Chapter 1

The Chemistry of Life

In This Chapter

- Getting to the heart of all matter: Atoms
- Checking into chemical reactions and compounds
- Making sense of metabolism

We can hear your cries of alarm. You thought you were getting ready to learn about the knee bone connecting to the thigh bone. How in the heck does that involve (horrors!) *chemistry?* As much as you may not want to admit it, chemistry — particularly *organic chemistry,* or that branch of the field that focuses on carbon-based molecules — is a crucial starting point for understanding how the human body works. When all is said and done, the universe boils down to two fundamental components: *matter,* which occupies space and has mass; and *energy,* or the ability to do work or create change. This is the chapter where we review the interactions between matter and energy to give you some insight into what you need to know to ace those early-term tests.

Building from Scratch: Atoms and Elements

All matter — be it solid, liquid, or gas — is composed of atoms. An *atom* is the smallest unit of matter capable of retaining the identity of an element during a chemical reaction. An *element* is a substance that can't be broken down into simpler substances by normal chemical reactions. There are 92 naturally occurring atoms in nature and 17 (at last count) artificially created atoms for a total of 109 known atoms. However, additional spaces have yet to be filled in on the periodic chart of elements, which organizes all the elements by name, symbol, atomic weight, and atomic number. The key elements of interest to students of anatomy and physiology are

- Hydrogen, symbol H
- Oxygen, symbol O
- Nitrogen, symbol N
- Carbon, symbol C

TIP: HONC your horn for the four organic elements. These four elements make up 96 percent of all living material.

Atoms are made up of the subatomic particles *protons* and *neutrons*, which are in the atom's *nucleus,* and clouds of *electrons* orbiting the nucleus. The *atomic weight,* or *mass,* of an atom is the total number of protons and neutrons in its nucleus. The *atomic number* of an atom is its number of protons or electrons; conveniently, atoms always have the same number of protons as electrons, which means that an atom is always electrically neutral because it always has the same number of positive charges as negative charges. Opposite charges attract, so negatively charged electrons are attracted to positively charged protons. The attraction holds electrons in orbits outside the nucleus. The more protons there are in the nucleus, the stronger the atom's positive charge is and the more electrons it can attract.

Electrons circle an atom's nucleus at different energy levels, also known as *orbits* or *shells* (see Figure 1-1). Each orbit can accommodate only a limited number of electrons and lies at a fixed distance from the nucleus. Each level must be filled to capacity with electrons before a new level can get started. The orbit closest to the nucleus, which may be referred to as the *first level* or *first shell,* can accommodate up to two electrons. The second level can have eight electrons and the third also can have eight electrons. Higher orbits exist, but anatomy and physiology students only need to know about the first three levels.

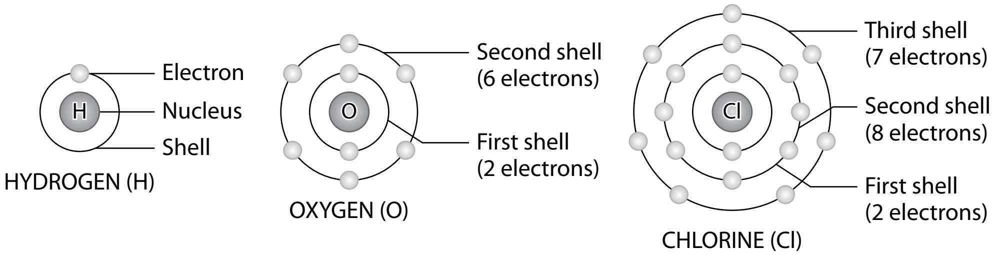

Figure 1-1: Grouping electrons into shells or orbits.

Other key chemistry terms that you need to know as an anatomy and physiology student are

- **Isotopes:** Atoms of an element that have a different number of neutrons and a different atomic weight than usual. In other words, isotopes are alternate forms of the same chemical element, so they will always have the same number of protons as that element, but a different number of neutrons.
- **Ions:** Because electrons are relatively far from the atomic nucleus, they are most susceptible to external fields. Atoms that have gained or lost electrons are transformed into ions. Getting an extra electron turns an atom into a negatively charged ion, or *anion,* whereas losing an electron creates a positively charged ion, or *cation.*

  TIP: To keep anions and cations straight, think like a compulsive dieter: Gaining is negative, and losing is positive.
- **Acid:** A substance that becomes ionized when placed in solution, producing positively charged hydrogen ions, H^+. An acid is considered a proton donor. (Remember, atoms always have the same number of electrons as protons. Ions are produced when an atom gains or loses electrons.)
- **Base:** A substance that becomes ionized when placed in solution, producing negatively charged hydroxide ions, $(OH)^-$. Bases are referred to as being more *alkaline* than acids and are known as proton acceptors.
- **pH (potential of hydrogen):** A mathematical measure on a scale of 0 to 14 of the acidity or alkalinity of a substance. A solution is considered *neutral,* neither acid nor base, if its pH is exactly 7. (Pure water has a pH of 7.) A substance is *basic* if its pH is greater than 7 and *acidic* if its pH is less than 7. Interestingly, skin is considered acidic because it has a pH around 5. Blood, on the other hand, is basic with a pH around 7.4.

