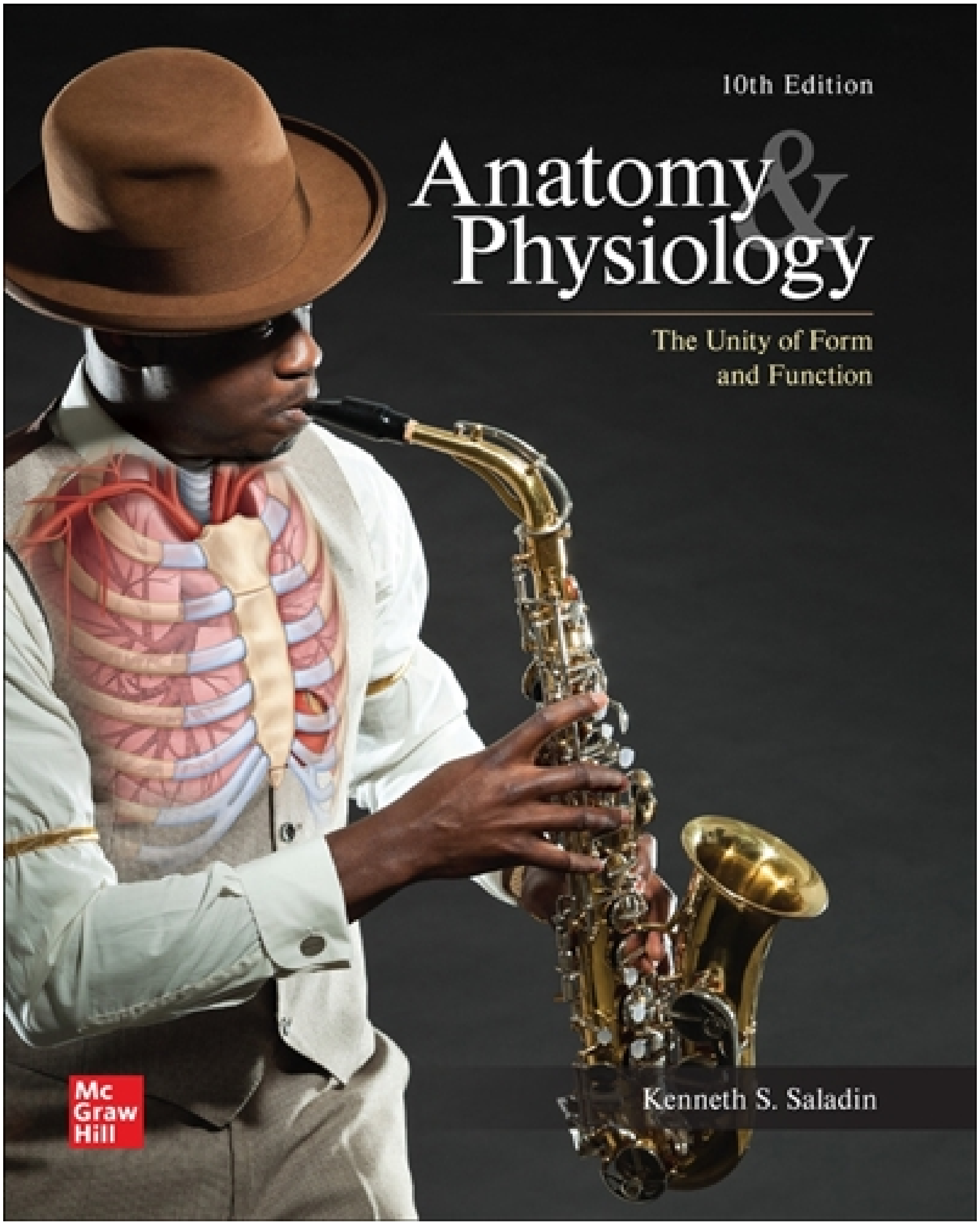
Solutions for Anatomy & Physiology The Unity of Form and Function 10th Edition by Saladin

CLICK HERE TO ACCESS COMPLETE Solutions



Solutions

2 Diagnosing a Disease

Objectives

In this chapter we will study

- the thought process and procedures involved in clinical diagnosis;
- methods used in the physical examination of a patient;
- common diagnostic tests performed in the laboratory;
- common diagnostic tests performed on the living body;
- some signs of disease; and
- some terms and abbreviations for diseases and diagnostic tests.

Medical Diagnosis

In chapter 1 of this manual, we examined some characteristics of disease. Now we turn our attention to some of the ways a clinician **diagnoses** a disease. The word *diagnose* literally means "to know through"—that is, how a clinician can know, through examination of the patient's signs and symptoms, what the underlying cause is. This chapter describes some of the processes and medical terminology associated with determining a diagnosis.

The diagnosis of a medical condition by a clinician generally involves first performing a history evaluation following by a physical examination. Based on the history and physical examination, a list of possible diagnosis, termed the differential diagnosis is made. Selective laboratory tests are then ordered to rule in or out the various list of diseases on the differential diagnosis; hopefully a single diagnosis can be determined. However, sometimes the patient's condition involves more than one disease. After a determination of the disease or diseases, a treatment plan is determined.

The write-up of the history portion of the patient evaluation generally follows the following order: Chief Complaint, History of Present Illness, Past Medical History, Family History, Social History, and Review of Organ Systems.

The Chief Complaint

Diseases are sometimes discovered when patients report for routine medical checkups. Some diseases are **asymptomatic**—they do not produce any discomfort. For example, hypertension (high blood pressure) is nicknamed "the silent killer" because it typically does not produce noticeable symptoms until the damage is already extensive. Since a blood pressure measurement is one of the routine procedures in a medical examination, it may reveal hypertension of which the patient is unaware.

Often, however, a patient **presents** him- or herself at a clinic because he or she feels that something is wrong. The patient's primary medical concern is called the **chief complaint (CC).** When a CC is identified, the search begins for the underlying etiology. The clinician then becomes a medical detective, bent on identifying the culprit so that it can be treated.

Diagnosis as Hypothesis Testing

The process of diagnosis is an application of the *hypothetico-deductive* scientific method. The clinician formulates hypotheses ("These signs could be caused by⋯") and then embarks on a search for evidence that either supports or rules out each hypothesis.

The first few symptoms the patient reports and the first few signs the clinician observes may lend themselves to multiple interpretations—that is, the cause could be any number of things. For example, the patient may complain of leg pain. This could have a musculoskeletal, neurological, or cardiovascular etiology. The clinician's task is to ask the appropriate questions and observe the appropriate signs to support one of these hypotheses and rule out the others. Are the ankles swollen? This could indicate a cardiovascular problem. Do the patient's joints hurt when he or she moves? This could indicate a musculoskeletal disorder. Does the patient feel pain shooting down the back of the leg? This could indicate a neurological disorder. The clinician can then ask further questions during the interview to progressively narrow down the possibilities: Where is the pain? What is it like? How bad is it? How often does it occur? How long does it last? When does it occur? Is it worse at night; when the patient is at work; when he or she climbs stairs? What factors make the pain better or worse? Has the patient tried analgesics or any other remedy for the pain?

