

Chapter Summary

Metabolism is the sum total of all chemical and physical processes by which the body catabolizes and anabolizes molecules. Metabolic pathways are controlled by hormones and made more efficient by enzymes, coenzymes, and cofactors. The four major reactions involved in metabolism are condensation, hydrolysis, phosphorylation, and oxidation–reduction. Carbon dioxide, water, and ATP are the end products of glucose oxidation, which occurs in three stages: glycolysis, the TCA cycle, and electron transport. Once triglycerides are broken down to glycerol and fatty acids, the glycerol is converted to glucose or oxidized for energy, and the fatty acids are oxidized or converted to ketones when carbohydrates are depleted. After deamination, the carbon skeletons of protein are broken down to pyruvate or acetyl CoA to produce carbon dioxide, water, ATP, and urea.

Amino groups stripped from proteins can be used to synthesize nonessential amino acids. In the stomach, up to 20% of consumed alcohol can be oxidized, but the remainder is oxidized by the liver at a steady rate of one drink per hour. Energy is stored in the form of glycogen (glucose storage) and triglycerides (lipid storage). Carbohydrates, lipids, proteins, and alcohol all contribute to lipogenesis. The body can synthesize glucose, most fatty acids, and NEAAs from available metabolites and transamination, but EAAs must be consumed in their existing form. Insulin is the primary anabolic hormone, while glucagon, epinephrine, and cortisol are primarily catabolic. During fasting, the body relies on glycogen and triglycerides for the short term and fatty acids, ketones, and gluconeogenesis for the long term.

Nutrition Myth or Fact addresses the question: “Speed up Your metabolism!” Is it just a dream?

Learning Objectives

After studying this chapter, the student should be able to:

1. Describe the properties of metabolism, catabolism, and anabolism, including the roles of ATP, ADP, and AMP (pp. 252–254).
2. Illustrate the following types of metabolic reactions: hydrolysis, dehydration synthesis, phosphorylation, and oxidation–reduction (pp. 254–258).
3. Identify the metabolic processes and stages involved in extracting energy from carbohydrates (pp. 258–264).
4. Identify the metabolic processes and stages involved in extracting energy from fats (pp. 264–269).
5. Explain how the catabolism of proteins differs from the catabolism of carbohydrates and lipids (pp. 270–272).

6. Delineate the process by which alcohol is metabolized (pp. 272–274).
7. Identify the body's mechanisms for storing excess glucose, triglycerides, and proteins (pp. 275–276).
8. Describe the processes by which glucose, fatty acids, cholesterol, and nonessential amino acids are synthesized (pp. 276–278).
9. Explain the role of insulin, glucagon, epinephrine, and cortisol in regulating metabolism (pp. 279–280).
10. Explain how the states of feasting and fasting affect metabolism (pp. 280–284).

Key Terms

acetyl CoA	coenzyme	lipogenesis
adenosine diphosphate	dehydration synthesis	lipolysis
adenosine monophosphate	<i>de novo</i> synthesis	metabolism
adenosine triphosphate	electron transport chain	microsomal ethanol oxidizing system
albumin	flavin adenine dinucleotide	nicotinamide adenine dinucleotide
alcohol dehydrogenase	glucokinase	β -oxidation (fatty acid oxidation)
aldehyde dehydrogenase	gluconeogenesis	oxidation–reduction reactions
anabolism	glycolysis	phosphorylation
calorimeter	hydrolysis	proteolysis
carbon skeleton	keto acid	TCA cycle
carnitine	ketogenic amino acid	
catabolism	ketone bodies	
cofactor	lactate (lactic acid)	

Chapter Outline

I. Why Is Metabolism Essential for Life?

- A. Metabolism is the sum of all chemical processes by which the body breaks down and builds molecules.
 1. All cells require energy for growth, repair, maintenance, and reproduction.
 2. Every chemical reaction either requires or releases energy.
- B. Anabolism and catabolism require or release energy.
 1. Anabolism is the process of making complex molecules from more basic ones.
 - a. The body uses metabolic “building blocks” like glucose, amino acids, and fatty acids to synthesize thousands of complex substances.
 - b. Anabolic reactions require chemical energy.
 2. Catabolism is the breakdown, or degradation, of complex molecules to more basic ones.
 - a. It is the opposite of anabolism; it releases chemical energy.
 - b. It begins with digestion when food is catabolized to amino acids, fatty acids, glycerol, and monosaccharides.
 - c. In the cell, these smaller compounds are catabolized for energy.