Answer these practice questions about atoms and elements:

1. The four key elements that make up most living matter are

a. Carbon, hydrogen, nitrogen, and phosphorus

b. Oxygen, carbon, sulfur, and nitrogen

c. Hydrogen, nitrogen, oxygen, and carbon

d. Nitrogen, potassium, carbon, and oxygen

2. Among the subatomic particles in an atom, the two that have equal weight are

a. Neutrons and electrons

b. Protons and neutrons

c. Positrons and protons

d. Neutrons and positrons

3. For an atom with an atomic number of 19 and an atomic weight of 39, the total number of neutrons is

a. 19

b. 20

c. 39

d. 58

4. Element X has 14 electrons. How many electrons are in its outermost shell?

a. 2

b. 6

c. 14

d. 4

5. A substance that, in water, separates into a large number of hydroxide ions is

a. A weak acid

b. A weak base

c. A strong acid

d. A strong base

6. A hydroxyl, or hydroxide, ion has an oxygen atom

a. Only

b. And an extra electron

c. And a hydrogen atom and an extra electron

d. And a hydrogen atom and one less electron

7.–12. Fill in the blanks to complete the following sentences:

Different isotopes of the same element have the same number of **7.** _______________ and **8.** _______________ but different numbers of **9.** _______________. Isotopes also have different atomic **10.** _______________. An atom that gains or loses an electron is called an **11.** _______________. If an atom loses an electron, it carries a **12.** _______________ charge.

Compounding Chemical Reactions

Atoms tend to arrange themselves in the most stable patterns possible, which means that they have a tendency to complete or fill their outermost electron orbits. They join with other atoms to do just that. The force that holds atoms together in collections known as *molecules* is referred to as a *chemical bond.* There are two main types and some secondary types of chemical bonds:

- **Ionic bond:** This chemical bond (shown in Figure 1-2) involves a transfer of an electron, so one atom gains an electron while one atom loses an electron. One of the resulting ions carries a negative charge, and the other ion carries a positive charge. Because opposite charges attract, the atoms bond together to form a molecule.

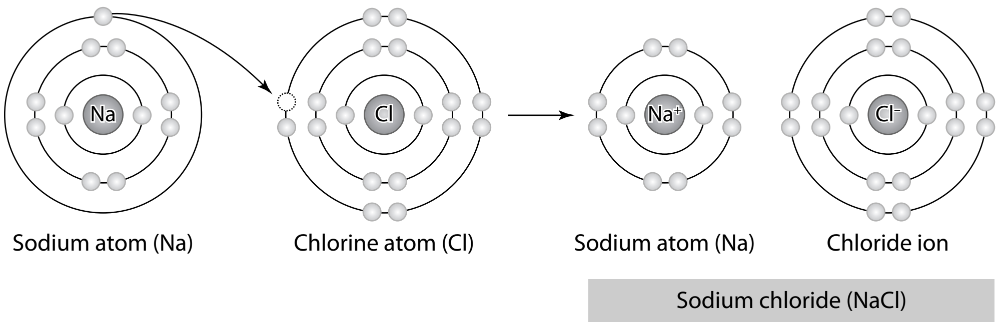

Figure 1-2: Ionic bonding.

- **Covalent bond:** The most common bond in organic molecules, a covalent bond (shown in Figure 1-3) involves the sharing of electrons between two atoms. The pair of shared electrons forms a new orbit that extends around the nuclei of both atoms, producing a molecule. There are two secondary types of covalent bonds that are relevant to biology:

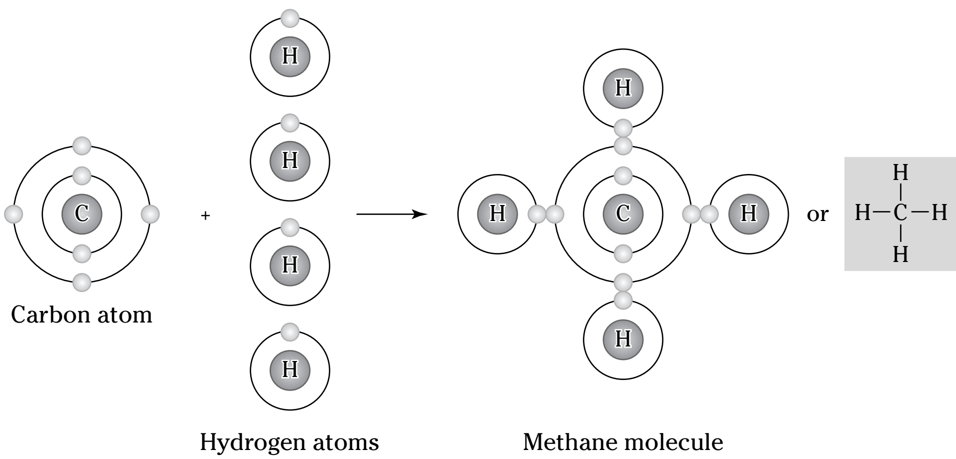

Figure 1-3: Covalent bonding.

  - **Polar bond:** Two atoms connected by a covalent bond may exert different attractions for the electrons in the bond, producing an unevenly distributed charge. The result is known as a *polar bond,* an intermediate case between ionic and covalent bonding, with one end of the molecule slightly negatively charged and the other end slightly positively charged. Although the resulting molecule is neutral, at close distances the uneven charge distribution can be important. Water is an example of a polar molecule; the oxygen end has a slight positive charge whereas the hydrogen ends are slightly negative. Polarity explains why some substances dissolve readily in water and others do not.

