

Chapter 8: An Introduction to Metabolism

1. Define metabolism.

Metabolism (from the Greek *metabole*, change) is the totality of an organism's chemical reactions and is an emergent property of life that arises from orderly interaction between molecules. As a whole, metabolism manages the material and energy resources of a cell through metabolic pathways.

2. There are two types of reactions in metabolic pathways: anabolic and catabolic.

Anabolic (or biosynthetic) reactions consume energy, build up larger molecules, and include photosynthesis. Catabolic reactions release energy, break down molecules, require enzymes to catalyze reactions, and include cellular respiration. Energy released from the "downhill" reactions of catabolic pathways can be stored and then used to drive "uphill" anabolic reactions.

3. Contrast kinetic energy with potential energy.

Kinetic energy is associated with the relative motion of objects; moving objects can perform work by imparting motion to other matter. Potential energy is possessed by matter because of its location or structure (such as water behind a dam), even though it is not presently moving.

4. Which type of energy does water behind a dam have? A mole of glucose?

Water behind a dam has potential energy. A mole of glucose has chemical energy, the potential energy available for release in a chemical reaction.

5. What is free energy? What is its symbol?

Free energy is the portion of a system's energy that can perform work when temperature and pressure are uniform throughout the system, as in a living cell. This helps define the free energy of a system regardless of its surroundings. Free energy is expressed by G .

6. For an exergonic reaction, is ΔG negative or positive?

Only processes with a negative ΔG are spontaneous. Exergonic reactions, resulting in a net release of energy, have a negative ΔG and are energetically favorable.

7. Is cellular respiration an endergonic or an exergonic reaction? What is ΔG for this reaction?

Cellular respiration is an exergonic reaction; ΔG for this reaction, which converts glucose and oxygen to carbon dioxide and water, is -686 kcal/mol .

8. Is photosynthesis endergonic or exergonic? What is the energy source that drives it?

Photosynthesis is an endergonic process driven by sunlight.

9. To summarize, if energy is released, ΔG must be what?

If energy is released, the change in free energy must be negative.

10. List three main kinds of work that a cell does. Give an example of each.

Chemical work drives endergonic reactions that would not occur spontaneously, such as the synthesis of polymers from monomers. Transport work pumps substances across membranes against the direction of spontaneous movement.

Mechanical work, involves physical processes such as the beating of cilia, the contraction of muscle cells, and the movement of chromosomes during cellular reproduction.

11. *Here is a molecule of ATP. Label it. Use an arrow to show which bond is likely to break.* ✍

That bond will break by the process of hydrolysis. ATP consists of adenosine triphosphate (the sugar ribose, with the nitrogenous base adenine and a chain of three phosphate groups bonded to it).

12. *When the terminal phosphate bond is broken, a molecule of inorganic phosphate P_i is formed...*

...and energy is released. For the exergonic reaction $ADP + P_i \rightarrow ATP + H_2O$, ΔG is 7.3 kcal/mol (30.5 kJ/mol).

13. *What is energy coupling?*

Energy coupling is the use of an exergonic process to drive an endergonic one. ATP is responsible for mediating most energy coupling in cells, and in most cases it acts as the immediate source of energy that powers cellular work. In many cellular reactions, a phosphate group is transferred from ATP to some other molecule in order to make the second molecule less stable. The second molecule is said to be abbreviated.

14. *If you couldn't regenerate ATP by phosphorylating ADP, how much ATP would you need to consume each day?*

Humans would use up nearly their body weight in ATP each day!

15. *What is a catalyst?*

A catalyst is a chemical agent that speeds up a reaction without being consumed by the reaction. Without regulation by enzymes, chemical traffic through metabolic pathways would become terribly congested; for instance, it could take upward of 50 years to digest a meal!

16. *What is activation energy (E_A)?* ✍

Activation energy is the amount of energy the reactants must absorb to enable a chemical reaction to begin.

17. *Label this figure and define enzyme, substrate, active site, and products.* ✍

An enzyme is a macromolecule that acts as a catalyst. The substrate is the reactant an enzyme acts on, and is converted to products. The active site is typically an indentation on the enzyme's surface where catalysis occurs.

18. *What is meant by induced fit? How is it shown in this figure?*

An induced fit brings chemical groups of the active site into positions that enhance their ability to catalyze the chemical reaction: an enzyme is not a stiff structure locked into a given shape. Rather, enzymes and other proteins seem to “dance” between subtly different shapes in a dynamic equilibrium, with slight differences in free energy for each “pose”.

19. *Explain how protein structure is involved in enzyme specificity.*

The amino acid sequence of an enzyme determines its shape; how congruously the shape of its active site and the shape of the substrate fit together measures its specificity.