Diagnosis, then, is essentially a process of elimination in which more and more evidence is gathered, alternative hypotheses are discarded when inconsistent with the evidence, and eventually a hypothesis emerges that is supported by the preponderance of evidence.

The Process of Diagnosis

The diagnostic process is commonly described as having four main steps, although they overlap somewhat, and steps 3 and 4 are not always necessary.

1. Medical History

The clinician begins by obtaining and recording the patient's **medical history.** This includes **identifying data** (name, address, date of birth, sex, family composition, and occupation); the nature of the chief complaint; the symptoms and their duration; medications or other treatments tried so far; a **family history** (for example, whether any of the patient's close relatives have diabetes, heart disease, cancer, or high blood pressure); and a review of the organ systems other than the one that is the focus of the complaint (How is your hearing? Do you have any trouble breathing? How is your digestion? and so on).

An important part of physician training is the development of good interviewing skills. The physician must be a good listener—able to put the patient at ease, ask the right questions, think analytically about the patient's responses, and adapt his or her approach to the age, sex, education, cultural background, and values of the patient.

2. *Physical Examination*

After this talk with the patient, the clinician carries out a physical examination that involves inspecting the patient's body. The physical examination is also called a **gross examination** because it involves only gross anatomy (that which is visible without magnification). There are several aspects to the physical examination:

Vital Signs Before a patient sees the physician, a nurse typically records the patient's height, weight, and **vital signs:** temperature, heart (pulse) rate, respiratory rate, and blood pressure. The normal ranges of these vital signs are given in the Appendix of Normal Values at the end of this manual. This information is useful not only for assessing the patient's body proportions (whether a patient is underweight, overweight, or obese, for example), but also for determining the proper dosage of some medications.

Inspection The clinician makes note of what can be visually observed about the patient. To some extent, this begins during the interview. While taking the history, the clinician can observe the patient's posture, gait, body proportions, and skin condition (color, texture, and moisture). If the patient has a medical complaint, the relevant area of the body is observed especially closely.

Palpation The clinician touches or presses on the body surface with the fingertips or palmar surface of the fingers and hands. This procedure provides information about body surface temperature, turgor (firmness of the skin), texture, moisture, shape, and vibrations. There are specific techniques for properly palpating different regions of the body, such as the neck, abdomen, breasts, prostate gland, and joints.

Percussion The clinician places the distal segment of the middle finger of one hand on an area such as the chest or abdomen and strikes it sharply with the middle fingertip of the other hand. This produces a vibration and sound. Clinicians are trained to recognize five different tones (*percussion notes*)—called flatness, dullness, resonance, hyperresonance, and tympany—that give information about the density of tissues, accumulations of air, fluid, or scar tissue, and other normal and abnormal conditions.

Auscultation The clinician listens, usually with a stethoscope, to sounds produced by the body, especially respiratory and cardiac sounds. Qualities to note include the pitch, intensity, and duration of the sound, as well as any added, abnormal sounds such as wheezes or heart murmurs.

As you can see, a thorough physical examination requires the examiner to use his or her senses of vision, hearing, touch, and smell. In addition, clinicians use a variety of instruments to enhance their powers of observation. Besides the *stethoscope,* used for listening to sounds of the heart, lungs, and abdominal cavity, these include the *sphygmomanometer* for measuring blood pressure; the *otoscope* and *ophthalmoscope* for viewing the inside of the auditory canal and eye, respectively; the *vaginal speculum* for examining the vagina and cervix; the *percussion hammer* for testing reflexes; and a *tuning fork* for producing the pure tone used in tests of hearing.

The physical examination may provide enough information to diagnose some conditions, but in other cases it only narrows the possibilities to a **preliminary diagnosis.** Further tests may be required, which leads us to step 3.

3. *Laboratory Tests*

Because medical diagnosis often requires knowledge of the current and recent physiological activity of the tissues, a very common step in diagnosis is the performance of laboratory tests on fluid or tissue specimens obtained from the patient. It should be noted here that, although the physician may recommend further tests, the patient has the right to refuse to have them done.

No two fluids are as valuable to diagnosis as blood and urine. For example, if a patient complains of insatiable thirst and hunger and frequent urination, he or she seems likely to have diabetes mellitus. However, laboratory blood and urine tests are needed to confirm that diagnosis.

Blood Tests The blood mediates exchanges between nearly all of the body's tissues and the external environment. It has such a central importance that a great range of diseases are diagnosed (or first discovered, as in the case of asymptomatic diseases) with the aid of data obtained from the blood. The diagnostic examination of the blood is called **clinical hematology.** Some blood tests include red cell (RBC), white cell (WBC), and platelet counts; a differential white cell count (relative numbers of the different classes of white blood cells); the red cell fragility test; bleeding and coagulation (clotting) times; blood gas measurements; hormone, enzyme, and cholesterol levels; hemoglobin concentration; ABO and Rh blood typing; and blood urea nitrogen (BUN) level, a measure of how well the kidneys are clearing metabolic wastes from the blood.

A **complete blood count (CBC)** includes the total and differential WBC counts, RBC count, hematocrit (percent of the blood composed of RBCs), hemoglobin concentration, and platelet count. A CBC provides valuable information for diagnosing infections, allergies, inflammation, bone marrow failure, anemia, leukemia, sickle-cell disease, infectious mononucleosis, and many other conditions.

The concentrations of hormones, enzymes, cholesterol, and other blood components are often expressed in terms of quantities in blood serum. **Serum** is produced by separating the blood plasma from the cellular components, letting the plasma coagulate (clot), and then removing the coagulated protein.

Urinalysis In addition to blood work, **urinalysis (U/A)** is an important part of routine examinations and diagnostic sleuthing. Among the properties examined in urinalysis are urine color and odor, pH, specific gravity (a measure of its concentration of solids), and tests for the presence of blood, pus, protein, glucose, sodium chloride, urates, and phosphates. Disease is indicated by the presence of substances that do not normally appear in the urine, such as protein (*proteinuria*), blood (*hematuria*), ketones, glucose (*glucosuria*), (*ketonuria*), or pus (*pyuria*).

Other Common Tests Besides blood and urine, other specimens often examined include throat swabs, which are cultured to check for *Streptococcus* ("strep") or other infectious organisms; sputum, the mixture of mucus and other matter that is coughed or spit up; semen, which is examined for sperm count, sperm motility, and sperm morphology in tests for infertility; and feces (stool samples), which are examined for parasites or blood (a possible indication of colon cancer or polyps).

The removal and microscopic examination of living tissue from a patient is called a **biopsy.** A relatively simple and common biopsy is the **Pap smear,** in which cells are scraped from the uterine cervix and examined for signs of cervical cancer. A **shave biopsy (skin scrapings)** may be used to diagnose infestations by fungi, mange mites, or other pathogens. **Needle biopsy,** in which small bits of tissue are withdrawn through a needle, is used to test for muscle diseases and to sample tumors to test for malignancy.