- **Hydrogen bond:** Because they're polarized, two adjacent H_2O (water) molecules can form a linkage known as a *hydrogen bond,* where a (electronegative) hydrogen atom of one H_2O molecule is electrostatically attracted to the (electropositive) oxygen atom of an adjacent water molecule. Consequently, molecules of water join together transiently in a hydrogen-bonded lattice. Hydrogen bonds have only about 1/20 the strength of a covalent bond, yet even this force is sufficient to affect the structure of water, producing many of its unique properties, such as high surface tension, specific heat, and heat of vaporization. Hydrogen bonds are important in many life processes, such as in replication and defining the shape of DNA molecules.

A chemical reaction is the result of a process that changes the number, the types, or the arrangement of atoms within a molecule. The substances that go through this process are called the *reactants.* The substances produced by the reaction are called the *products.*

REMEMBER

Chemical reactions are written in the form of an equation, with an arrow indicating the direction of the reaction. For instance: $A + B \rightarrow AB$. This equation translates to: Atom, ion, or molecule *A* plus atom, ion, or molecule *B* yields molecule *AB*.

When elements combine through chemical reactions, they form *compounds.* When compounds contain carbon, they're called *organic compounds.* The four families of organic compounds with important biological functions are

- **Carbohydrates:** These molecules consist of carbon, hydrogen, and oxygen in a ratio of roughly 1:2:1. If a test question involves identifying a compound as a carbohydrate, count the atoms and see if they fit that ratio. Carbohydrates are formed by the chemical reaction process of *concentration,* or *dehydration synthesis,* and broken apart by *hydrolysis,* the cleavage of a chemical by a reaction that adds water. There are several subcategories of carbohydrates:
  - *Monosaccharides*, also called *monomers* or *simple sugars,* are the building blocks of larger carbohydrate molecules and are a source of stored energy (see Figure 1-4). Key monomers include *glucose* (also known as blood sugar), *fructose,* and *galactose.* These three have the same numbers of carbon (6), hydrogen (12), and oxygen (6) atoms in each molecule — formally written as $C_6H_{12}O_6$ — but the bonding arrangements are different. Molecules with this kind of relationship are called *isomers.*
  - *Disaccharides,* or *dimers,* are sugars formed by the bonding of two monosaccharides, including *sucrose* (table sugar), *lactose,* and *maltose.*
  - *Polysaccharides,* or *polymers,* are formed when many monomers bond into long, chain-like molecules. *Glycogen* is the primary polymer in the body; it breaks down to form glucose, an immediate source of energy for cells.
- **Lipids:** Commonly known as fats, these molecules contain carbon, hydrogen, and oxygen, and sometimes nitrogen and phosphorous. Insoluble in water because they contain a preponderance of nonpolar bonds, lipid molecules have six times more stored energy than carbohydrate molecules. Upon hydrolysis, however, fats form glycerol and fatty acids. A fatty acid is a long, straight chain of carbon atoms with hydrogen atoms attached (see Figure 1-5). If the carbon chain has its full number of hydrogen atoms, the fatty acid is *saturated* (examples include butter and lard). If the carbon chain has less than its full number of hydrogen atoms, the fatty acid is *unsaturated* (examples include margarine and vegetable oils). All fatty acids contain a carboxyl or acid group, $-COOH$, at the end of the carbon chain. *Phospholipids,* as the name suggests, contain phosphorus and often nitrogen and form a layer in the cell membrane. *Steroids* are fat-soluble compounds such as vitamins A or D and hormones that often serve to regulate metabolic processes.

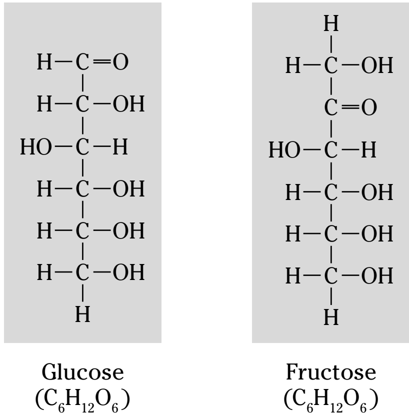

Figure 1-4: Monosaccharides.

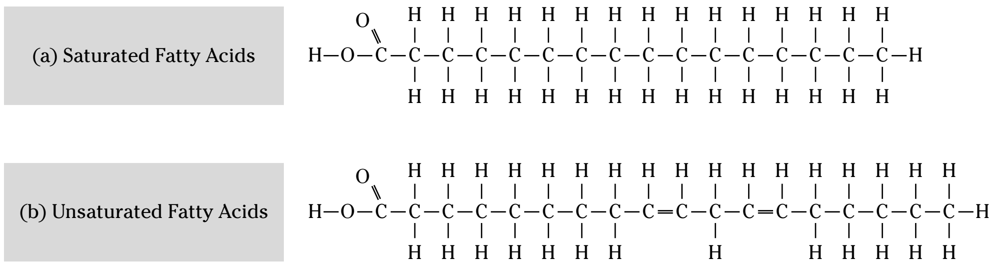

Figure 1-5: Fatty acids.

- **Proteins:** Among the largest molecules, proteins can reach molecular weights of some 40 million atomic units. Proteins always contain the four HONC elements — hydrogen, oxygen, nitrogen, and carbon — and sometimes contain phosphorus and sulfur. The human body builds protein molecules using 20 different kinds of smaller molecules called *amino acids* (see Figure 1-6). Each amino acid molecule is composed of an amino group, $-NH_2$, and a carboxyl group, $-COOH$, with a carbon chain between them. Amino acids link together by peptide bonds to form long molecules called *polypeptides,* which then assemble into proteins. Examples of proteins in the body include *antibodies, hemoglobin* (the red pigment in red blood cells), and *enzymes* (catalysts that accelerate reactions in the body).