20. *Enzymes use a variety of mechanisms to lower activation energy. Describe four of these mechanisms.*

First, in reactions involving two or more reactants, the active site provides a template on which the substrates can come together in the proper orientation for a reaction to occur between them.

Second, as the active site of an enzyme clutches the bound substrates, the enzyme may stretch the substrate molecules toward their transition-state form, stressing and bending critical chemical bonds that must be broken during the reaction. Because E_A is proportional to the difficulty of breaking the bond, distorting the substrate helps it approach the transition state and thus reduces the amount of free energy that must be absorbed to achieve that state.

Third, the active site may also provide a microenvironment that is more conducive to a particular type of reaction than the solution itself would be without the enzyme. For example, if the active site has amino acids with acidic R groups, the active site may be a pocket of low pH in an otherwise neutral cell. In such cases, an acidic amino acid may facilitate H^+ transfer to the substrate as a key step in catalyzing the reaction.

A fourth mechanism of catalysis is the direct participation of the active site in the chemical reaction. Sometimes this process even involves brief covalent bonding between the substrate and the side chain of an amino acid of the enzyme. Subsequent steps of the reaction restore the side chains to their original states, so that the active site is the same after the reaction as it was before.

21. Explain how pH, temperature, and the initial concentration of substrate affect the rate of enzyme action.

Up to a point, the rate of an enzymatic reaction increases with increasing temperature, partly because substrates collide with active sites more frequently when the molecules move rapidly. Above that temperature, however, the speed of the enzymatic reaction drops sharply. The thermal agitation of the enzyme molecule disrupts the hydrogen bonds, ionic bonds, and other weak interactions that stabilize the active shape of the enzyme, and the protein molecule eventually denatures. Each enzyme has an optimal temperature at which its reaction rate is greatest. Without denaturing the enzyme, this temperature allows the greatest number of molecular collisions and the fastest conversion of the reactants to product molecules. Just as each enzyme has an optimal temperature, it also has a pH at which it is most active.

22. Enzymes are globular proteins. Why can extremes of pH or very high temperatures affect enzyme activity?

Certain conditions that favor the most active shape for the enzyme molecule are optimal for enzymes. Extremes of pH or very high temperatures can influence a protein's structure.

23. Name a human enzyme that functions well in pH 2. Where is it found?

Pepsin, a digestive enzyme in the human stomach, works best at pH 2.

24. Distinguish between cofactors and coenzymes. Give examples of each.

Cofactors are nonprotein helpers for catalytic activity that may be bound tightly to the enzyme as permanent residents, or loosely and reversibly along the substrate. Coenzymes are cofactors that are organic molecules.

25. Compare and contrast competitive inhibitors and noncompetitive inhibitors. Label each type of inhibitor in this figure. ✎

Competitive inhibitors reduce the productivity of enzymes by blocking substrates from entering active sites. This kind of inhibition can be overcome by increasing the concentration of substrate so that as active sites become available, more substrate molecules than inhibitor molecules are around to gain entry to the sites.

Noncompetitive inhibitors do not directly compete with the substrate to bind to the enzyme at the active site. Instead, they impede enzymatic reactions by binding to another part of the enzyme. This interaction causes the enzyme molecule to change its shape in such a way that the active site becomes less effective at catalyzing the conversion of substrate to product.

26. What is allosteric regulation?

Allosteric regulation refers to any case in which a protein's function at one site is affected by the binding of a regulatory molecule to a separate site. It may result in either inhibition or stimulation of an enzyme's activity.

27. How is it somewhat like noncompetitive inhibition? How might it be different?


Like allosteric regulation, noncompetitive inhibition can inhibit enzyme activity; however, unlike allosteric regulation, it can also stimulate enzyme activity.

28. Explain the difference between an allosteric activator and an allosteric inhibitor.

Allosteric activators stabilize the active form of an enzyme, while allosteric inhibitors stabilize its inactive form.

29. *Although it is not an enzyme, hemoglobin shows cooperativity in binding O_2 . Explain how hemoglobin works at the gills of a fish.*

Where oxygen is at high levels, such as in the lungs or gills, hemoglobin's affinity for oxygen increases as more binding sites are filled. In oxygen-deprived tissues, however, the release of each oxygen molecule decreases the oxygen affinity of the other binding sites, resulting in the release of oxygen where it is most needed.

30. *Study Fig. 8.22.* 

Threonine is the substrate molecule to initiate this metabolic pathway. Isoleucine is the inhibitor molecule. It is a noncompetitive inhibitor. It has the most significant regulatory effect when it binds to an allosteric site. This type of metabolic control is called feedback inhibition.