Aspiration is the removal of a body fluid (liquid or air) or tissue (bone marrow) by suction through a puncture in the body wall. It is performed either for diagnostic purposes or to relieve pressure and other pathologic conditions. The suffix *–centesis* denotes a puncture of the body wall made for such purposes as aspiration. Thus, **spinocentesis (lumbar puncture, spinal tap)** is the sampling of cerebrospinal fluid from a membranous sac below the spinal cord; **thoracocentesis** is the aspiration of fluid or air from the pleural cavity; **paracentesis** is the aspiration of fluid from any body cavity, especially the abdomen; and **amniocentesis** is the aspiration of amniotic fluid from the pregnant uterus, usually to check for genetic defects in the fetus.

4. Tests Performed on the Body Itself

Many tests are performed directly on the patient rather than on materials removed from the body. Among these procedures are medical imaging, endoscopy, and electrophysiological techniques.

Medical Imaging In the past, it was common to perform **exploratory surgery**—to open the body and take a look inside to determine what was wrong with a patient. Now, however, this practice has become less common with the invention of several methods of *noninvasive imaging,* techniques for obtaining an image of the inside of the body without having to open a body cavity. These methods include radiography, sonography, computed tomography (CT) scans, magnetic resonance imaging (MRI), and positron emission tomography (PET) scans. Other noninvasive methods of imaging are also available, many of them specialized for certain branches of medicine, such as cardiology.

Endoscopy Endoscopy is the viewing of the interior of a hollow organ or canal with an **endoscope.** The endoscope is a narrow instrument with a light at its tip to illuminate the organ. It may be designed for direct visual examination of the passage, or it may have an optic fiber connected to a video camera and monitor outside the patient. A *bronchoscope* is an endoscope for examining the bronchial tree of the lungs; a *sigmoidoscope* is used for inspecting the lower colon; an *arthroscope* is used for examining joint cavities; and a *laparoscope* is an endoscope for viewing the abdominal cavity. In addition to simply viewing the interior of an organ, endoscopy is used for biopsies and removing foreign bodies. A number of surgical procedures are now performed by endoscopy, ranging from the repair of knee injuries to appendectomies. Endoscopic surgery requires only a few small incisions for the insertion of the endoscope and surgical instruments.

Electrophysiological Techniques Nervous and muscular tissues generate electrical currents through their actions. These currents are conducted to the skin surface, where they can be picked up by metal plate electrodes placed on the skin and connected to a recording device. Three common electrophysiological recording methods are **electrocardiography (ECG),** the recording of the electrical activity of the heart; **electroencephalography (EEG),** the recording of electrical brain waves; and **electromyography (EMG),** the recording of electrical activity associated with muscle contraction.

Final Diagnosis

When sufficient information has been collected, the ideal result is a **final diagnosis** of the apparent cause of the disease. When the preliminary diagnosis indicates that two or more similar diseases may be responsible for a patient's condition, and the choice between them is reached through further testing, the final diagnosis is called a **differential diagnosis.** From the final diagnosis, the clinician can offer a **prognosis** (the predicted course and outcome of the disease) and formulate a plan of treatment.

Terminology of Clinical Conditions, Signs, and Symptoms

The health professions, like most others, have a specialized vocabulary. Not only must physicians, nurses, therapists, and other health-care providers be familiar with the common terms and abbreviations used in medicine, but so must people in other professions, such as medical transcriptionists, attorneys, and health insurance claims analysts. Table 2.1 lists some common word roots, prefixes, and suffixes that denote clinical conditions and their signs and symptoms. Becoming familiar with the meanings of these word parts will help you not only to remember them but also to figure out the meanings of other similar words that you encounter in the future. Table 2.2 lists common abbreviations for clinical conditions, and table 2.3 lists some abbreviations used in patient records.

Table 2.1 Word Elements Denoting Clinical Conditions, Signs, and Symptoms

Root, Prefix, or Suffix	Meaning	Example and Definition
-agra	Intense pain	Pellagra (severe vitamin C deficiency)
-algesia	Pain	Analgesia (relief from pain)
-algia	Pain, ache	Neuralgia (nerve pain)
-asthenia	Weakness	Myasthenia (muscle weakness)
brady-	Slow	Bradycardia (abnormally slow heartbeat)
carcino-	Cancer	Carcinoma (malignant tumor)
-cele	Hernia	Omphalocele (herniated umbilicus)
-cyesis	Pregnancy	Salpingocyesis (tubal pregnancy)
-dynia	Pain, ache	Odontodynia (toothache)
dys-	Abnormal, bad, difficult	Dyspnea (difficulty breathing)
-ectasis	Dilation, stretching	Bronchiectasis (dilation of the bronchi)
-emesis	Vomiting	Hematemesis (vomiting blood)
febri-	Fever	Febrile (feverish)
hyper-	Above normal	Hypertension (high blood pressure)
hypo-	Below normal	Hyponatremia (blood sodium deficiency)
-ia	Condition	Arrhythmia (irregular heart rhythm)
-iasis	Presence of	Cholelithiasis (gallstones)
-ism	Process, condition	Hyperthyroidism (overactive thyroid gland)
-itis	Inflammation	Cystitis (bladder inflammation)
-lepsy	Seizure	Narcolepsy (a sleep disorder)
-malacia	Abnormal softening	Osteomalacia (softening of bones)
-megaly	Abnormal enlargement	Hepatomegaly (enlarged liver)
-oma	Tumor	Osteosarcoma (bone tumor)
onco-	Tumor	Oncogenic (producing tumors)
-osis	Condition	Thrombosis (abnormal blood clotting)
-osis	Increase	Leukocytosis (elevated white blood cell count)
-paresis	Slight paralysis	Hemiparesis (partial paralysis on one side)
-pathy	Disease	Neuropathy (disease of the nervous system)
-penia	Deficiency	Thrombocytopenia (platelet deficiency)
-phobia	Morbid fear	Acrophobia (abnormal fear of heights)
-phoria	Feeling, mental state	Euphoria (feeling unusually good)
-plasia	Formation	Neoplasia (growth of new tissue)
-plegia	Paralysis	Quadriplegia (paralysis of all four limbs)
-porosis	Becoming porous	Osteoporosis (loss of bone tissue)
-ptosis	Sagging, prolapse	Hysteroptosis (prolapse of uterus into vagina)
-ptysis	Spitting up	Hemoptysis (spitting up blood)
pyro-	Fever	Antipyretic (fever-reducing drug)
-rhage	Excessive discharge	Hemorrhage (excessive bleeding)
-rhea	Discharge, flow	Amenorrhea (cessation of menstrual periods)
-rhexis	Rupture, split	Cystorrhexis (ruptured urinary bladder)
-sclerosis	Hardening	Arteriosclerosis (hardening of the arteries)
sepso-	Infection	Sepsis (infection)
septico-	Infection	Septicemia (bacteria in the blood)
-spasm	Twitch, cramp	Phrenospasm (spasms of the diaphragm—hiccups)
-stenosis	Narrowing	Mitral stenosis (narrowing of heart valve)
tachy-	Fast	Tachypnea (abnormally rapid breathing)
terato-	Monster, birth defect	Teratogenic (producing birth defects)
-tocia	Childbirth, labor	Oxytocin (labor-inducing hormone)

