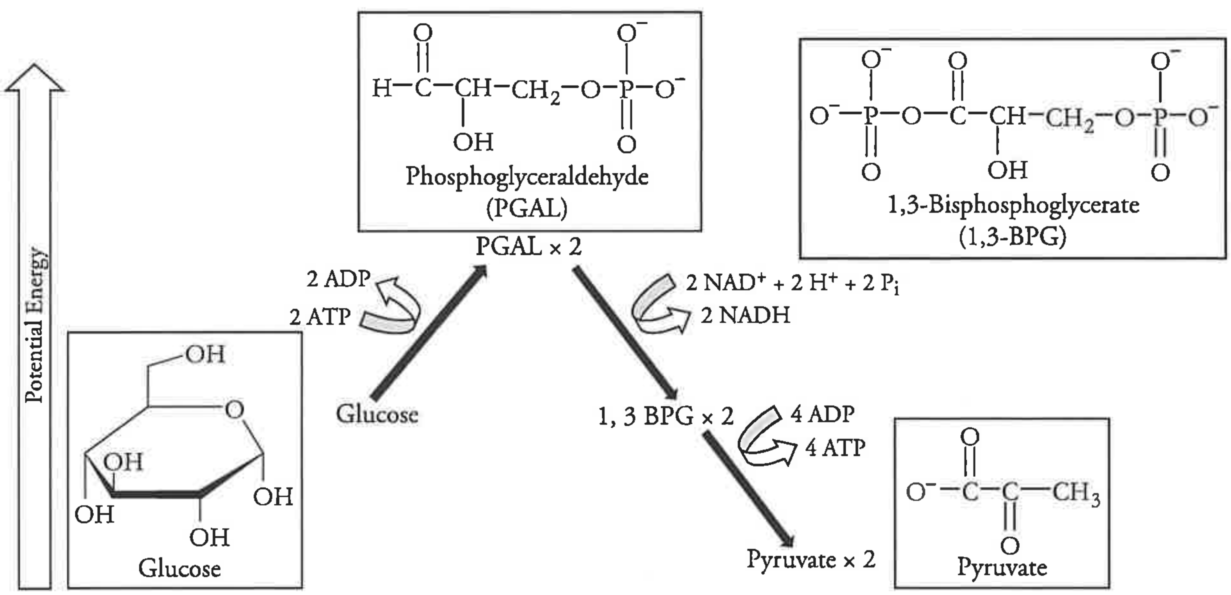
Glycolysis and the Krebs Cycle

What reactions occur in the cell to turn glucose into carbon dioxide?

Why?

Glucose is a high potential energy molecule. Carbon dioxide on the other hand is a very stable, low potential energy molecule. When a glucose molecule is converted to carbon dioxide and water during cellular respiration, energy is released and stored in high potential energy ATP molecules. The three phases of cellular respiration that oxidize the glucose molecule to carbon dioxide are **glycolysis**, the **Link reaction** and the **Krebs cycle**.

Model 1 – Glycolysis



1. Refer to Model 1.

   a. What molecule from food is the primary reactant for glycolysis?

   Glucose.

   b. How many carbon atoms are in that reactant molecule?

   Glucose has six carbon atoms.

2. The carbon atoms from glucose end up in pyruvate molecules as a product of glycolysis.

   a. How many carbon atoms are in a pyruvate molecule?

   Pyruvate has three carbon atoms.

   b. How many pyruvate molecules are made from each glucose molecule?

   Two pyruvate molecules are made from one glucose molecule.

3. Does the process of glycolysis require an input of energy? Provide specific evidence from Model 1 to support your answer.

   Yes, two ATP molecules are needed to convert a glucose molecule to two PGAL molecules.

4. Refer to Model 1. Propose an explanation for why the author of this activity put PGAL at the highest point in the Model 1 diagram.

   The PGAL molecule has higher potential energy than the glucose molecule. The energy from the ATP molecule converting to ADP has increased the potential energy of the PGAL.

5. Does pyruvate have more or less potential energy than glucose? Provide specific evidence from Model 1 to support your answer.

   Pyruvate is at a lower point than glucose in Model 1, and four ATP molecules are made as PGAL is converted to pyruvate, so pyruvate has less potential energy than glucose.

6. What is the net production of ATP by glycolysis?

   Two ATP are needed, four are produced, so the net production of ATP is two.

7. What molecule acts as an electron acceptor in glycolysis?

   NADH accepts electrons when PGAL converts to 1,3 BPG.

