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Bioenvironmental Engineering Journeyman

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NOW THAT YOU have successfully completed technical training and reported to your duty station, this Career Development Course (CDC) 4B051, *Bioenvironmental Engineering Journeyman*, is the next step in becoming a proficient journeyman in your new career field. This course is made up of six volumes. This first volume is devoted to basic fundamentals and sciences of bioenvironmental engineering. The second volume introduces you to health risk assessment and management and ends with water/liquid sampling. The third volume addresses biological, chemical and physical hazard assessment and control. The fourth volume is comprised of two sub-volumes, and concentrates on radiological hazard assessment and control. The fifth and final volume explains health risk management programs, occupational health, and emergency management principles.

In this first volume, you will learn about fundamental knowledge of the bioenvironmental engineering (BE) career field.

Unit 1 describes how BE fits into the Air Force Medical Service (AFMS).

Units 2 and 3 provide a review of basic chemistry and anatomy and physiology.

Unit 4 introduces toxicology and the importance the dose-response relationship plays in measuring exposures.

Unit 5 provides a brief review of basic ecology principles with the added bonus of introducing the concepts of transportation and fate of chemicals in the environment and how these substances affect human health.

A glossary is included for your use.

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For Guard and Reserve personnel, this volume is valued at 16 hours and 4 points.

NOTE:

In this volume, the subject matter is divided into self-contained units. A unit menu begins each unit, identifying the lesson headings and numbers. After reading the unit menu page and unit introduction, study the section, answer the self-test questions, and compare your answers with those given at the end of the unit. Then complete the unit review exercises.

Unit 1. Mission and Organization of the Air Force Medical Service

CONSIDER YOURSELF FORTUNATE to be in the bioenvironmental engineering (BE) career field. Not only are BE specialty skills honored professions in the civilian community, this career field as a whole is a vital function in support of the primary Air Force (AF) mission. Given the expeditionary mission of the United States Air Force (USAF), you will have a personal and moral responsibility to help maintain the health and readiness of our forces. Regardless of your specific duties, the overall mission will not be accomplished unless you perform your assigned tasks faithfully and to the best of your ability.

As a member of BE, you must be able to meet and feel comfortable with personnel at all levels of command to present facts and recommendations convincingly. You must write effectively, speak persuasively, and continually educate yourself and the public in your specialty. You should strive to present an outstanding appearance, personality, and belief in your profession, so that other people will have confidence in you and your work. This broad challenging field is constantly changing. It is your duty and responsibility to learn continually, on and off the job, to sustain dynamic growth in your specialty.

You are now a member of the Air Force Medical Service (AFMS) (fig. 1–1); we welcome you. We hope your service time will be rewarding to you and beneficial to the organization. As in all serious undertakings, your reward will be equal to the effort you place in your duties. We will start this phase of your career development training by looking at AFMS and the overall mission your career field team helps to accomplish.

Figure 1–1. Seal of the AFMS.

1–1. The Air Force Medical Service

Air Force missions will increasingly face unprecedented obstacles and health threats. Global reach and rapid tempo characterize flying operations; unique health hazards from new weapons, such as directed energy and fourth generation chemical weapons, will threaten virtually every operation. The key to successfully executing USAF missions will be Airmen physically and mentally prepared to perform at optimum capability to meet the challenge—the focus of AFMS.

Health services personnel must ensure they themselves are ready medical forces and that other Air Force members are medically ready. A ready medical force means health services personnel are organized, trained, and equipped to provide rapid response capabilities to support combatant commanders' broad range of missions. A medically ready force means proper application of medical initiatives aimed at protecting and maximizing the performance of our fellow military members before, during, and after deployments.

This section addresses the important aspects of the AFMS mission, vision, and capabilities that prepare our medical and fighting forces. Together, ready medical forces and healthy, medically ready forces ensure Air Force stability and mission responsiveness.

001. Purpose and organization of the Air Force Medical Service

First, we must address the AFMS mission, for an organization's mission describes its purpose—the "what we are here to do" of our job. In a sense, the mission is a target (fig. 1–2). Without it, people usually spend time trying to accomplish 'something' in their jobs; however, there is no real direction or purpose established for them to use as a guide. Though intentions may be good, they may not necessarily be on target. We need a mission to focus resources and capabilities.

Figure 1–2. Illustration of mission target.

Air Force Medical Service mission and vision

As leader of the AFMS, the Air Force Surgeon General (AFSG) establishes its medical service mission, making sure it supports the Air Force mission. The AFMS mission lays its foundation and sets the direction for the entire organization. In turn, each organization within AFMS establishes a mission that supports the AFSG defined mission. Doing this ensures a unified top-to-bottom approach to achieving the AFMS mission.