Table 2.2 Abbreviations for Clinical Conditions

AD	Alzheimer disease	HVD	Hypertensive vascular disease
AIDS	Acquired immunodeficiency syndrome	MD	Muscular dystrophy
ASHD	Atherosclerotic heart disease	MI	Myocardial infarction
CA	Cancer	MS	Multiple sclerosis
CF	Cystic fibrosis	OA	Osteoarthritis
CHF	Congestive heart failure	PID	Pelvic inflammatory disease
COPD	Chronic obstructive pulmonary diseases	PKU	Phenylketonuria
CVA	Cerebrovascular accident (stroke)	PMF	Progressive massive fibrosis (of lungs)
DM	Diabetes mellitus	RA	Rheumatoid arthritis
DT	Delirium tremens	SIDS	Sudden infant death syndrome
FUO	Fever of undetermined origin	SLE	Systemic lupus erythematosus
Fx	Fracture	SOB	Shortness of breath
GC	Gonococcus (gonorrhea)	STD	Sexually transmitted disease
GI	Gastrointestinal (conditions)	TB	Tuberculosis
GU	Genitourinary (conditions)	TIA	Transient ischemic attack
HDN	Hemolytic disease of the newborn	URI	Upper respiratory infection
HIV	Human immunodeficiency virus	UTI	Urinary tract infection

Table 2.3 Abbreviations Used in Medical Records

A&P	Auscultation and percussion	Hx	Medical history
BMR	Basal metabolic rate	I&O	Intake and output
BP	Blood pressure	IVP	Intravenous pyelogram
BUN	Blood urea nitrogen	LMP	Last menstrual period
Bx	Biopsy	NPO	Nothing by mouth (*nil per os*)
CBC	Complete blood count	OV	Office visit
CPR	Cardiopulmonary resuscitation	Para 1, 2, 3	Number of live births
CXR	Chest X ray	PE	Physical examination
D&C	Dilation and curettage	p/o	Postoperative
DOA	Dead on arrival	pre-op	Preoperative
DOB	Date of birth	pt	Patient
Dx	Diagnosis	ROM	Range of motion of a joint
FBS	Fasting blood sugar	Rx	Treatment, therapy
FH	Family history	stat.	Immediately (*statim*)
GB	Gallbladder	Sx	Symptoms
GI	Gastrointestinal (conditions)	T	Temperature
GTT	Glucose tolerance test	T&A	Tonsillectomy and adenoidectomy
GU	Genitourinary (conditions)	Tx	Treatment
Hb, Hgb	Hemoglobin	U/A	Urinalysis
HCT	Hematocrit	VS	Vital signs
h/o	History of	y/o	Year old

Case Study 2 The female with severe tiredness

Jane is a 22- year- old female that is experiencing severe tiredness and dizziness on standing which started 6 weeks prior. This brought her to her doctor's office. Jane states that she during the month of January 2020 traveled to China. Jane states that sometimes she has heavy menstrual periods. She does occasionally have an alcoholic beverage, and occasionally smokes a cigarette. She has suffered anemia on one occasion in the past. She did have an ovarian cyst removal one year prior and does take antihypertensive medications. Her mother has diabetes and hypertension. Jane is allergic to tomatoes. The clinician asks Jane about various conditions associated with numerous body organs and systems; she responds that she remembers she does have a nasal septal defect. Jane's physical exam is unremarkable except for a somewhat low blood pressure (90/60), slight pallor of the palms, and slightly fast heart rate. Her pulse is fast and slightly weak. Jane's breath and heart sounds are normal. The clinician orders several lab tests to rule in or out certain diseases. A CBC is taken and it shows a decreased hemoglobin and red blood cell level. A urinalysis is also performed. Her blood glucose level is checked and is normal. The chest X-ray is normal and her EKG is normal except for showing a fast heart rate. Serum tests for iron, Epstein Barr Virus and Coronavirus are performed.

Critically analyze this clinical presentation using your knowledge of human physiology. Answer the questions below and be able to explain the rationale for your answers.

1. What are Jane's symptoms that suggest she may have an illness?
2. What is Jane's chief complaint?
3. Carefully read the patient presentation and list factors that could contribute to her tiredness and dizziness. Be able to explain the physiological reasoning behind her tiredness and dizziness on standing.
4. What risk factors could contribute to her condition?
5. What is the term for the upper blood pressure number; 90 in the case of Jane. What is the term for the lower blood pressure number? What stage(s) of the cardiac cycle are represented by the upper and lower blood pressure numbers?
6. Of the four physical examination techniques, which is generally used to check a person's pulse?
7. Of the four physical examination techniques, which is used to check a person's breath and heart sounds?
8. What lab test was performed to determine Jane's blood cell count and hemoglobin level?
9. What could be the significance of noting that Jane has heavy menstrual periods?
10. Explain the physiology of a faster heart rate with a reduced blood volume.

Activity

Obtain a history on an individual as shown in this clinical application chapter. Write the history in the format described. On the same individual perform a blood pressure check and obtain a pulse rate. Listen to the person's heart sounds and breath sounds. With available equipment, perform an EKG. Using the EKG tracing, determine the person's heart rate. Compare that EKG heart rate to the heart rate obtained from the physical exam.

Selected Clinical Terms

aspiration The removal of tissue, fluid, or air from the body by suction, either to relieve a pathologic state (such as fluid pressure) or to obtain samples for diagnostic examination.

asymptomatic Lacking symptoms even when disease is present.

biopsy The removal and microscopic examination of a sample of living tissue for diagnostic purposes.

chief complaint (CC) The primary reason a patient presents him- or herself for examination or treatment; the major abnormality of structure or function noticed by the patient.

clinical hematology Diagnostic examination of the blood to help assess a person's health or diagnose an illness.

diagnosis Identification of the cause of illness through such methods as the patient interview, physical examination, and laboratory tests.

endoscopy Viewing the interior of the body with a viewing instrument called an endoscope.

medical history A report on a patient that includes identifying data, family medical data, and other information gained through the patient interview.

prognosis Prediction of the course and outcome of a disease as a basis for patient care and treatment.

urinalysis (U/A) Diagnostic examination of the urine to help assess a person's health or diagnose an illness.

vital signs A person's temperature, heart rate, respiratory rate, and blood pressure.

Saladin, A&P, Extended Chapter Outline

Chapter 2 The Chemistry of Life

I. Atoms, Ions, and Molecules

A. A chemical element is the simplest form of matter to have unique chemical properties.

1. Each element is identified by an *atomic number*.

2. The elements are represented by one- or two-letter symbols based on their English or sometimes Latin names.

3. There are 91 naturally occurring elements.

a. Twenty-four elements play normal physiological roles in the human body.

i. Six elements account for 98.5% of the body's weight: oxygen, carbon, hydrogen, nitrogen, calcium, and phosphorus.

ii. Another 6 elements make up 0.8%: sulfur, potassium, sodium, chlorine, magnesium, and iron.

iii. The remaining 12 elements are known as trace elements and make up 0.7% of the body's weight.

b. Other elements that do not have physiological roles can contaminate and disrupt the body's functions, such as the heavy metals.

