P.
c) NAD+.
d) Water.
e) Acetyl-CoA.

PRACTICE: Which of the metabolic pathways produce ATP?

a) Glycolysis.
b) Pentose Phosphate Pathway.
c) Entner-Doudoroff Pathway.
d) A and B.
e) B and C.
f) A and C.

CONCEPT: PYRUVATE OXIDATION

●*Recall:* Glycolysis *results* in _____ pyruvate molecules, which are then transported to the *mitochondrial* _____.

●**Pyruvate Oxidation**: 2nd step of cellular respiration that converts each *pyruvate* into a molecule of *Acetyl-*_____.

□ Occurs in *mitochondrial matrix* & produces ___ acetyl-CoA, ____ NADH, & ____ CO_2 molecules (per 1 glucose).

EXAMPLE: Pyruvate Oxidation.

PRACTICE: Each of the following describes the pyruvate oxidation reaction except that _____.

a) It connects glycolysis to the citric acid cycle.
b) Each pyruvate is converted to an acetyl-CoA molecule.
c) NAD^+ is reduced to NADH.
d) This reaction occurs within the cytoplasm.
e) Carbon dioxide is released as a by-product.

PRACTICE: In aerobic cellular respiration, pyruvate molecules must be transformed through a process called pyruvate oxidation before they can be broken down in the Krebs Cycle. What are the products of pyruvate oxidation?

a) Acetyl CoA, O_2, and ATP.
b) Acetyl and CO_2.
c) Acetyl CoA, $FADH_2$, and CO_2.
d) Acetyl CoA, NADH, and CO_2.
e) Acetyl CoA, NAD^+, ATP, and CO_2.

CONCEPT: KREBS CYCLE

- _____ **Cycle**: 3rd stage of aerobic cellular respiration; also known as the ***Citric Acid Cycle*** & the ***TCA Cycle***.
  - □ Oxidizes acetyl-CoA *producing* energy in the form of ATP, NADH, & $FADH_2$.

Phases of The Krebs Cycle

- Krebs Cycle consists of a series of *multiple* reactions, which can be grouped into _____ phases:
  - **A** **Acetyl-CoA Entry**: *2 carbons* of Acetyl-CoA enter & react with *oxaloacetate*, producing _____.
    - □ NOTE: "CoA" does _____ enter the Krebs Cycle (just the _____ carbons enter).
  - **B** **Citrate Oxidation**: Rearrangement & _____ of *citrate*.
    - □ Produces of 1 ATP & 2 NADH, & 2 CO_2 molecules.
  - **C** **Oxaloacetate Regeneration**: _____ of *oxaloacetate* by *oxidation*.
    - □ Produces 1 NADH & 1 $FADH_2$ molecule.
- _____ rounds of the Krebs Cycle occur for every 1 glucose molecule (1 round of Krebs Cycle per acetyl-CoA).

CONCEPT: KREBS CYCLE

EXAMPLE: How many turns of the Krebs Cycle are needed to completely break down one molecule of glucose?

a) 2. b) 3. c) 1. d) 4. e) 5.

PRACTICE: Which product of the Krebs cycle is also used as a reactant in the Krebs cycle?

a) Citrate.
b) ATP.
c) Acetyl-CoA.
d) Oxaloacetate.

PRACTICE: Taking one molecule of glucose through glycolysis, pyruvate oxidation, and the Krebs cycle generates:

a) 6 CO_2, 8 NADH, 2 $FADH_2$ and 4 ATP.
b) 6 CO_2, 8 NADH, 1 $FADH_2$ and 2 ATP.
c) 6 CO_2, 10 NADH, 2 $FADH_2$ and 4 ATP.
d) 6 CO_2, 10 NADH, 2 $FADH_2$ and 2 ATP.

CONCEPT: ELECTRON TRANSPORT CHAIN

- **Electron Transport Chain** (_____): 4th step of aerobic respiration; consists of *mitochondrial inner-membrane proteins*.
  - □ Harnesses energy of _____ from NADH & $FADH_2$ in a series of _____ reactions.
  - □ ETC uses energy from electrons to generate a _____ *gradient* by pumping H^+ into the *intermembrane space.*
  - □ **Final Electron Acceptor**: the *final* molecule that *accepts* the ETC's electrons is _____ *gas* (O_2).
    - □ When Oxygen gas (O_2) serves as the *final electron acceptor*, it interacts with H^+ to form *water* (H_2O).

EXAMPLE: Electron Transport Chain.

Remembering the ETC

CONCEPT: ELECTRON TRANSPORT CHAIN

PRACTICE: In the electron transport chain, the final electron acceptor is:

a) H_2O. b) CO_2. c) H_2O. d) O_2. e) NAD^+.

PRACTICE: Which of the following events takes place in the electron transport chain?

a) The breakdown of glucose into six carbon dioxide molecules.
b) The breakdown of NADH and $FADH_2$ to carbon dioxide.
c) Harnessing energy from high-energy electrons derived from glycolysis, pyruvate oxidation, and the Krebs cycle.
d) Substrate-level phosphorylation.

Electron Transport Chain in Prokaryotes

●Prokaryotic ETCs are similar to eukaryotic ETCs except they are found in the cell's _____ *membrane*.

Recall: Prokaryotic cells do NOT have mitochondria.

EXAMPLE: Electron Transport Chain in the gram-negative bacteria *E. coli.*

PRACTICE: TRUE or FALSE: Electron transport in eukaryotes occurs in the inner mitochondrial membrane.

a) True. b) False.

