Cellular Respiration:

Mitochondria Structure:

- Double membrane-bound organelle
- Matrix – large semi-fluid interior of mitochondria → Cirtic Acid Cycle occurs here
- inner membrane of the mitochondria → Electron Transport Chain occurs here

Overall Process:
Glucose is broken down to release energy. This energy is used to regenerate ATP from ADP + Phosphate (P). The overall equation given below actually occurs in many steps, releasing a little bit of energy at a time.

Summary of Cell Respiration:
Glucose ($C_6H_{12}O_6$) + $6O_2$ + ADP + P → → → → $6CO_2$ + $6H_20$ + ~32ATP (maximum)

Overview: 3 Main Steps of Cellular Respiration:
1. Glycolysis: Glucose (6-carbon sugar) is split into 2 pyruvic acids (3-carbon sugar), 2 ATP are made from 2ADP + 2P, hydrogens and electrons are picked up by carrier molecules (NADH).
2. Cirtic Acid Cycle – Two pyruvic acids are broken down to $6CO_2$, 2 more ATP are made from 2ADP + 2P, hydrogens and electrons are picked up by carrier molecules (NADH and FADH2).
3. Electron Transport Chain – Electrons from NADH and FADH2 (carrier molecules generated in Glycolysis and Cirtic Acid cycle) are sent down an electron transport chain, releasing enough energy to convert ~34 ADP + 34 P to ~34 ATP.

Step 1: Glycolysis:

- Occurs in the cytoplasm of the cell – outside the mitochondria.
- Glucose (6 carbons) is split into 2 pyruvic acids (a 3 Carbon sugar)
- This reaction releases energy which is used to generate 2 ATP plus 2 NADH

A. Reactants (what goes into the reaction)
   - 1 glucose (a 6 carbon sugar)
   - 2NAD+
   - 2ADP and 2 Phosphate (P)

B. Products (results of reaction)
   - 2 pyruvic acid (3 carbon sugar)
   - 2 NADH – generated from NAD+ in the cell, carries Hydrogen and 2 electrons to the electron transport chain.
   - 2 ATP – Regenerated from 2ADP and 2P in the cell. Used for cellular energy

Step 2: Cirtic Acid Cycle

- Occurs in the matrix of the mitochondria
- Bonds between carbons in pyruvic acid are broken. Result is 3 CO_2 per pyruvic acid (6 CO_2 per glucose).
- Breaking bonds releases energy (exergonic reaction) which is used to convert ADP + P into ATP (1 ATP per pyruvic acid so 2 ATP per glucose) (endergonic reaction). Hydrogens and electrons released also lead to NADH and $FADH_2$ being formed.

A. Reactants:
   - 2 pyruvic acid (3 carbon sugars – $C_3H_4O_3$) – from glycolysis
   - NAD+ and FAD
   - 2ADP and 2 Phosphate
   -

B. Products from **2** pyruvic acid:
   - 6 CO_2 (3 per pyruvic acid) – Waste Product – we exhale it when we breathe out.
   - NADH – Generated from NAD^+ in the cell, carries hydrogen & electrons to electron transport chain.

- $FADH_2$ - Generated from FAD in the cell, carries 2 Hydrogens and electrons to the Electron Transport Chain.
- 2 ATP – Regenerated from ADP and P in the cell. Used for cellular energy

Step 3: Electron Transport Chain

- Occurs in the cristae of mitochondria (inner membrane)
- Electrons carried by NADH and $FADH_2$ are passed from one electron acceptor to another in a transport chain; a little bit of energy is released at each step. This energy is used to regenerate ATP.

  For those that want to know, this is what happens: (the italized part will not be on the test)
  - *This energy is used to move H^+ (hydrogen ions) across the cristae into the inner membrane space (space between two membranes of the mitochondria). This is moving the H^+* ***against*** *its concentration gradient (from low concentration to high concentration). So now the hydrogen ions are more concentrated in the inner membrane space.*
  - *The H^+ ions leave the inner membrane space through a protein called ATP synthase into the matrix. As they pass through the ATP synthase* ***with*** *their concentration gradient they release energy. The ATP synthase uses the energy released to regenerate ATP from ADP + Phosphate (P).*
- Oxygen is the final acceptor of the hydrogen and electrons at the end of the transport chain. Oxygen picks up the electrons, along with the H+ and forms water.

A. Reactants:

- NADH (from glycolysis and Cirtic Acid cycle)
- $FADH_2$ (from Cirtic Acid cycle)
- 6O2 – obtained from breathing.
- ADP + P

B. Products:

- ~28 ATP
- 6 H_20 – made from combining oxygen with hydrogen at end of the transport chain
- NAD+ and FAD which will go back to glycolysis and citric acid cycle to pick up more hydrogens and electrons

Can molecules besides glucose be used in cell respiration? Yes. Molecules, like amino acids and fatty acids, can be fed into the cell respiration pathway in different stages and used to produce ATP.

Anaerobic Metabolism – Fermentation:
Some organisms always live without oxygen while others are capable of doing without oxygen for varying lengths of time when oxygen is not available (i.e. yeast or your muscles during strenuous exercise)

Fermentation, or anaerobic metabolism, uses only the first step of cell respiration, glycolysis. So it only produces 2 ATP per glucose instead of 34. In yeast, the pyruvic acid that is produced is broken down to alcohol (used to make bread, wine, beer) and carbon dioxide. Other organisms break the pyruvic acid down to lactic acid (lactate). This is common in organisms used to make cheese and yogurt. Your muscles also make lactate when you exercise them anaerobically, meaning that you are using the oxygen faster than your blood can supply it. The lactic acid causes muscle soreness.

The efficiency of aerobic (cell respiration) vs. anaerobic (fermentation) metabolism:
Aerobic metabolism (cell respiration) yields about (38 ATP per glucose) 40% of the energy available in glucose, the rest is lost as heat. Anaerobic metabolism (fermentation) yields only 2 ATP, so it is much less efficient.

How to study this topic:
Take it one step at a time, and don't move to the next step until you have mastered the previous step.

1. Memorize the overall equation
2. Memorize the name of the each step
3. Memorize where each step occurs in the cell
4. Memorize reactants and products for each step and be able to describe where they came from
5. Describe the each step in your own words – explaining the figures out loud to someone else.