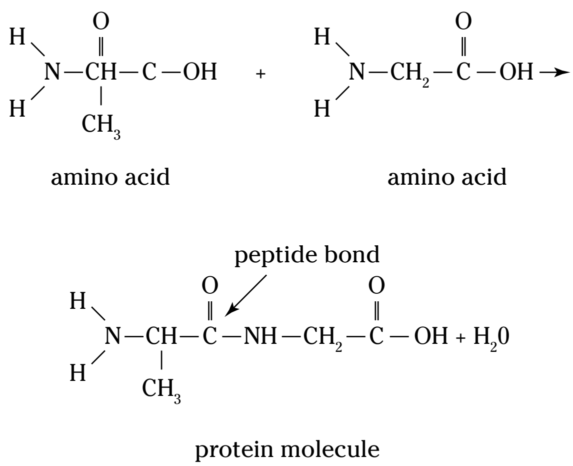

Figure 1-6: Amino acids in a protein molecule.

- **Nucleic acids:** These long molecules, found primarily in the cell's nucleus, act as the body's genetic blueprint. They're comprised of smaller building blocks called *nucleotides.* Each nucleotide, in turn, is composed of a five-carbon sugar (*deoxyribose* or *ribose*), a phosphate group, and a nitrogenous base. The nitrogenous bases in DNA (deoxyribonucleic acid) are *adenine, thymine, cytosine,* and *guanine;* they always pair off A-T and C-G. In RNA (ribonucleic acid), which occurs in a single strand, thymine is replaced by *uracil,* so the nucleotides pair off A-U and C-G. In 1953, James Watson and Francis Crick published their discovery of the three-dimensional structure of DNA — a polymer that looks like a ladder twisted into a coil. They called this structure the *double-stranded helix* (see Figure 1-7).

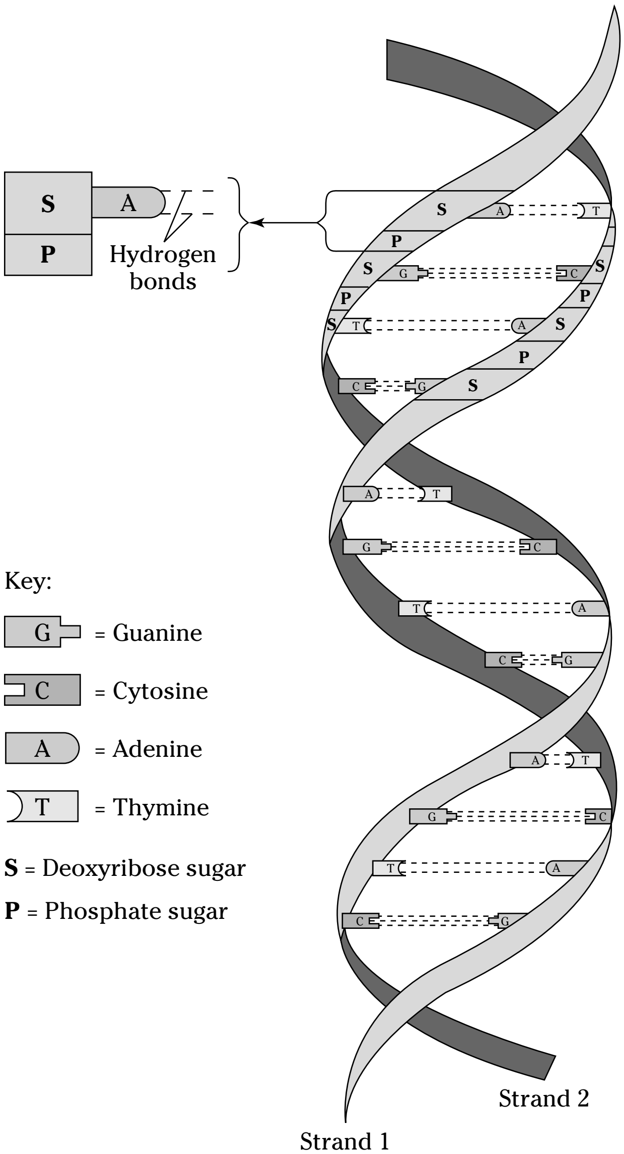

Figure 1-7: The DNA double helix.

The following is an example question dealing with chemical reactions:

Q. Oxygen can react with other atoms because it has

a. Two electrons in its inner orbit

b. Eight protons

c. An incomplete outer electron orbit

d. Eight neutrons

A. The correct answer is an incomplete outer electron orbit. Even if you don't know the first thing about oxygen, remembering that atoms tend toward stability answers this question for you.

13. Bonds formed as a result of sharing one or more electrons between atoms are

a. Valence bonds

b. Covalent bonds

c. Ionic bonds

d. Electrovalent bonds

14. The formation of chemical bonds is based on the tendency of an atom to

a. Move protons into vacant electron orbit spaces

b. Fill its outermost energy level

c. Radiate excess neutrons

d. Pick up free protons

15. Which of the following statements is *not* true of DNA?

a. DNA is found in the nucleus of the cell.

b. DNA can replicate itself.

c. DNA contains the nitrogenous bases adenine, thymine, guanine, cytosine, and uracil.

d. DNA forms a double-helix molecule.