- d. The energy gained from catabolism is used for all anabolic processes.
- 3. A balance between anabolism and catabolism maintain health and function.
- C. Energy stored in adenosine triphosphate fuels the work of all body cells.
 - 1. Energy that is released during catabolism is packaged as ATP.
 - a. ATP contains adenosine and three phosphate groups.
 - 2. When the high-energy phosphate bonds of ATP are broken, energy is released for work.
 - 3. Adenosine diphosphate (ADP) is produced when one high-energy phosphate bond is broken and a single phosphate group is released.
 - 4. Adenosine monophosphate (AMP) is produced when two phosphates are removed.
 - 5. All cells store a small amount of ATP for immediate use.
 - 6. Cells produce more ATP by catabolizing the by-products of food.

Key Terms: metabolism, calorimeter, anabolism, catabolism, adenosine triphosphate (ATP), adenosine diphosphate (ADP), adenosine monophosphate (AMP)

Nutrition Animation: The Energy Currency: ATP (located in IR-DVD folder)

Figures:

Figure 7.1: Anabolic reactions use energy to convert simple chemical compounds into larger, more complex structures.

Figure 7.2: Structure of adenosine triphosphate (ATP)

II. What Chemical Reactions Are Fundamental to Metabolism?

- A. Metabolic pathways are clusters of chemical reactions that occur sequentially and achieve a particular goal.
 - 1. Cells use different metabolic pathways to release the energy from nutrients.
 - 2. The pathways occur within a specific part of cell because many metabolic enzymes are restricted to certain locations within a cell.
- B. The mitochondria are the primary site of chemical reactions that produce energy.
 - 1. Mitochondria contain large numbers of metabolic enzymes.
 - 2. Cells that lack mitochondria rely on less energy-producing cytoplasm.
 - 3. The liver, muscle, and adipose tissue are key sites for integration of metabolic pathways.
- C. In dehydration synthesis and hydrolysis reactions, water reacts with molecules.
 - 1. Dehydration synthesis reactions are anabolic and also known as condensation because water is a by-product.
 - 2. Hydrolysis or hydration reactions are catabolic by the addition of water.
- D. In phosphorylation reactions, molecules exchange phosphate.
 - 1. Dephosphorylation occurs when phosphate groups are removed from a molecule.
- E. In oxidation–reduction reactions, molecules exchange electrons.
 - 1. The molecule that gives up an electron is said to be oxidized, because an electron has typically been removed by an oxygen atom.
 - 2. The molecule that gains an electron is said to be reduced and becomes more negatively charged.

3. Because they involve the exchange of electrons, oxidation-reduction (redox) reactions are classified as exchange reactions.

F. Enzymes mediate metabolic reactions.

1. In order to function, enzymes generally require cofactors, nonprotein substances that either enhance or are essential for the action of the enzyme.
2. If the cofactor is organic (contains carbon), it is termed a coenzyme.
3. Vitamins and minerals functioning as cofactors or coenzymes are essential to ensuring the efficiency of metabolic pathways.
4. An example of an enzyme-driven metabolic process is glucokinase.

Key Terms: dehydration synthesis, hydrolysis, phosphorylation, oxidation-reduction reactions, flavin adenine dinucleotide (FAD), cofactors, coenzyme, glucokinase

Nutrition Animation: Hydrolytic and Condensation Reactions (located in IR-DVD folder)

Figures:

Figure 7.3: Structure of a typical cell.

Figure 7.4: Dehydration of glucose and fructose.

Figure 7.5: Oxidation and reduction of FAD and FADH₂

Figure 7.6: Cofactors combine with enzymes to activate them.

III. How Is Energy Extracted from Carbohydrates?

A. Most dietary fiber is digested and absorbed as glucose that is transported to the liver.

B. Fructose and galactose can be converted into glucose or channeled into the glycolysis pathway.

C. The oxidation of glucose for the production of energy progresses through three stages:

1. Glycolysis
2. The tricarboxylic acid (TCA) cycle (Krebs cycle or citric acid cycle)
3. The electron transport chain, which is where the process of oxidative phosphorylation occurs.

