Section 4.2: Aerobic Respiration: The Details

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A. Answer may vary. Sample Answer: The limewater turned cloudy. Limewater reacts with carbonic acid to form calcium carbonate, a white precipitate. The following reaction shows the formation of calcium carbonate: $Ca(OH)_2(aq) + CO_2(g) \rightarrow CaCO_3(s) + H_2O(l)$.

B. The phenolphthalein and limewater or base solution changed from pink to clear, indicating a change in pH from a basic solution to an acidic solution. The solution became acidic because CO_2 forms carbonic acid, H_2CO_3, in solution. The following equation shows the formation of carbonic acid: $CO_2(g) + H_2O(g) \rightarrow H_2CO_3(aq)$.

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A. The only order of cards that allowed the complete electron transfer transport is 1, 2, 3, 4, 5, 6 from the NADH end to the oxygen end.

B. This investigation models the protein complexes in the electron transport chain as follows: The electrons are pulled in a direction toward molecules that are most electronegative and away from molecules that are least electronegative. In both this investigation and the electron transport chain, only one order of molecules allows this to happen.

C. In glycolysis and the citric acid cycle, NAD^+ and FAD obtain electrons. These electrons originally came from glucose.

D. The electrons cannot move along the chain without oxygen because the complexes will only pull electrons through the chain if they are missing electrons, and only oxygen can ultimately remove the electrons from the complexes.

E. If there was no source of NADH the energized electrons that are carried to the electron transport chain proteins would not be transported so the electron transport chain would come to a halt. There would be no electrons for oxygen to remove.

F. Once NADH loses its electrons it becomes oxidized to NAD^+ and returns to the citric acid cycle as a reactant.

G. The large container would represent pyruvate oxidation, which produces high-energy acetyl-CoA. It is electrons from acetyl-CoA that move through the electron transport chain.

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1. Glycolysis is considered to be fundamental and ancient for the following reasons:

• Glycolysis is universal, being found in almost all organisms, both prokaryotes and eukaryotes, on all branches of the tree of life.

• Unlike other stages of cellular respiration, glycolysis does not require oxygen, which became abundant in Earth’s atmosphere only about 2.5 billion years ago—about 1.5 billion years after scientists think life developed.

• Glycolysis occurs in the cytosol of all cells and uses water-soluble enzymes; therefore it does not require sophisticated electron transport chains or cellular organelles in order to operate.

• Glycolysis provides energy, which is vital.

2. Glycolysis is not very efficient at converting glucose to ATP: only 2.2 % efficient. Other high-energy products of glycolysis are two pyruvate molecules and two NADH molecules, which will continue to stages 2, 3, and 4 of aerobic respiration, and eventually convert to ATP.

3. NADH, $FADH_2$, ADP, and P_i

4. The electron transport chain facilitates the transfer of electrons from NADH and $FADH_2$ to O_2. The chain consists of four protein complexes: I, II, III, and IV, with increasing electronegativity along the chain. Electron flow from one complex to another is facilitated by two mobile electron shuttles. Oxygen is highly electronegative and is the driving force in the electron transport chain. It takes two electrons from cytochrome *c* (cyt *c*), causing a chain reaction with electrons being passed from molecules that are more electronegative to molecules that are less electronegative.

5. (a) The electrons in NADH have the most free energy in the electron transport chain.

(b) These bond formations result in energy being released as the electrons form stronger and stronger bonds as they move through the electron transport chain.

6. The stage of aerobic cellular respiration that does not occur in the mitochondria is glycolysis. Glycolysis occurs in the cytosol. All of the other stages of aerobic respiration—pyruvate oxidation, the citric acid cycle, the electron transport chain, and chemiosmosis—occur in the mitochondria.

7. (a) glycolysis: glucose + 2 ADP + 2 P_i + 2 NAD^+ → 2 pyruvate + 2 ATP + 2 NADH + $2H^+$

(b) pyruvate oxidation: 2 pyruvate + $2NAD^+$ + 2CoA → 2 acetyl-CoA + 2 NADH + $2H^+$ + $2CO_2$

(c) citric acid cycle: acetyl-CoA + 3 NAD^+ + FAD + ADP + P_i + 2 H_2O →
2 CO_2 + 3 NADH + 3 H^+ + $FADH_2$ + ATP + CoA

8. The important molecule is needed for oxidative phosphorylation but not needed for substrate-level phosphorylation is oxygen.

9. The primary function of the proton-motive force is the establishment of a chemical and concentration gradient of protons across the membrane. This represents a source of energy that can be harnessed to do work. Cells use the proton-motive force in the process called chemiosmosis, which synthesizes ATP.

10. An example of uncoupling is brown adipose fat. This fat can use uncoupling to generate thermal energy from the electron transport chain instead of generating ATP. Uncoupling produces energy to maintain body temperature in hibernating animals and in very young offspring, including human infants.

11. Answers may vary. Sample answer: Ionophores are compounds that help move ions across lipid membranes by altering the membrane’s permeability. Ionophores are used as antibiotics and as a feed additive in the cattle industry to increase disease resistance and increase weight gain and feed efficiency.

12. (a) The product that is produced is water.

(b) For every mole of oxygen you breathe in, one mole of water is formed.

(c) Answers may vary. Sample answer: Many desert animals have an adaptation in their nasal passages that allows them to reabsorb this normally “lost” water of metabolism from the air they exhale, and reduce the amount of water lost.