4. Minerals are inorganic elements extracted from soil and passed up the food chain to humans.

a. Minerals constitute 4% of the body's weight. Nearly 3/4 is calcium and phosphorous, and the rest is made up of chlorine, magnesium, potassium, sodium, and sulfur.

b. Minerals contribute to body structures.

i. Bones and teeth are composed, in part, of crystals of minerals.

ii. Minerals such as phosphorus and sulfur are major components of nucleic acids, ATP, proteins, and cell membranes.

c. Minerals also enable enzyme function.

d. Mineral salts, or electrolytes, are vital to nerve and muscle function.

B. The Greek philosopher Democritus, in the fifth century BCE, was the first to use the term *atom* for particles so small that they were indivisible. John Dalton, in 1803, proposed an atomic theory of matter, and Niels Bohr, in 1913, proposed a model of structure.

1. The nucleus of an atom is composed of protons and neutrons.

a. Protons have a positive electrical charge, whereas neutrons have no charge.

b. The *atomic mass* of protons and neutrons is 1 amu (*atomic mass unit*); the atomic mass of an element is the total of its protons and neutrons.

2. Electrons surround the nucleus in concentric clouds.

a. Electrons have a negative electrical charge.

b. The atomic mass of electrons is negligible and therefore not considered in an element's atomic mass.

c. The number of electrons is equal to the number of protons, so an atom is electrically neutral.

3. Electrons swarm about the nucleus in regions called *electron shells* or *energy levels.*

a. Shells hold a limited number of electrons; the one closest to the nucleus contains a maximum of 2, the next a maximum of 8, and the third a maximum of 18.

b. The known elements do not exceed seven electron shells, but the elements involved in physiology do not exceed four.

4. The electrons of the outermost shell are called valence electrons.

a. The valence electrons determine chemical bonding properties of an element.

b. An atom tends to bond with other atoms that will fill its outer shell and produce a stable number of valence electrons.

C. All elements have varieties called isotopes, which differ from one another in the number of neutrons the atom contains.

Insight 2.1 Medical History: Radiation and Madame Curie

1. Hydrogen, which normally has a single proton, has two isotopes: *deuterium* with one proton and one neutron, and *tritium* with one proton and two neutrons.

2. The *atomic weight* of an element is the sum of the mixture of isotopes of that element that occurs in nature. The atomic weight of carbon is 12.011.

3. Some isotopes are unstable and *decay* (break down) into stable isotopes, giving off radiation. These are called radioisotopes, and the process of decay is called radioactivity.

4. Some forms of radiation are harmless, such as light and radio waves, but high-energy radiation, or ionizing radiation, destroys molecules and tissues.

5. In high doses, ionizing radiation is fatal; in low doses, it can be *mutagenic* (causing DNA mutations) or *carcinogenic* (triggering cancerous changes in cells).

a. Examples of radiation include ultraviolet rays, X-rays, and three kinds of additional radiation caused by decay: *alpha particles, beta particles,* and *gamma rays.*

i. An alpha particle is composed of two protons and two neutrons and does not penetrate deeply; however, alpha particle emitters are dangerous if they enter the body.

ii. A beta particle is a free electron and also does not penetrate deeply, but can be dangerous if emitted inside the body.

iii. Gamma rays have high energy, are deeply penetrating, and can be dangerous even if emitted outside the body.

6. The physical half-life of an isotope is the time required for 50% of its atoms to decay.

a. Nuclear plants produce hundreds of radioisotopes that will be radioactive beyond the life of any disposal container.

7. The biological half-life of an isotope is the time required for half of it to disappear from the body.

a. The biological half-life depends on both physical decay and physiological clearing.

b. Cesium-137 has a physical half-life of 30 years but a biological half-life of 17 days.

8. Intensity of ionizing radiation is measured in *sieverts (Sv);* a dosage of 5 Sv or more is usually fatal.

a. Americans receive about 2.4 millisieverts (mSv) per year in *background radiation* and another 0.6 mSv from artificial sources, including medical X-rays, radiation therapy, color televisions, smoke detectors, etc.

b. A limit of 50 mSv per year is considered acceptable occupational exposure.

D. Ions are charged particles with unequal numbers of protons and electrons.

1. *Ionization* occurs when an element gives up electrons or gains electrons in its outer shell.

2. An anion has a negative charge; a cation has a positive charge.

a. In sodium chloride, NaCl, sodium has 1 electron in its outer shell, which it gives up. Chlorine has 7 electrons in its outer shell, and gaining an electron from sodium fills its outer shell.

b. Some elements, such as iron, have two or more ionized forms; for example, ferrous (Fe^{2+}) and ferric (Fe^{3+}).

c. Molecules may also be ions; for example, phosphate (PO_4^{3-}) and bicarbonate (HCO_3^-).

3. Physiologically, ions with opposite charges tend to follow each other through the body. When sodium is excreted in the urine, chlorine tends to follow it.

4. Electrolytes are salts that ionize in water, forming solutions that can conduct electricity.

a. Electrolytes are important for their chemical reactivity, osmotic effects, and electrical effects.

b. Electrolyte balance is one of the most important considerations in patient care.

5. Free radicals are chemical particles with an odd number of electrons, such as the *superoxide anion*, O_2^{-}•.

a. Free radicals are produced by some metabolic reactions, by radiation, and by chemicals such as nitrites.

b. Free radicals have short lives because they are unstable and combine with other molecules, creating free-radical chain reactions and damaging tissues.

c. Antioxidants are chemicals that neutralize free radicals, such as the enzyme *superoxide dismutase*. Dietary antioxidants include vitamins C and E, β-carotene, and selenium.

E. Molecules are chemical particles composed of two or more atoms united by a chemical bond.

1. Molecules composed of two or more different elements are called compounds. O_2 is a molecule but not a compound; CO_2 is a compound.

2. Molecules can be represented by a *molecular formula* or by a *structural formula*.

a. Molecules with the same molecular formula but different arrangements of atoms are called isomers.

b. Structural formulas differentiate isomers.

3. The molecular weight of a compound is the sum of the atomic weights of its atoms.

4. Chemical bonds hold molecules together and include *ionic bonds*, *covalent bonds*, *hydrogen bonds*, and *van der Waals forces*.

a. An ionic bond is the attraction of a cation to an anion, as in NaCl.

i. Ionic bonds can be formed by more than two ions, as in $CaCl_2$.

b. Ionic bonds are weak and easily dissociate in the presence of more attractive molecules, such as in water.

c. A covalent bond forms by the sharing of electrons between two atoms.

i. A *single covalent bond* is the sharing of a single pair of electrons; a *double covalent bond* is the sharing of two pairs of electrons.

ii. When shared electrons spend approximately equal time around each nucleus, the result is a *nonpolar covalent bond*.

iii. When shared electrons spend more time around one nucleus, they form a *polar covalent bond* that results in a small charge difference between different regions of the molecule. This is represented as δ– and δ+.

5. A hydrogen bond is a weak attraction between a slightly positive hydrogen atom in one molecule and a slightly negative oxygen or nitrogen atom in another.

a. Water molecules form hydrogen bonds with each other.

b. Hydrogen bonds may form between different regions of a single large molecule, as in protein and DNA molecules.

c. Hydrogen bonds are extremely important in physiology.

6. Van der Waals forces are weak, brief attractions between neutral atoms caused by random fluctuations in electron orbits.

a. Van der Waals attractions are at work when plastic wrap clings, spiders walk across ceilings, etc.

b. Van der Waals attraction also plays a role in protein folding and binding.