D. In glycolysis, glucose is broken down into pyruvate.

1. Glycolysis occurs anaerobically in the cytosol.
2. One six-carbon glucose is converted to two three-carbon pyruvate molecules.
3. The phosphorylation of glucose requires two ATP to produce glucose 6-phosphate and ADP.
4. Several enzyme-driven reactions then produce pyruvate.
5. The process produces four ATP molecules, yielding a net two ATP.
6. This oxidative pathway produces two hydrogen atoms, which are picked up by nicotinamide adenine dinucleotide (NAD) to form NADH.
7. If the pyruvate molecules are to be used for the production of energy they must go through additional metabolic steps, which vary depending on whether oxygen is present (aerobic environment) or absent (anaerobic environment).
8. If energy is not immediately needed, pyruvate can resynthesize glucose in a process called gluconeogenesis.

- E.** In the absence of oxygen, pyruvate is converted to lactic acid.
1. This one-step reaction involves hydrogen transfer, which regenerates NAD and allows for continued function of the glycolysis pathway.
 2. Lactate production occurs in cells with few or no mitochondria and in muscle cells during high-intensity activity.
 3. Glycolysis is an inefficient energy producer and, in the muscle, can lead to a buildup of lactic acid, which may cause fatigue.
- F.** In the presence of oxygen, pyruvate is converted to acetyl CoA.
1. Acetyl CoA is a two-carbon chain that cannot be converted to glucose.
 2. The conversion to acetyl CoA links stage 1 (glycolysis) to stage 2 (the TCA cycle).
 3. Pyruvate moves from the cytosol to the mitochondria to begin this step.
 4. Acetyl CoA can then enter the TCA cycle or be converted to citrate for fatty acid synthesis.
- G.** The TCA cycle begins with the entry of acetyl CoA.
1. The TCA cycle is a continuous loop of eight metabolic reactions.
 2. Although the TCA cycle is self-regenerative, acetyl CoA is not regenerated.
 3. Oxaloacetate and other metabolic intermediates within the TCA cycle are necessary for its continued functioning of the TCA cycle.
 - a. When these compounds are limited, energy production decreases.
 - b. Although oxaloacetate can be made from some amino acids, dietary carbohydrate is the primary source.
 4. The two-carbon acetyl CoA reacts with four-carbon oxaloacetate to form six-carbon citrate (hence the term *citric acid cycle*), and the metabolic cycle begins.
 5. The eight-step TCA cycle produces CO₂, ATP, GTP, and reduced coenzymes.
 - a. The hydrogen-rich NADH and FADH₂ transition to stage 3 electron transport.
 - b. One molecule of glucose completes two rotations of the TCA cycle and produces two ATP, two GTP, and then reduced coenzymes.
- H.** Oxidative phosphorylation captures energy as ATP.
1. Oxidative phosphorylation occurs through the electron transport chain in the inner membrane of the mitochondria.
 - a. Various proteins accept and donate electrons, releasing energy through a series of reactions.
 - b. The electrons from NADH and FADH₂ are donated to O₂.
 - c. The energy released from O₂ reduction to H₂O phosphorylates ADP to ATP.
 2. Oxygen is essential for cellular energy production, and without it cellular metabolism halts.
 3. About two to three ATP are produced per NADH and one to two per FADH₂.
- I.** One glucose molecule metabolized through all pathways produces a net 30–38 ATP, depending on the source of information.

Key Terms: glycolysis, nicotinamide adenine dinucleotide (NAD), lactate (lactic acid), acetyl CoA, TCA cycle, electron transport chain

Nutrition Animations: Glycolysis; TCA Cycle; Electron Transport Chain (located in IR-DVD folder)

Figures:

Figure 7.7: Overview of glycolysis

Figure 7.8: Anaerobic conversion of pyruvate to lactate.

Figure 7.9: Aerobic conversion of pyruvate to acetyl CoA.

Figure 7.10: Metabolic crossroads.

Figure 7.11: Overview of the TCA cycle.

Figure 7.12: Overview of the electron transport chain.