16. Polysaccharides

a. Can be reduced to fatty acids

b. Contain nitrogen and phosphorus

c. Are complex carbohydrates

d. Contain adenine and uracil

17. Amino acids are the building blocks of

a. Carbohydrates

b. Proteins

c. Lipids

d. Nucleic acids

Cycling through Life: Metabolism

Metabolism (from the Greek *metabole,* which means "change") is the word for the myriad chemical reactions that happen in the body, particularly as they relate to generating, storing, and expending energy. All metabolic reactions are either *catabolic* or *anabolic. Catabolic reactions* break food down into energy (memory tip: it can be *cata*strophic when things break down). *Anabolic reactions* require the expenditure of energy to build up compounds that the body needs. The chemical alteration of molecules in the cell is referred to as *cellular metabolism. Enzymes* can be used as catalysts, accelerating chemical reactions without being changed by the reactions. The molecules that enzymes react with are called *substrates.*

Adenosine triphosphate (ATP) is a molecule that stores energy in a cell until the cell needs it. As the *tri–* prefix implies, a single molecule of ATP is composed of three phosphate groups attached to a nitrogenous base of adenine. ATP's energy is stored in high-energy bonds that attach the second and third phosphate groups. (The high-energy bond is symbolized by a wavy line.) When a cell needs energy, it removes one or two of those phosphate groups, releasing energy and converting ATP into either the two-phosphate molecule *adenosine diphosphate* (ADP) or the one-phosphate molecule *adenosine monophosphate* (AMP). (You can see ADP and ATP molecules in Figure 1-8.) Later, through additional metabolic reactions, the second and third phosphate groups are reattached to adenosine, reforming an ATP molecule until energy is needed again.

Oxidation-reduction reactions are an important pair of reactions that occur in carbohydrate, lipid, and protein metabolism (see Figure 1-10). When a substance is *oxidized,* it loses electrons and hydrogen ions, removing a hydrogen atom from each molecule. When a substance is *reduced,* it gains electrons and hydrogen ions, adding a hydrogen atom to each molecule. Oxidation and reduction occur together, so whenever one substance is oxidized, another is reduced. The body uses this chemical-reaction pairing to transport energy in a process known as the respiratory chain, or the *electron transport chain.*

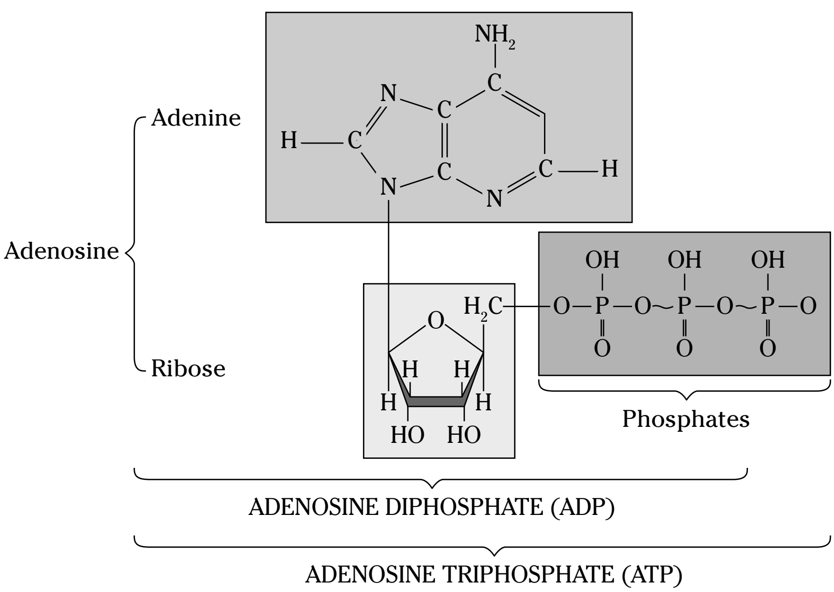

Figure 1-8: The structures of ADP and ATP.

Carbohydrate metabolism involves a series of *cellular respiration* reactions, which are illustrated in Figure 1-9. All food carbohydrates are eventually broken down into glucose; therefore, carbohydrate metabolism is really glucose metabolism. Glucose metabolism produces energy that is then stored in ATP molecules. The oxidation process in which energy is released from molecules, such as glucose, and transferred to other molecules is called cellular respiration. It occurs in every cell in the body and it is the cell's source of energy. The complete oxidation of one molecule of glucose will produce 38 molecules of ATP. It occurs in three stages: *glycolysis,* the *Krebs cycle,* and the *electron transport chain:*

1. **Glycolysis**

   From the Greek *glyco* (sugar) and *lysis* (breakdown), this is the first stage of both *aerobic* (with oxygen) and *anaerobic* (without oxygen) respiration. Using energy from two molecules of ATP and two molecules of NAD^+ *(nicotinamide adenine di-nucleotide),* glycolysis uses a process called *phosphorylation* to convert a molecule of six-carbon glucose — the smallest molecule that the digestive system can produce during the breakdown of a carbohydrate — into two molecules of three-carbon *pyruvic acid* or *pyruvate,* as well as four ATP molecules and two molecules of NADH *(nicotinamide adenine dinucleotide).* Taking place in the cell's cytoplasm (see Chapter 2), glycolysis doesn't require oxygen to occur. The pyruvate and NADH move into the cell's *mitochondria* (detailed in Chapter 2), where an aerobic (with oxygen) process converts them into ATP.