II. Water and Mixtures

A. A mixture consists of substances that are physically blended but not chemically combined.

B. Most mixtures in the body consist of chemicals dissolved in water.

1. Water constitutes 50% to 75% of our body weight.

2. Two aspects of its structure are important: Its atoms are joined by polar covalent bonds, and the molecule is V-shaped with a 105° bond angle.

a. The molecules are therefore polar and form hydrogen bonds.

b. This polarity gives water properties that account for its ability to support life: *solvency, cohesion, adhesion, chemical reactivity,* and *thermal stability*.

3. *Solvency* is the ability to dissolve other chemicals; water is sometimes called the *universal solvent.*

a. Substances that dissolve in water, such as sugar, are said to by hydrophilic.

b. Substances that do not dissolve in water, such as fats, are said to be hydrophobic.

c. To be soluble in water, a molecule must be polarized or charged.

i. When sodium chloride is dissolved in water, water molecules form a *hydration sphere* around each ion.

ii. The hydration spheres help keep the ions separated and dissolved.

4. *Adhesion* is the tendency of one substance to cling to another; *cohesion* is the tendency of a substance to cling to itself.

a. Water adheres to other substances, such as tissues of the body, and forms a lubricating film.

b. Water is also very cohesive and can form a surface film held together by *surface tension.*

5. Water participates in many chemical reactions because of its ability to ionize other chemicals and also because of its ability to become ionized itself.

6. Water has a high heat capacity, meaning that it can absorb energy without changing state.

a. Water's high heat capacity gives it *thermal stability*, which helps stabilize the body's internal temperature.

b. Water is also an effective coolant because it carries away so much heat energy when it evaporates.

C. Mixtures of substances in water can be classified as *solutions, colloids, and suspensions.*

1. A solution consists of particles of matter called a solute mixed with a more abundant substance, usually water, called a solvent.

a. Solute particles are under 1 nm in size.

b. Such small particles do not scatter light noticeably.

c. Solute particles will pass through most selectively permeable membranes.

d. The solute does not separate from the solvent when the solution is allowed to stand.

2. A colloid is a mixture of larger particles in a solvent, such as albumin in blood plasma.

a. Colloid particles range from 1 to 100 nm in size.

b. Particles this large scatter light, so colloids are usually cloudy.

c. The particles are too large to pass through most selectively permeable membranes.

d. The particles do remain permanently mixed, however, and do not separate from the solvent.

3. A suspension has large particles mixed in a solvent, such as red blood cells in blood plasma.

a. Suspended particles exceed 100 nm in size.

b. The suspension is cloudy or opaque.

c. The particles are too large to pass through selectively permeable membranes.

d. The particles do not remain permanently mixed, so suspensions separate upon standing.

4. An emulsion is a suspension of one liquid in another, such as an oil and vinegar salad dressing and breast milk.

5. Blood is an example of a mixture that fits in more than one category; it is a solution, a colloid, and a suspension.

D. Concentration is a measure of the amount of solute in a given volume of solution.

1. Weight per volume is a simple way to express concentration and is given in grams per liter of solution (g/L).

a. For biological purposes, milligrams per deciliter (mg/dL) is more often used.

2. Percentages are also used, but whether the percentage refers to weight or volume must be specified, e.g. 5% w/v (weight per volume), 70% v/v (volume per volume).

3. For physiological purposes, molarity is used.

a. Each molecule has a characteristic molecular weight, such as 180 for glucose and 342 for sucrose.

b. The molecular weight of a substance expressed in grams is termed 1 *mole* of that substance.

c. A mole of any substance contains the same number of molecules as a mole of any other substance, namely Avogadro's number (6.023×10^{23} molecules).

d. Molarity is the number of moles of a solute per liter of solution; a *one-molar* (1.0 M) solution of glucose contains 180 grams of glucose per liter.

i. In physiological solutions, clinicians and researchers usually work with *millimolar (mM)* and *micromolar (μM)* solutions.

4. Electrolyte concentrations are measured in terms of *equivalents (Eq)*.

a. One Eq of an electrolyte is defined as the amount that would electrically neutralize 1 mole of hydrogen ions (H^+) or hydroxide ions (OH^-).

b. Body fluids typically have low concentrations of electrolytes, so milliequivalents per liter (mEq/L) is more often used.

c. A relationship exists between molarity and equivalents, and it is based on the valence of the ion: A solution of 1 mM Na^+ is equal to 1mEq/L, whereas a solution of 1 mM Ca^{2+} is equal to 2 mEq/L.

E. An acid is any *proton donor,* that is, a molecule that releases H^+ in water. A base is a proton acceptor. (p. 51)

1. Acidity is expressed in terms of pH, which is derived from the molarity of H^+.

a. The pH scale is logarithmic, so that a change of one whole number on the scale represents a 10-fold change in H^+ concentration.

b. Slight disturbances of pH can disrupt physiological functions; larger deviations can even lead to death.

c. Buffers are chemical solutions that resist changes in pH.

Insight 2.2 Clinical Application: pH and Drug Action

III. Energy and Chemical Reactions

A. Energy is the capacity to do work. Work is the action of moving something, whether it is a muscle or a molecule.

1. Energy can be classified as *potential energy* or *kinetic energy*.

a. Potential energy is energy an object contains because of its position or internal state, but that is not doing work at the time.

b. Kinetic energy is the energy of motion, energy that is doing work.

c. Ions in greater concentration on one side of a membrane have potential energy. When the ions flow through to the other side, their kinetic energy is used to create an electrical signal.

2. *Chemical energy* is potential energy stored in the bonds of molecules.

3. *Heat* is the kinetic energy of molecular motion.

4. *Electromagnetic energy* is the kinetic energy of moving "packets" of energy called *photons.*

5. *Electrical energy* is both potential, as charged particles at a battery terminal, and kinetic, as when those particles begin to move and produce an electrical current.

6. Free energy is the potential energy available in a system to do work.

a. In human physiology, the most relevant free energy is stored in chemical bonds.

B. A chemical reaction is a process in which a covalent or ionic bond is formed or broken.

1. The course of a chemical reaction is symbolized by a chemical equation, with *reactants* on the left side and *products* on the right side.

2. Chemical reactions can be classified as *decomposition, synthesis,* or *exchange reactions.*

a. In decomposition reactions, a large molecule breaks down into two or more smaller ones, such as when starch is broken down into glucose.

b. In synthesis reactions, two or more small molecules combine to form a larger one, such as when the body synthesizes proteins.

c. In exchange reactions, two molecules exchange atoms or groups of atoms. Such a reaction would occur when sodium bicarbonate from the pancreas neutralizes hydrochloric acid in the stomach; sodium exchanges bicarbonate for chlorine.

3. Reversible reactions can go in either direction under different circumstances.

a. The direction in which a reversible reaction goes is determined by the relative abundance of substances on each side of the equation, and thus is an example of the law of mass action.

b. Reversible reactions exist in a state of equilibrium, in which the ratio of products to reactants is stable.

C. The rate of a reaction depends on the nature of the reactants and the frequency and force of collisions between molecules.