8. In the last steps of glycolysis 4 ATP molecules are produced. Analyze Model 1 to find the source of the four inorganic phosphates (P_i) that are added to the ADP molecules to make the four ATP molecules. Describe the origins of the four inorganic phosphates here.

   Two of the P_i groups are added to the glucose molecule in the reaction that produces PGAL. Two more P_i groups are added to PGAL in the reaction that produces 1,3 BPG. Those four P_i groups are removed in the final steps that produce pyruvate.

STOP

12. Coenzyme A carries the remainder of the pyruvate molecule to the site of the Krebs cycle.

   a. What is the name of decarboxylated pyruvic acid?

   Acetyl (or Acetate).

   b. How many carbons of the pyruvate molecule remain when is it attached to Coenzyme A?

   Two carbon atoms.

   c. When coenzyme A bonds to the decarboxylated pyruvic acid what molecule is produced?

   Acetyl-CoA.

   d. The connection between Coenzyme A and the acetyl group is weak. How is this illustrated in Model 2?

   The bond between Coenzyme A and the acetyl group is shown with a dashed line.

13. Has any ATP been used or produced during the link reaction?

   No.

14. Have any other high potential energy molecules been produced during the link reaction?

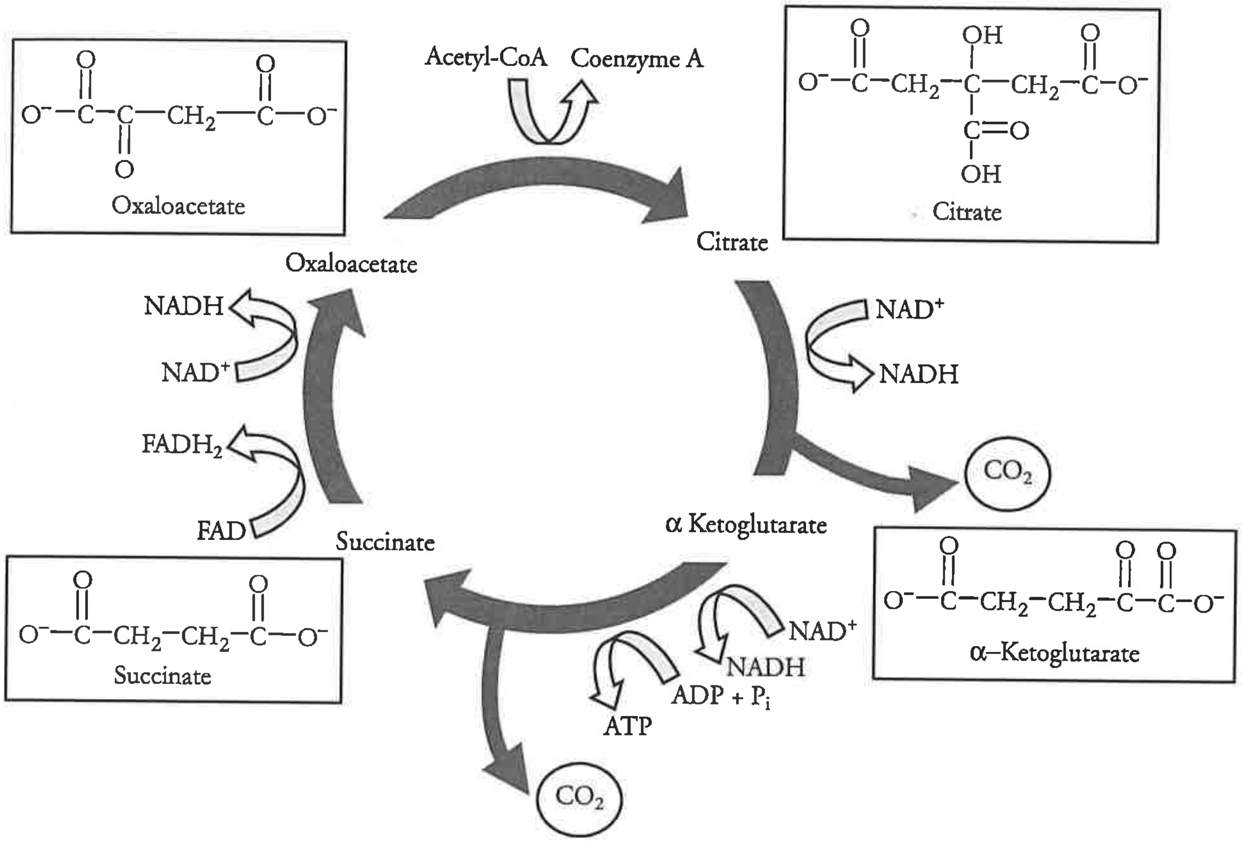
   Yes, one NADH molecule was produced.