2. **Krebs cycle**

   Also known as the *tricarboxylic acid cycle* or *citric acid cycle,* this series of energy-producing chemical reactions begins in the mitochondria after pyruvate arrives from glycolysis. Before the Krebs cycle can begin, the pyruvate loses a carbon dioxide group to form *acetyl coenzyme A* (acetyl CoA). Then acetyl CoA combines with a four-carbon molecule (*oxaloacetic acid,* or OAA) to form a six-carbon citric acid molecule that then enters the Krebs cycle. The CoA is released intact to bind with another acetyl group. During the conversion, two carbon atoms are lost as carbon dioxide and energy is released. One ATP molecule is produced each time an acetyl CoA molecule is split. The cycle goes through eight steps, rearranging the atoms of citric acid to produce different intermediate molecules called *keto acids.* The acetic acid is broken apart by carbon (or *decarboxylated*) and oxidized, generating three molecules of NADH, one molecule of FADH2 (flavin adenine dinucleotide), and one molecule of ATP. The energy can be transported to the electron transport chain and used to produce more molecules of ATP. OAA is regenerated to get the next cycle going, and carbon dioxide produced during this cycle is exhaled from the lungs.

3. **Electron transport chain**

   The electron transport chain is a series of energy compounds attached to the inner mitochondrial membrane. The electron molecules in the chain are called *cytochromes.* These electron-transferring proteins contain a heme, or iron, group. Hydrogen from oxidized food sources attaches to coenzymes that in turn combine with molecular oxygen. The energy released during these reactions is used to attach inorganic phosphate groups to ADP and form ATP molecules.

   Pairs of electrons transferred to NAD^+ go through the electron transport process and produce three molecules of ATP by oxidative phosphorylation. Pairs of electrons transferred to FAD enter the electron transport after the first phosphorylation and yield only two molecules of ATP. Oxidative phosphorylation is important because it makes energy available in a form the cells can use.

   At the end of the chain, two positively charged hydrogen molecules combine with two electrons and an atom of oxygen to form water. The final molecule to which electrons are passed is oxygen. Electrons are transferred from one molecule to the next, producing ATP molecules.

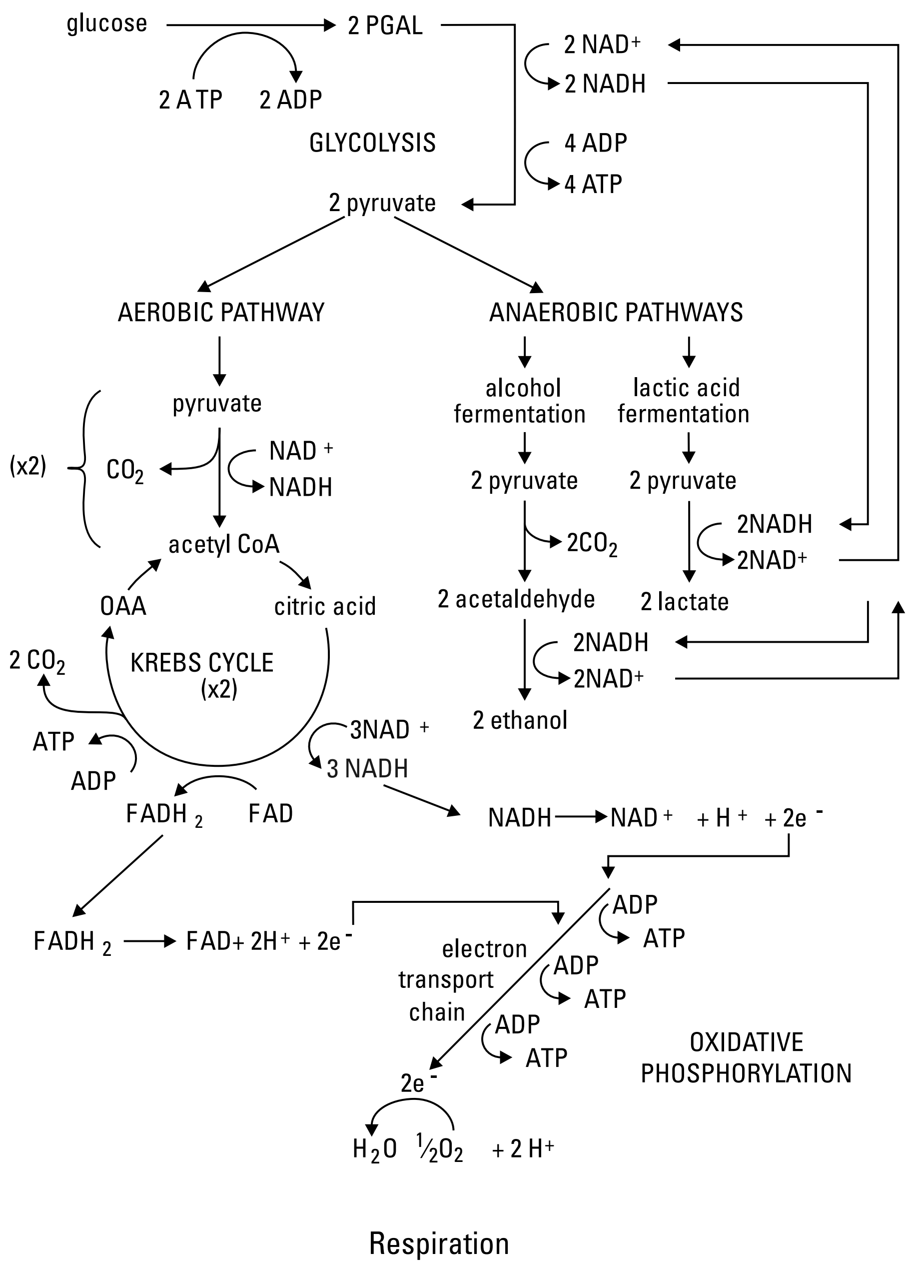

Figure 1-9: Cellular respiration: Glycolysis, aerobic (Krebs cycle) and anaerobic respiration, and oxidative phosphorylation, all of which convert energy from fuel into ATP.