1. Reaction rates increase when the reactants are more concentrated and thus collide more frequently.
2. Reaction rates increase when the temperature rises because the molecules tend to move more rapidly and collide with greater force and frequency.
3. Reaction rates are increased by catalysts, substances that temporarily bind to reactants and hold them in a favorable position to react with each other.

D. All the chemical reactions that take place in the body are collectively termed metabolism, which can be subclassified as *catabolism* and *anabolism*.

1. Catabolism consists of energy-releasing decomposition reactions; such reactions are called *exergonic* reactions.
2. Anabolism consists of energy-storing synthesis reactions, such as the production of protein or fat. Such reactions require an input of energy and are called *endergonic* reactions.

E. Oxidation is any reaction in which a molecule gives up electrons and releases energy.

1. A molecule is *oxidized* (gives up electrons), and the molecule that takes electrons from it is called an *oxidizing agent* (electron acceptor).
2. Oxygen is often involved as the electron acceptor, but many oxidation reactions do not require oxygen, such as fermentation.

F. Reduction is a chemical reaction in which a molecule gains electrons and energy.

1. A molecule that accepts electrons is said to be *reduced*, and the molecule that donates electrons is called a *reducing agent* (electron donor).
2. A reduction reaction may involve more than transfer of electrons. In some cases, the electrons are transferred in the form of hydrogen atoms. The fact that protons are also involved is immaterial.

IV. Organic Compounds

A. *Organic chemistry* is the study of compounds of carbon.

1. Organic molecules are broadly classified as *carbohydrates*, *lipids*, *proteins*, and *nucleic acids*.
2. Carbon is a versatile atom with four valence electrons, able to form up to four covalent bonds.
3. Carbon atoms readily combine with each other to form carbon backbones in the form of long chains, branched molecules, and rings.

4. Carbon backbones can carry a variety of functional groups—small clusters of atoms that determine properties of an organic molecule, such as carboxyl, phosphate, hydroxyl, methyl, and amino groups.

B. Some organic molecules are gigantic *macromolecules* with large molecular weights.

1. A polymer is a molecule consisting of a long chain made up of monomers—identical or similar subunits linked together.

a. Starch is a polymer of about 3,000 glucose monomers.

2. *Polymerization*, the joining together of monomers as a polymer, is achieved by means of dehydration synthesis (condensation).

a. In dehydration synthesis, a hydroxyl (–OH) group is removed from one monomer and a hydrogen (–H) from another, producing water as a by-product.

b. The two monomers are joined by a covalent bond into a *dimer;* the dimer is then expanded with further rounds of dehydration synthesis.

3. The opposite of dehydration synthesis is hydrolysis.

a. In hydrolysis, water is ionized into H^+ and OH^-.

b. A covalent bond between monomers is broken, with H^+ being added to one monomer and OH^- being added to the other one.

i. All digestion is accomplished by hydrolysis.

C. A carbohydrate is a hydrophilic organic molecule with the general formula $(CH_2O)_n$, where n is the number of carbon atoms.

1. The most familiar carbohydrates are the sugars and starches.

2. The root word *sacchar-* and the suffix *-ose* both mean sugar or sweet.

3. The simplest carbohydrates are the monosaccharides, including glucose, fructose, and galactose.

a. Glucose is the "blood sugar" that provides energy to our cells.

4. Disaccharides are sugars composed of two monosaccharides, such as sucrose, lactose, and maltose.

5. Polysaccharides are long chains of glucose; examples important to human physiology are glycogen, starch, and cellulose.

a. Glycogen is a branched, energy-storage polysaccharide produced by cells of the liver, muscles, brain, uterus, and vagina; it is produced after a meal and broken down between meals.

b. Starch is the energy-storage polysaccharide made by plants; they produce it when sunlight and nutrients are available and draw from it at night and in winter.

c. Cellulose is a structural polysaccharide made by plants; it cannot be broken down in the human body but is important as fiber in the diet.

6. Carbohydrates are a source of energy that can be quickly mobilized, but have other functions as well.

a. Carbohydrates are ultimately converted to glucose, which provides energy to most of our cells.

b. Carbohydrates also have other functions when conjugated with proteins and lipids.

i. Glycolipids and glycoproteins are components of cell membranes; glycoproteins are a major component of mucus, a protective substance.

ii. Proteoglycans are a type of conjugated molecule in which the carbohydrate is dominant and the protein forms a smaller component; proteoglycans have many roles in the body as gelatinous fillers, lubricants, and cushions in the joints.

iii. In conjugated molecules, each type of component is called a moiety; proteoglycans have a protein moiety and a carbohydrate moiety.

D. Lipids are hydrophobic molecules usually composed only of carbon, hydrogen, and oxygen, with a high ratio of hydrogen to oxygen.

1. Lipids are less oxidized than carbohydrates, and therefore have more calories per gram.

2. A fatty acid is a chain of usually 4 to 24 carbon atoms with a carboxyl group at one end and a methyl group at the other.

a. A saturated fatty acid, such as palmitic acid, has as much hydrogen as it can carry.

b. An unsaturated fatty acid, such a linoleic acid, has some carbons joined by double covalent bonds—and is thus not “saturated” with hydrogen.

c. Polyunsaturated fatty acids have many double bonds.

d. Most fatty acids can be synthesized in the body, but the essential fatty acids cannot and must be obtained from food.

3. A triglyceride is a molecule consisting of three fatty acids bonded to glycerol, a three-carbon alcohol; each bond is formed by dehydration synthesis.

a. Once bonded to glycerol, a fatty acid is no longer an acid, so triglycerides are called neutral fats.

b. Oils are generally, but not always, liquid at room temperature, whereas fats are solid.

c. Animal fats are usually made of saturated fatty acids; most plant triglycerides are polyunsaturated.

Insight 2.3 Clinical Application: *Trans* Fats and Cardiovascular Health

d. The primary function of fat is energy storage; it also serves as thermal insulation and cushions vital organs.

4. Phospholipids are similar to neutral fats, but in place of one fatty acid, they have a phosphate group, which is linked to other functional groups.

a. Lecithin is a common phospholipid that has *choline* as a functional group.

b. The two fatty acid "tails" are hydrophobic, but the phosphate "head" is hydrophilic, giving phospholipid molecules an amphipathic nature.

c. The most important function of phospholipids is as a structural component of cell membranes.

5. Eicosanoids are 20-carbon compounds derived from a fatty acid called *arachidonic acid*.

a. Eicosanoids have a hormonelike function.

b. Prostaglandins are eicosanoids that have a 5-carbon ring structure; they act as signals in many processes, including inflammation, blood clotting, labor contractions, etc.

6. A steroid is a lipid with 17 of its carbon atoms arranged in four rings.

a. Cholesterol is the "parent" steroid from which all others are synthesized, including cortisol, progesterone, estrogens, testosterone, and bile acids.

Insight 2.4 Clinical Application: "Good" and "Bad" Cholesterol

b. Cholesterol is synthesized only by animals and is a natural product of the body.

c. The body produces 85% of its cholesterol; only about 15% comes from the diet.

d. Cholesterol is critical to cell membranes and proper nervous system function.