AFMS mission statement

The following is the AFMS mission statement:

> The AFMS mission is to ensure medically fit forces, provide expeditionary medics, and improve the health of all we serve to meet our nation's needs.

The AFMS recognizes that each Airman is essential to the function of the USAF as a whole. To fulfill its mission, the AFMS is dedicated to optimizing the potential of each individual. To do so, the AFMS must promote human performance sustainment and enhancement technologies, provide preventive health maintenance and ensure appropriate treatment/therapy for any health and performance deficits, whether physical or mental. The following items include several avenues AFMS pursues to accomplish its mission.

- The AFMS partners with individuals to accomplish healthcare maintenance activities.
- The AFMS works with commanders and weapons systems designers to optimize the interface between personnel and machines. AFMS expertise is integral for force protection, sustainment and mobility operations.
- In addition, the AFMS identifies, evaluates, designs, and recommends controls to health hazards to prevent illness and injuries.
- If prevention fails, the AFMS will rapidly restore each Airman to a combat ready status or arrange for the appropriate rehabilitative services.

The mission is "what we're here to do" *today*. However, it is important to understand that an organization also needs a vision to guide it to the future. For this reason, the AFSG establishes the AFMS vision.

AFMS vision statement

The following is the AFMS vision statement:

> The AFMS strives to provide reliable access to safe, quality care for all that we serve, promoting positive patient experiences and outcomes. To achieve this goal, we are committed to providing Trusted Care, Anywhere, around the globe at every Air Force medical facility.

The AFMS will provide quality healthcare and health service support anywhere in the world at any time to support the entire military family, be they active duty, retired, or a family member. With highly motivated, trained and respected Airmen, the AFMS will accomplish its mission with integrity and the ability to integrate with Joint Forces. The overarching vision is to provide a world-class health system that supports the military mission by fostering, protecting, sustaining, and restoring health, which, in many ways, mirrors the four AFMS effects we will discuss shortly.

Support for the air expeditionary force

Now that we have discussed the AFMS mission and vision, we need to address what the organization "brings to the fight" to support the air expeditionary force (AEF). The Air Force has transitioned from a force founded on the strategy of forward-based presence to one built on the vision of global engagement—the AEFs. The Air Force mission has shifted from major theater war scenarios to multiple, smaller regional conflicts. The AEF concept is one way of responding to the increasing number of contingencies that call for worldwide deployments. As a result, the Air Force has transformed from a threat-based environment to an effects- and capabilities-based service, and with it, so has the AFMS.

What do the terms "effects and capabilities" mean? To adjust to the current expeditionary role of the AEF, Air Force planners have realized the advantages of first identifying the desired outcome (or desired effect) of achieving military objectives and then focusing on the required capabilities, instead of particular programs or weapons systems, to achieve that outcome. Simply stated, capabilities are the means necessary to achieve desired effects.

In order to support the operational missions carried out by air component commanders, the AFMS must have certain capabilities required to achieve the desired effects of the missions. The AFMS has identified human health effects and capabilities needed to provide medical support to the AEFs and peacetime healthcare. The AFMS effects describe health service support for the warfighter. AFMS effects are what the medical service "brings to the fight."

Air Force Medical Service effects

AFMS has five effects-based mission areas. These include promoting and sustaining a medically ready force, prevent illness and injury, restore health, optimize and sustain human performance, and Systematize high reliability throughout the Aerospace & Operational Medicine Enterprise.

Promoting and sustaining a medically ready force

AFMS defines programs and standards that sustain a fit and healthy force and maintains these standards through prevention and treatment. Health services for this effect include mental and physical health assessments at pre- and post-deployment; medical testing and monitoring; health promotion; disease prevention; and evaluating, preventing, and treating environmental and occupational health issues.

Prevent illness and injury

Preventive medicine activities ensure the force is available to accomplish the mission. Health services for this effect include identifying, assessing and controlling hazards from the full spectrum of health hazards encountered in garrison or deployed environments. It also includes communicating associated hazard risks, so commanders understand the potential outcomes of exposure, and providing solution sets for managing hazards while continuing the mission.

Restore health

If prevention fails, the AFMS works to restore health as rapidly as possible from equipping and training forces to performing self-aid/buddy care to casualty management services. These services include triaging, transporting, treating, and rehabilitating ill or injured members until fully recovered.

Optimize and sustain human performance

This AFMS effect includes enhancing the human weapon system to optimize warfighter performance in all environments; support initiatives range from new fatigue management to Laser-Assisted In-Situ Keratomileusis (LASIK).

Systematize high reliability throughout the Aerospace & Operational Medicine Enterprise

This AFMS effect includes standardizing workflow processes, leader work and management systems. It also includes continuously improving processes and systematizing organizational learning.