IV. How Is Energy Extracted from Fats?

- A.** The energy potential of fat is higher than glucose, but there are more steps to convert it.
 - 1. Three fatty acids are removed from the glycerol backbone by lipolysis.
 - 2. Cellular energy is obtained from circulating triglycerides or body fat stores.
 - 3. Triglycerides are broken down by specific lipases.
- B.** Glycerol is converted to pyruvate.
- C.** Fatty acids are converted to acetyl CoA.
 - 1. Fatty acids are attached to albumin for transport to the cells.
 - 2. Fatty acids, activated by Coenzyme A, move from the cytosol to the mitochondria with the aid of carnitine.
 - 3. β -oxidation systematically breaks fatty acid chains into two-carbon segments.
 - a. The cleavage of fatty acids results in transfer of high-energy electrons to NAD^+ and FAD.
 - b. Acetyl CoA generated from fatty acid oxidation feeds into the TCA cycle.
 - 4. Fats yield more energy than glucose.
 - a. Fatty acids almost always have more than six carbons, which yield more acetyl CoA.
 - b. Because fatty acids provide more opportunity for oxidation than glucose, more NADH and FADH_2 are produced.
- D.** Fatty acids cannot be converted to glucose.
- E.** Ketones are a by-product of fat catabolism.
 - 1. When TCA cycle activity decreases for any reason, acetyl CoA from fat metabolism accumulates in the liver.
 - 2. The liver diverts acetyl CoA to an alternative pathway producing ketone bodies.
 - 3. Ketone production increases when fat metabolism is high, little carbohydrate is available, or TCA intermediates are limited.
 - 4. Ketone bodies can be used as an alternative fuel for the brain, kidneys, and other cells in the absence of glucose.
 - 5. Energy production from ketones is inefficient because β -oxidation does not occur.
 - 6. Ketosis occurs when ketone production rises above its use.
 - a. The body attempts to eliminate acidic ketones through urine, causing dehydration.
 - b. Ketoacidosis occurs when the body's pH falls too low and dehydration becomes severe, resulting in coma or death.
 - c. Ketogenic diets have been used to successfully treat conditions such as childhood epilepsy.

Key Terms: lipolysis, albumin, β -oxidation (fatty acid oxidation), carnitine, ketone bodies

Nutrition Animations: Energy Production from Triglycerides; Ketone Body Formation (located in IR-DVD folder)

Figures:

Figure 7.14: Overview of β -oxidation of fatty acids.

Figure 7.15: Extraction of energy from triglycerides.

Figure 7.16: A comparison of glucose and fatty acid structures.

Figure 7.17: Overview of ketone synthesis.

V. How Is Energy Extracted from Proteins?

A. In proteolysis, proteins are broken down to amino acids.

1. In oxidative deamination, the amino group is removed, leaving ammonia and a carbon skeleton, also referred to as a keto acid.
2. After oxidative deamination, the carbon skeleton feeds into energy production.
 - a. The carbon skeletons are channeled into glycolysis or the TCA cycle.
 - b. Glucogenic amino acids are converted to pyruvate.
 - c. Ketogenic amino acids are converted directly to acetyl CoA.
 - d. Many amino acids have multiple functions and can enter the TCA cycle at various entry points.
 - e. The amount of ATP produced depends on where the carbons enter the metabolic pathway.
 - f. No amino acid produces as much ATP as one glucose or fatty acid molecule.
3. If proteins are consumed in excess, the carbon skeleton feeds into fatty acid synthesis.

B. Ammonia is a by-product of protein catabolism.

1. The liver converts ammonia to urea, which is excreted as urine.
2. Very high protein intake increases the production of urea and the risk for dehydration.

Key Terms: proteolysis, carbon skeleton, keto acid, glucogenic amino acid, ketogenic amino acid

Figures and Table:

Figure 7.18: The process of oxidative deamination.

Figure 7.19: Extraction of energy from amino acids.

Figure 7.20: Overview of urea synthesis.

Table 7.1: Extraction of Energy from Carbohydrate, Triglycerides, Protein, and Alcohol

VI. How Is Alcohol Metabolized?

A. Alcohol is metabolized through oxidation.

1. In moderate alcohol consumption, alcohol dehydrogenase (ADH) oxidizes alcohol to acetaldehyde, which is oxidized by aldehyde dehydrogenase (ALDH) into acetate. The acetate is then converted into acetyl CoA.
2. In chronic alcohol abusers, alcohol is oxidized through the microsomal ethanol oxidizing system (MEOS).
3. The oxidation of alcohol creates imbalances in metabolic coenzymes, which can lead to health problems.