Lipid metabolism only requires portions of the processes involved in carbohydrate metabolism. Lipids contain about 99 percent of the body's stored energy and can be digested at mealtime, but as people who complain about fats going "straight to their hips" can attest, lipids are more inclined to be stored in *adipose tissue* — the stuff generally identified with body fat. When the body is ready to metabolize lipids, a series of catabolic reactions breaks apart two carbon atoms from the end of a fatty acid chain to form acetyl CoA, which then enters the Krebs cycle to produce ATP. Those reactions continue to strip two carbon atoms at a time until the entire fatty acid chain is converted into acetyl CoA.

Protein metabolism focuses on producing the amino acids needed for synthesis of protein molecules within the body. But in addition to the energy released into the electron transport chain during protein metabolism, the process also produces byproducts, such as ammonia and keto acid. Energy is released entering the electron transport chain. The liver converts the ammonia into urea, which the blood carries to the kidneys for elimination. The keto acid enters the Krebs cycle and is converted into pyruvic acids to produce ATP.

One last thing: That severe soreness and fatigue you feel in your muscles after strenuous exercise is the result of lactic acid buildup during *anaerobic respiration.* Glycolysis continues because it doesn't need oxygen to take place. But glycolysis does need a steady supply of NAD^+, which usually comes from the oxygen-dependent electron transport chain converting NADH back into NAD^+. In its absence, the body begins a process called *lactic acid fermentation,* in which one molecule of pyruvate combines with one molecule of NADH to produce a molecule of NAD^+ plus a molecule of the toxic byproduct lactic acid.

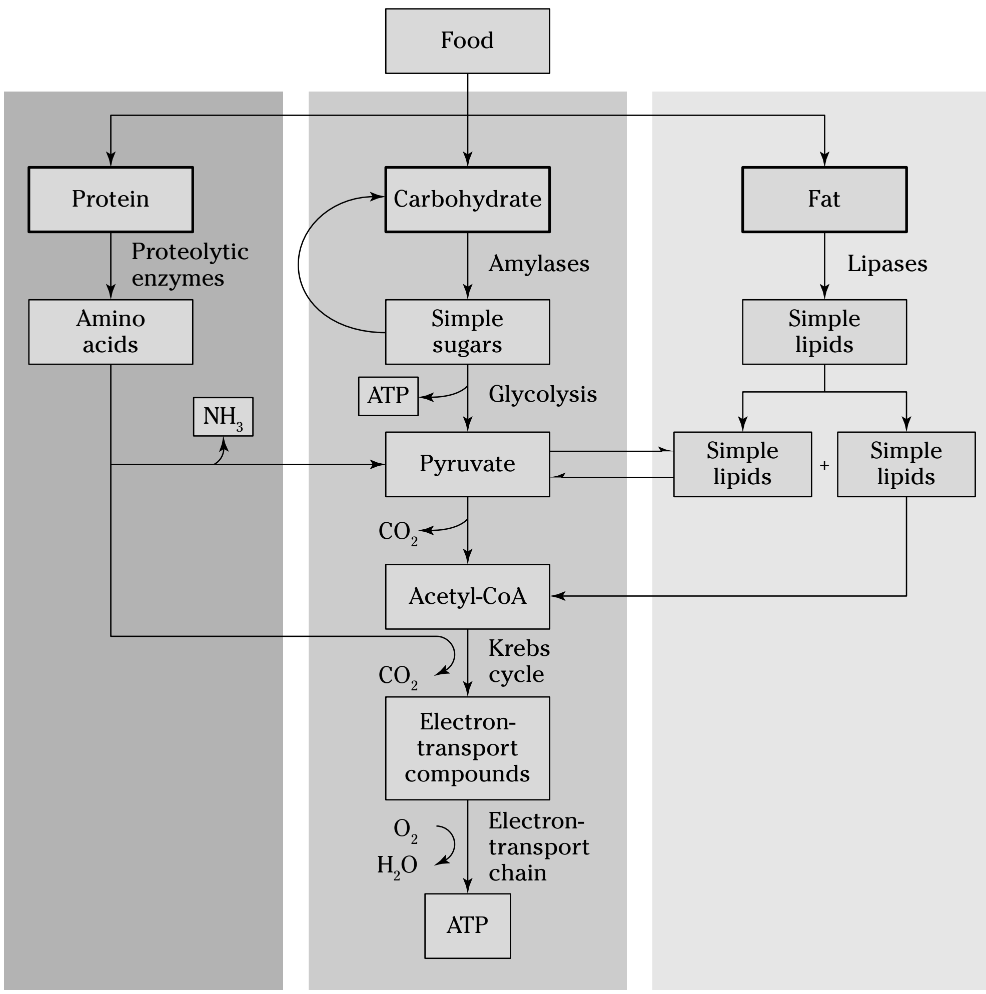

Figure 1-10: Protein, carbohydrate, and fat metabolism.

Check out an example question on metabolism:

EXAMPLE

Q. Cells obtain ATP by converting the energy in

a. Carbohydrates

b. Proteins

c. Lipids

d. All of these

A. The correct answer is all of these. While it's true that carbohydrates provide the most immediately available energy, proteins and lipids also contribute to the production of ATP.