E. Proteins are the most versatile molecules in the body.

1. A protein is a polymer of amino acids.

a. An amino acid has a central carbon atom with an amino ($-NH_2$) and a carboxyl group ($-COOH$) bound to it.

b. Amino acids also have a *radical* (R group) attached to the central carbon; this R group may be a single hydrogen or a complex ring of carbon.

c. There are 20 amino acids involved in proteins of the human body.

2. A peptide is any molecule composed of two or more amino acids joined by peptide bonds.

a. Chains of fewer than 10 or 15 amino acids are called oligopeptides; chains larger than that are called polypeptides.

b. A protein is a polypeptide of 50 or more amino acids.

c. The average protein has a molecular weight of 30,000 amu, and the range is from 4,000 to hundreds of thousands of amu.

3. Proteins have complex coiled and folded structures and even slight changes in their conformation can destroy function.

4. Proteins have three to four levels of complexity, from primary through quaternary structure.

a. Primary structure is the protein's amino acid sequence.

b. Secondary structure is a coiled or folded shape held together by hydrogen bonds.

i. Common secondary structures include the alpha (α) helix and the beta (β) pleated sheet.

ii. Many proteins have multiple alpha-helical and beta-pleated regions joined by short segments.

c. Tertiary structure is formed by further bending and folding resulting from the association of hydrophobic R groups with each other to avoid water, while hydrophilic R groups are attracted to water.

i. Van der Waals forces play a role in stabilizing tertiary structure.

ii. Two types of proteins with tertiary structure include *globular proteins* such as enzymes and antibodies, and *fibrous proteins* that provide strength to skin, hair, and tendons.

iii. Tertiary structure may also include disulfide bridges in which two sulfur-containing amino acids associate with one another by forming a bond between their sulfur groups. Insulin is a molecule held together by disulfide bridges.

d. Quaternary structure is the association of two or more polypeptide chains by noncovalent forces, such as ionic bonds and hydrophilic–hydrophobic interactions.

i. Hemoglobin contains four polypeptide chains: two alpha chains and two beta chains.

e. Proteins can change conformation reversibly, and this property is important to processes such as muscle contraction and enzyme function.

f. Denaturation is usually an irreversible conformational change, such as occurs when cooking an egg.

g. *Conjugated proteins* have a non-amino acid moiety called a prosthetic group.

i. The iron-containing ring called *heme* in hemoglobin is a prosthetic group.

h. Proteins have a variety of functions in the body.

i. Structure; for example, keratin in nails, hair, and skin.

ii. Communication; for example, receptors on the surface of cells that bind a hormone as a ligand.

iii. Membrane transport; such as channels and transport proteins in cell membranes.

iv. Catalysis; metabolic pathways are controlled by enzymes, which act as catalysts.

v. Recognition and protection; some proteins serve to recognize and fight invaders, others bring about blood clotting to stop bleeding.

vi. Movement; for example, motor proteins that bring about everything from intracellular transport to the act of running.

vii. Cell adhesion; proteins bind cells to each other.

F. Enzymes are proteins that function as biological catalysts, permitting biochemical reactions to occur rapidly at body temperatures.

1. Some enzyme names are arbitrary; others reflect the enzyme's substrate or its action.

2. Enzymes lower the activation energy of reactions; they do so by releasing energy in small steps rather than all at once.

Insight 2.5 Clinical Application: Blood Enzymes as Disease Markers

3. Enzyme structure is related to its action in a metabolic process.

a. A substrate molecule approaches the active site of its enzyme; this site has a conformation that allows amino acid side groups to bind functional groups on the substrate.

b. The substrate is bound, forming an enzyme–substrate complex; enzymes have selectivity and are intended to bind to only one substrate, for example, the enzyme sucrase will bind to only sucrose.

c. The enzyme breaks the bond holding substrate components together, for example, sucrase breaks sucrose by hydrolysis, releasing its components, glucose and fructose (reaction products); the enzyme remains unchanged.

d. Factors that change the shape of an enzyme tend to alter or destroy its ability to bind its substrate; temperature and pH are notable examples.

4. Many enzymes require cofactors (nonprotein partners) in order to function.

a. Cofactors include iron, copper, zinc, magnesium, or calcium ions; these affect an enzyme's conformation.

b. Coenzymes are organic cofactors usually derived from water-soluble vitamins; for example, NAD^+ is derived from niacin and shuttles electrons from one pathway to another in ATP production.

5. A metabolic pathway is a chain of reactions with each step catalyzed by a different enzyme.

G. Nucleotides are organic compounds consisting of a carbon–nitrogen ring called a *nitrogenous base*, a monosaccharide, and one or more phosphate groups.

1. Adenosine triphosphate (ATP) is one of the best-known nucleotides and is the body's most important energy-transfer molecule.

a. The second and third phosphate groups of ATP are high-energy covalent bonds.

b. Enzymes called adenosine triphosphatases (ATPases) hydrolyze the third phosphate bond, producing ADP and an inorganic phosphate group, plus 7.3 kcals of energy per mole of ATP broken down.

c. The free phosphate groups are often added to enzymes to activate them, a process called phosphorylation, which is carried out by kinases.

2. The energy for ATP synthesis comes from glucose oxidation.

a. The first stage is glycolysis, the splitting of glucose into *pyruvic acid.*

b. If oxygen is unavailable, pyruvic acid is then converted to lactic acid through anaerobic fermentation.

c. If oxygen is abundant, a more efficient pathway of aerobic respiration occurs, breaking down pyruvic acid into carbon dioxide and water.

3. Other nucleotides include guanosine triphosphate (GTP) and cyclic adenosine monophosphate (cAMP), also known as a "second messenger."

4. Nucleic acids are polymers of nucleotides.

a. DNA is the largest nucleic acid, typically 100 million to 1 billion nucleotides in length.

b. RNA comes in three forms, which range from 70 to 10,000 nucleotides in length.

c. DNA and RNA play roles in genetics and protein synthesis.

Insight 2.6 Clinical Application: Anabolic–Androgenic Steroids

Saladin, *Anatomy & Physiology* 10e
Chapter 2, The Chemistry of Life
Answer Key

Testing Your Comprehension

1. The loss of stomach acid by profuse and prolonged vomiting raises the pH of the body fluids. When acid is lost from the body, surplus base remains and the pH rises.

2. As the carbon dioxide concentration in the body fluids drops, the carbonic acid reaction shifts in the following direction: $H_2CO_3 \rightarrow H_2O + CO_2$. The more CO_2 that is expelled (faster than it is produced), the less carbonic acid remains in the blood. With less carbonic acid, the blood pH rises, becoming more basic.

3. This is an exergonic reaction, because it releases energy in the form of the gamma ray. It is neither an anabolic nor a catabolic reaction, however. These are branches of metabolism, and metabolism is the formation and breakdown of chemical bonds. No chemical bonds are formed or broken in radioactive decay.

4. The function of an enzyme is to speed up a chemical reaction. Without enzymes, the body's metabolic rate would therefore slow down drastically, to a point incapable of supporting life.

5. An abnormally low pH slows down enzymatic reactions and may even irreversibly denature enzymes. As enzyme conformations change, their active sites change and cannot bind their substrates. Metabolic pathways can then shut down.