- B.** Oxidation of alcohol begins in the stomach.
 1. Gastric ADH reduces the amount of alcohol absorbed.
 2. Women, older men, and those who have fasted have decreased ADH activity.
 3. Women absorb 30–35% more alcohol than men.
- C.** The oxidation of alcohol continues in the liver.
 - 1 The ADH pathway dominates at low to moderate alcohol consumption.
 2. The MEOS pathway becomes more important as more alcohol is consumed.
 3. In the average healthy individual, alcohol is oxidized at a fairly constant rate.
 - a. The greater the disparity between alcohol consumption and the rate of oxidation, the higher the blood alcohol level rises.
 - b. Alcohol oxidizes at a rate of about one drink per hour, and there are no practical interventions that will speed it up.
 4. Accumulation of acetaldehyde depends on the activity of ADH and ALDH.
 5. Over time increased alcohol intake increases the MEOS pathway, metabolizing alcohol more efficiently and slowing the rise of blood alcohol levels.
 6. When alcohol and drugs broken down by the MEOS system are taken together, the alcohol is prioritized and the drugs circulate in the bloodstream, intensifying their effects.
 7. Alcohol awaiting oxidation is distributed equally in body fluids and tissue spaces, and about 10% is excreted through urine, breath, and sweat.

Key Terms: alcohol dehydrogenase (ADH), aldehyde dehydrogenase (ALDH), microsomal ethanol oxidizing system (MEOS)

Figures:

Figure 7.21: Pathways of alcohol metabolism

Figure 7.22: Effect of alcohol on blood alcohol concentration (BAC) and driving behavior.

VII. How Is Energy Stored?

- A.** The energy of dietary glucose is stored as muscle and liver glycogen.
 1. The amount of glycogen stored depends on carbohydrate intake and individual size.
 2. Glycogen stores are quickly depleted when carbohydrate intake is low and when physical activity is high.
- B.** The energy of dietary triglycerides is stored as adipose tissue.
 1. Conversion of dietary fat to body fat is efficient and requires little energy or change in structure.
 2. Storing carbohydrate as fat is less efficient, so the body will oxidize dietary glucose over fat when both are present.
- C.** The energy of dietary proteins is found as circulating amino acids, which are limited.

Table:

Table 7.2: Body Energy Reserves of a Well-Nourished 70-kg* Male

VIII. How Are Key Nutrients Synthesized?

- A.** Gluconeogenesis is the synthesis of glucose.
 1. In the absence of dietary carbohydrate, liver glycogen sustains blood glucose for several hours.

2. Once glycogen is depleted, glucose is made from glucogenic amino acids and glycerol.
3. Gluconeogenesis maintains blood glucose during sleep, fasting, illness, and exercise.

B. Lipogenesis is the synthesis of fatty acids.

1. The process is also called *de novo* synthesis of fatty acids because it is the synthesis of new fatty acids from nonfat compounds.
2. Lipogenesis occurs in the cytosol of the liver.
3. Acetyl CoA units from glucose, ketogenic amino acids, and alcohol metabolism are reassembled into fatty acid chains.
4. Fatty acids then combine with glycerol to form triglycerides.
5. These triglycerides are released into the bloodstream as VLDLs until they are taken up by adipose tissue.

C. All cells can synthesize cholesterol.

1. The liver and intestine synthesize as much, or more, cholesterol than most people consume in their diet.
2. Cholesterol is synthesized from acetyl CoA produced during the metabolism of fatty acids, alcohol, ketogenic amino acids, and through pyruvate.

D. Amino acids are synthesized from carbohydrate- or fat-derived metabolites.

1. The amine group is donated through transamination.
2. Nonessential amino acids can be synthesized only when plenty of energy and nitrogen is available.

Key Terms: gluconeogenesis, lipogenesis, *de novo* synthesis

Figures:

Figure 7.23: Overview of gluconeogenesis.

Figure 7.24: Overview of lipogenesis.

Figure 7.25: Transamination and the synthesis of nonessential amino acids.

IX. What Hormones Regulate Metabolism?

A. Insulin, the primary anabolic hormone, activates storage enzymes and signals the cells.

1. Insulin signals the cells to take up glucose, fatty acids, and amino acids.
2. Insulin turns off catabolic processes in the body.