15. How many acetyl-CoA, carbon dioxide, and NADH molecules are produced in the link reaction for each glucose molecule that undergoes cellular respiration?

   Each glucose molecule makes two pyruvate molecules, so the link reaction happens twice for each glucose molecule. Therefore, two acetyl-CoA molecules, two carbon dioxide molecules, and two NADH molecules are produced.

STOP

Model 3 – The Krebs Cycle



16. Where in the cell does the Krebs cycle take place?

    The Krebs cycle takes place in the mitochondrial matrix.

17. What molecule is introduced to the Krebs cycle from the link reaction?

    Acetyl-CoA.

18. Is oxygen needed as a reactant in the Krebs cycle?

    No, oxygen is not needed.

19. Compare the oxaloacetate molecule with the citrate molecule.

    a. How many carbon atoms are in oxaloacetate?

    Four.

    b. How many carbon atoms are in citrate?

    Six.

    c. Where did the extra carbon atoms come from to convert oxaloacetate into citrate?

    Two carbons are in the acetyl group that enters the Krebs cycle from the link reaction.

26. How many "turns" of the Krebs cycle occur for every glucose molecule ($C_6H_{12}O_6$) that undergoes cellular respiration?

The Krebs cycle must complete two "turns" for each glucose molecule. Each glucose molecule makes two pyruvate molecules, which react to form two acetyl-CoA molecules.

27. How many of each of the molecules below are produced in the Krebs cycle of every glucose molecule that undergoes cellular respiration?

CO_2	ATP	NADH	$FADH_2$
Two	*Two*	*Six*	*Two*

28. Was oxygen used as a reactant in any of the processes explored in this activity—glycolysis, the link reaction or the Krebs cycle?

No, oxygen was not needed for any of the processes in this activity.

Read This!

Glycolysis will occur in a cell with or without oxygen present. If oxygen is present, the link reaction, Krebs cycle, and oxidative phosphorylation will complete the process of oxidizing glucose and maximizing the energy output. However, without oxygen, glycolysis is coupled with fermentation processes to provide a continual supply of energy to the cell. It is important to note that even though the link reaction and Krebs cycle do not use oxygen as a reactant, they will not occur in the cell without oxygen present.

Extension Questions

29. Identify two places in the Krebs cycle where a decrease in free energy is coupled with an increase in free energy.

    Answers will vary. Acetyl-CoA turning into CoA (lower potential energy) is coupled with oxaloacetate turning into citrate (higher potential energy). Citrate converts to α-ketoglutarate (lower potential energy) as NAD^+ converts to NADH (higher potential energy).

30. When the body runs out of readily available carbohydrate (glucose) molecules, it will turn to stored glycogen, then fats, and finally proteins as an energy source. The pathways below illustrate how these molecules are prepared to enter the cellular respiration pathway.

    glycogen ⟶ glucose

    fat ⟶ glycerol ⟶ PGAL

    fat ⟶ fatty acid (x 3) ⟶ acetyl-CoA (number varies, but numerous)

    protein ⟶ amino acids (numerous) ⟶ pyruvate and acetyl-CoA (or other molecules in the Krebs cycle)

    protein ⟶ amino acids (numerous) ⟶ ammonia ⟶ urea (waste)

    a. For each of the products above (excluding urea) identify the phase of cellular respiration where the molecules would enter the cellular respiration process.

    glucose—glycolysis PGAL—glycolysis acetyl-CoA—Krebs cycle pyruvate—link reaction

    b. Glucose has six carbons. A fat molecule could have ten times that many carbons. Predict how the number of ATP molecules produced would differ between a glucose molecule and a fat molecule.

    The PGAL molecule produced from the fat will make two pyruvate molecules, which will make two acetyl-CoA molecules (just like a glucose molecule). The acetyl-CoA molecules made from the fatty acids, however, will be numerous. Therefore, the total number of ATP made from a fat will be more than those made from a glucose molecule.

    c. Consider where proteins are "stored" in your body. What types of tissues would be affected if your body needed to use protein as an energy source?

    Muscle tissues would be compromised when protein is used as an energy source.