18. A molecule of glucose is broken down to pyruvic acid by

a. Glycolysis

b. The Krebs cycle

c. The electron transport chain

d. Oxidative phosphorylation

19. Pyruvic acid enters a mitochondrion and is converted into

a. Glucose

b. Acetyl CoA

c. Water

d. Protein

20. A molecule of glucose can be converted into how many ATP molecules?

a. 2

b. 3

c. 38

d. 45

21. The part of metabolism that involves creating compounds the body needs is called

a. A catabolic reaction

b. Cellular respiration

c. An anabolic reaction

d. Oxidation

22. Metabolic processes that don't require oxygen are called

a. Anaerobic

b. Aerobic

c. Fermentation

d. Carbon dioxination

23. Which two respiration processes take place in the cell's mitochondria?

a. Glycolysis and the Krebs cycle

b. Glycolysis and the electron transport chain

c. The Krebs cycle and the electron transport chain

d. The Krebs cycle and anaerobic respiration

24. Coal is to electricity as glucose is to

a. ATP

b. Pyruvate

c. Hydrogen

d. Glycolysis

25. The primary products of protein metabolism are

a. ATP molecules

b. Amino acids

c. Lipids

d. Carbon dioxide molecules

26. Fats are metabolized primarily during

a. Glycolysis

b. Lactic acid fermentation

c. Exercise

d. The Krebs cycle

Answers to Questions on Life's Chemistry

The following are answers to the practice questions presented in this chapter.

1 The four key elements that make up most living matter are **c. hydrogen, nitrogen, oxygen, and carbon.** We arranged them so that they spell HNOC instead of HONC, but you get the idea, right?

2 Among the subatomic particles in an atom, the two that have equal weight are **b. protons and neutrons.** That's why you add them together to determine atomic weight, or mass.

3 For an atom with an atomic number of 19 and an atomic weight of 39, the total number of neutrons is **b. 20.** The atomic number of 19 is the same as the number of protons. The atomic weight of 39 tells you the number of protons plus the number of neutrons: $39 - 19 = 20$.

4 Element X has 14 electrons. How many electrons are in its outermost shell? **d. 4.** The first orbit has the maximum two electrons, and the second orbit has the maximum eight electrons. That makes ten electrons in the first two orbits, leaving only four for the third, outermost orbit.

5 A substance that, in water, separates into a large number of hydroxide ions is **d. a strong base.** The more hydroxide ions there are, the stronger the base is.

6 A hydroxyl, or hydroxide, ion has an oxygen atom **c. and a hydrogen atom and an extra electron.** The first few letters of the word "hydroxide" are a dead giveaway that there's a hydrogen atom in there; plus hydroxide ions are negatively charged, which calls for that extra electron.

7–12 Different isotopes of the same element have the same number of **7. electrons/protons** and **8. protons/electrons** but different numbers of **9. neutrons**. Isotopes also have different atomic **10. weights**. An atom that gains or loses an electron is called an **11. ion**. If an atom loses an electron, it carries a **12. positive** charge.

13 Bonds formed as a result of sharing one or more electrons between atoms are **b. covalent bonds.** If the atoms had gained or lost electrons, it would be an ionic bond, but here they're sharing — valiantly cohabiting, if you will.

14 The formation of chemical bonds is based on the tendency of an atom to **b. fill its outermost energy level.** This is true whether an atom fills its outer shell by sharing, gaining, or losing electrons.

15 Which of the following statements is *not* true of DNA? **c. DNA contains the nitrogenous bases adenine, thymine, guanine, cytosine, and uracil.** This statement is false because only RNA contains uracil.

16 Polysaccharides **c. are complex carbohydrates.** The root *poly–* means "many," which you can interpret as "complex." The root *mono–* means "one," which you can interpret as "simple."

17 Amino acids are the building blocks of **b. proteins.** Being such large molecules, proteins need to be built from complex molecules to begin with.

18 A molecule of glucose is broken down to pyruvic acid by **a. glycolysis.** Remember that glucose must become pyruvic acid before it enters the Krebs cycle.

19 Pyruvic acid enters a mitochondrion and is converted into **b. acetyl CoA.** Don't forget that the Krebs cycle, during which pyruvate is broken down, occurs in the mitochondrion.

20 A molecule of glucose can be converted into how many ATP molecules? **c. 38.** Two net molecules of ATP come from glycolysis, two molecules come from the Krebs cycle, and the electron transport chain churns out 34.

21 The part of metabolism that involves creating compounds the body needs is called **c. an anabolic reaction.** Breaking things down is a catabolic reaction, but building them up is anabolic.

22 Metabolic processes that don't require oxygen are called **a. anaerobic.** Recall that during aerobic exercise, you're trying to circulate oxygen to your muscles. So anaerobic is the opposite.

23 Which two respiration processes take place in the cell's mitochondria? **c. The Krebs cycle and the electron transport chain.** The other answers are incorrect because glycolysis takes place in the cytoplasm, and anaerobic respiration isn't one of the three cellular respiration processes.

24 Coal is to electricity as glucose is to **a. ATP.** Just as you can't power a lamp with a lump of coal, cells can't use glucose directly. You need to turn the coal into electricity, and cells need to turn the glucose into ATP.

25 The primary products of protein metabolism are **b. amino acids.** Although some ATP comes from metabolizing proteins, the body primarily needs to get amino acids from any protein that's consumed.

26 Fats are metabolized primarily during **d. the Krebs cycle.** That's the only process that can use the acetyl CoA supplied by lipids.