B. Glucagon, epinephrine, and cortisol are catabolic hormones.

1. Glucagon prompts the release of glucose from glycogen stores when blood glucose is low.
2. Epinephrine stimulates the breakdown of stored energy during exercise.
3. Cortisol stimulates catabolism of energy stores during times of physical and emotional stress.
 - a. When energy release is stimulated in physically inactive individuals, it increases abdominal fat stores and/or glucose intolerance.
4. Homeostasis requires a balance among metabolism-regulating hormones.

Table:

Table 7.3: Hormonal Regulation of Metabolism

X. How Do Feeding and Fasting Affect Metabolism?

- A. The fed state is generally an anabolic state.
 - 1. Excessive glucose is converted to glycogen until stores are saturated and the remainder is stored as fat.
 - 2. Fatty acids are combined with glycerol for storage as triglycerides.
 - 3. The liver converts amino acids to needed proteins, then deaminates the remainder for conversion to fatty acids.
- B. Metabolic responses to short-term fasting are catabolic.
 - 1. Liver glycogen is broken down to maintain blood glucose, but its supply is limited.
 - 2. Most cells can switch to fatty acids for fuel, reserving blood glucose for brain and glucose-reliant cells.
 - 3. As the carbohydrate-deprived state continues, ketones accumulate.
 - 4. The more prolonged the fasting, the greater the rate of gluconeogenesis.
- C. Metabolic responses to prolonged starvation result in dramatic bodily changes.
 - 1. During survival mode, the body attempts to meet energy demand and maintain glucose levels while preserving muscle and maintaining brain and immune function.
 - 2. As voluntary physical activity declines, body temperature and resting metabolic rate also fall.
 - 3. Cells shift to fatty acids as their primary fuel source, and the brain uses ketones as fuel.
 - 4. Glucose is derived from glycerol and glucogenic amino acids, which sacrifices muscle protein.
 - 5. Over time, fat stores are depleted, muscle becomes a major source of fuel, and the immune system is sacrificed.
 - 6. Healthy adults will survive for one to three months of fasting in the presence of water, but both environmental and physical conditions affect survival of starvation.

Figures:

Figure 7.26a: Metabolic Responses to Feeding

Figure 7.26b: Metabolic Responses to Fasting

Activities

- 1. There are a number of animations of the metabolic pathways of energy that help students visualize the process. Teachers Domain offers several lessons on energy metabolism that include audio-visual aids that you may use in the classroom for no charge. You will be required to register, but there is no obligation. The Web address is: pbslearningmedia.org.
- 2. Print the various terms related to each metabolic pathway on index cards (you will need to print more than one card for terms that appear in each of the pathways, such as acetyl CoA, FAD, etc.). Give each student one card. Instruct students with terms involved in a specific pathway to form a group. Working as a group, instruct students to reproduce the pathway verbally or dramatically to explain the process to the rest of the class. All of the terms must be used in the explanation. The more descriptive and visual you make the explanation, the easier it will be to recall.

3. Students often find it difficult to learn energy metabolism because they do not understand its relevance for practical application. Allow students to brainstorm instances where their knowledge of energy metabolism will be useful. You might use this analogy: Computer technical supporters must understand the inner workings of the hardware and software they support; however, they do not explain this knowledge to you when they help you solve your computer problem. The better the students understand how they can use the information, the more likely they will be to learn it.
4. Have students investigate the energy supplements that are available on the market. As they research, they should look for the terms that are specific to this chapter. Do any of these substances actually have potential to increase energy production taken in supplemental form? Is there faulty logic in the rationale? What entices people to purchase these products?

Diet Analysis Activity

5. Because this chapter does not relate closely to food choices, this may be a good time to have students reevaluate their diets. Ask students to keep track of everything they eat for three typical days, and enter this information in their nutrition software program. Then have them compare their current analysis to their first analysis.
 - a. Did you improve, digress, or stay the same in most areas?
 - b. How did your intake of carbohydrates, fat, and protein change?
 - c. What changes in your eating habits contributed to the changes?
 - d. What changes could you make to further improve your eating habits?

Nutrition Debate Activity

6. Debate the following questions about energy drinks and “energy shots”: Do these products provide a valuable source of energy? Should these products be used by athletes? Should they be allowed or banned by athletic organizations? Should the manufacturers be allowed to advertise as they do? Is a zero-Calorie energy drink falsely advertising or misleading the consumer?

Web Resources

Nutrition and Metabolism

www.nutritionandmetabolism.com