CONCEPT: CHEMIOSMOSIS

- The H^+ gradient built by the ETC has tremendous potential energy that can be captured via _____.
  - □ **Chemiosmosis**: the diffusion of ions across a membrane _____ their concentration gradient (high to low).
  - □ **ATP Synthase**: *enzyme* that facilitates chemiosmosis & synthesizes _____.
- *Recall:* **Oxidative Phosphorylation**: *ETC* redox reactions & *chemiosmosis* "powering" phosphorylation to make _____.

EXAMPLE: Oxidative Phosphorylation = ETC + Chemiosmosis.

PRACTICE: Chemiosmotic creation of ATP is driven by:

a) Phosphate transfer through the plasma membrane.

b) Potential energy of the H+ concentration gradient created by the electron transport chain.

c) Substrate-level phosphorylation in the mitochondrial matrix.

d) Large quantities of ADP in the mitochondrial matrix.

PRACTICE: The electron transport chain pumps H+ ions into which location of the mitochondria?

a) Mitochondrial intermembrane space.

b) Mitochondrial matrix.

c) Mitochondrial inner membrane.

d) The H+ ions are pumped out of the mitochondria.

CONCEPT: REVIEW OF AEROBIC CELLULAR RESPIRATION

●*Recall:* the _____ stages of **Aerobic Cellular Respiration**:

PRACTICE: Through the first three stages of cellular respiration only 4 ATP molecules have been produced from the initial glucose molecule. In which of the products of these stages is the potential energy to produce more ATP molecules stored?

a) The 6 molecules of CO_2.

b) The H^+ ions produced.

c) The 10 NADH and 2 $FADH_2$ molecules.

d) The 4 molecules of ATP.

CONCEPT: REVIEW OF AEROBIC CELLULAR RESPIRATION

Total Products for Each Stage of Aerobic Cellular Respiration

●Fill in the table with the *total products* made from a *single glucose* molecule at each step of *aerobic cellular respiration*.

	1 Glycolysis	2 Pyruvate Oxidation	3 Krebs Cycle (Citric Acid)	4 Oxidative Phosphorylation	TOTALS
Start Molecule					
O–C–O					
ATP					
$FADH_2$					
NADH					
End Molecule					

PRACTICE: Water is one of the products of aerobic cellular respiration. What is the source of the oxygen atom utilized to create the water molecules?

a) Carbon dioxide (CO_2).
b) Glucose ($C_6H_{12}O_6$).
c) Oxygen gas (O_2).
d) Pyruvate ($C_3H_3O_3^-$).

PRACTICE: Approximately how many molecules of ATP are produced from the complete oxidation of one molecule of glucose ($C_6H_{12}O_6$) through the process of aerobic cellular respiration?

a) 4.
b) 2.
c) 26-34.
d) 30-38.

CONCEPT: FERMENTATION & ANAEROBIC RESPIRATION

What Happens to Aerobic Organisms If There's No Oxygen?

- Without oxygen, *aerobic cellular respiration* _____ occur.
  - □ The ETC gets "*backed-up*" (like a _____ *jam*) without O_2 as the final electron acceptor.
  - □ The amount of NADH _____ while the amount of NAD^+ _____.
- **Fermentation:** process that uses the electrons from NADH to *reduce* _____ & *regenerate* NAD^+.
  - □ Depending on the organism, pyruvate can be *reduced* to _____ *acid* or _____.
  - □ Makes very _____ ATP, so only *some uni*cellular organisms can survive on just *fermentation*.
  - □ Regeneration of NAD^+ allows glycolysis to continue in the _____ of Oxygen.

EXAMPLE: Fermentation.

PRACTICE: Fermentation allows a cell to:

a) Recycle NADH to NAD^+ for glycolysis.
b) Use NADH as a terminal electron acceptor.
c) Reduce NAD^+ to NADH for glycolysis.
d) Synthesize ATP via ATP synthase.

CONCEPT: FERMENTATION & ANAEROBIC RESPIRATION

Lactic Acid Fermentation

- _____ **Acid Fermentation**: pyruvate is reduced by NADH to form *lactic acid*/_____ & NAD^+.
  - □ Occurs in *human* _____ *cells* & in bacteria that gives yogurt its sour taste.

Alcohol Fermentation

- _____ **Fermentation**: pyruvate is reduced by NADH to form _____ & NAD^+.
  - □ Produces *beer* from barley & *wine* from grapes.

PRACTICE: Which of the following describes a primary function of both lactic acid fermentation and alcohol fermentation?

a) Reduction of NAD^+ to NADH.
b) Oxidation of NADH to NAD^+.
c) Reduction of FAD to $FADH_2$.
d) Hydrolysis of ATP to ADP.

CONCEPT: FERMENTATION & ANAEROBIC RESPIRATION

Anaerobic Respiration

- Some unicellular organisms can survive and make significant amounts of ATP _____ oxygen.
- _____ **Respiration**: uses other molecules (instead of O_2) as the *final electron acceptor* of ETC.
  - □ *Alternative* electron acceptors include: Nitrate (NO_3^-), Sulfate (SO_4^{2-}) & CO_2.
  - □ Makes _____ ATP than *fermentation*, but _____ ATP than *aerobic cellular respiration*.

PRACTICE: In which of the steps of aerobic and anaerobic cellular respiration does substrate-level phosphorylation occur?

a) In glycolysis only.
b) In the Krebs cycle only.
c) In the electron transport chain only.
d) In both glycolysis and the Krebs cycle.
e) In both the Krebs cycle and the electron transport chain.

PRACTICE: Which of the following statements about NAD^+ is true?

a) NAD^+ is reduced to NADH during glycolysis, pyruvate oxidation, and the Krebs cycle.
b) NAD^+ has more chemical energy than NADH.
c) NAD^+ donates high energy electrons to the electron transport chain.
d) In the absence of NAD^+, glycolysis can still function.