Now that we have defined and clarified the purpose of the AFMS, let us look at how the medical service is organized. As you read the next section, an important fact to remember is that organizations have both line and staff positions and responsibilities. To state it simply, line responsibility dictates the actual chain of command, while staff responsibility serves an advisory capacity. Staff members help the line leader to manage the organization and do not inherently have directive authority over subordinate line units.

Air Force Medical Service organization at the Air Force, major command, and wing level

The structure of the AFMS organization permits optimum care for its customers. It is neither possible nor productive to address all organizations within AFMS. Therefore, this section addresses the organization as it pertains to BE personnel. Figure 1–3 illustrates line and staff responsibilities that exist in the AFMS. It may be helpful to refer to this figure from time to time as we discuss the AFMS structure.

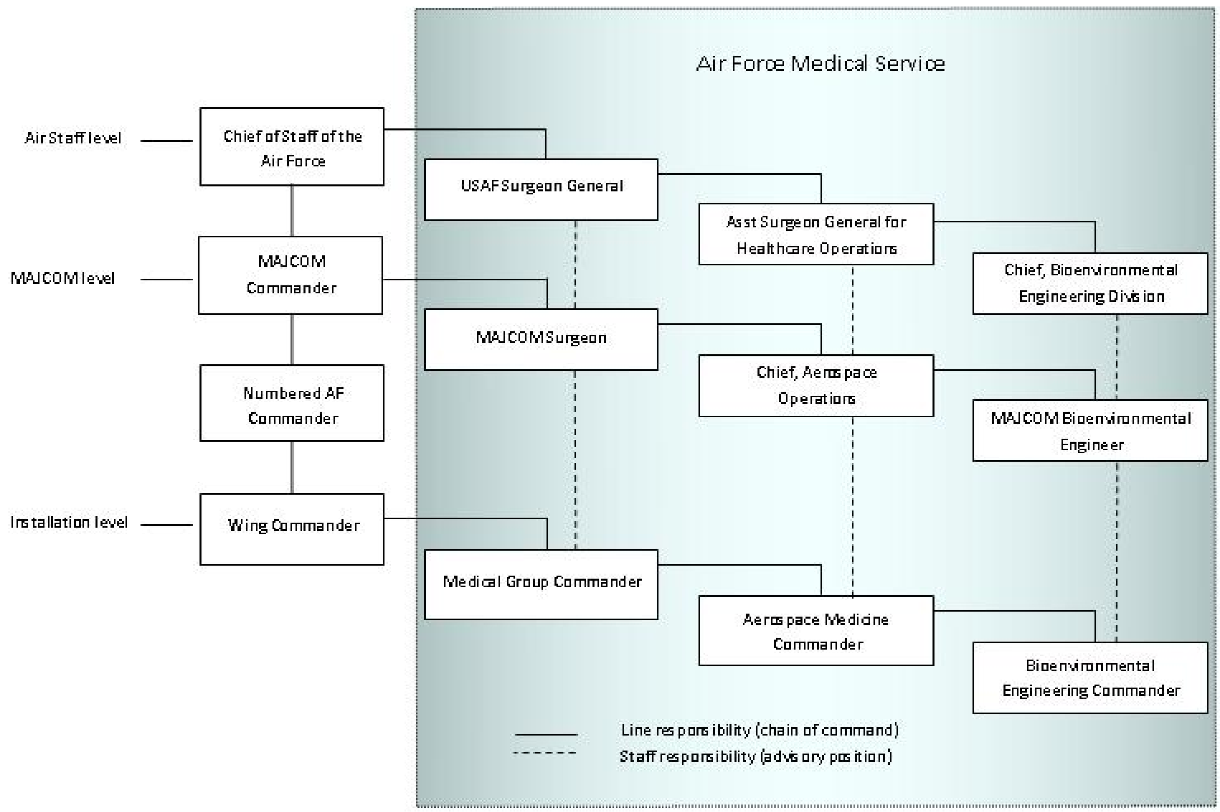


Figure 1–3. Organization from Chief of Staff of the Air Force to the BE Flight.

Air Force

The Air Force organization leaders are the Secretary of the Air Force (SECAF) and the Chief of Staff of the Air Force (CSAF). The SECAF, charged with policy and oversight of the Department, is assisted by a staff and advised by the CSAF. The CSAF, responsible for organizing, training and equipping AF units to meet combatant commanders' requirements, is also assisted by the Air Staff.

The Air Staff is a body of high-ranking officials—including AF/SG—who assist the CSAF in carrying out duties. The Air Staff is organized in what is known as the "A-staff" structure that divides duties and responsibilities into nine functional areas; A1–A9. Examples of the functional areas include Personnel, Intelligence, Logistics, and Plans & Programs. This staff structure closely mirrors the United States (US) Army's General Staff (G-staff); the US Navy's Deputy Chiefs of Naval Operations (N-staff); and the Joint Staff (J-staff), made up of personnel from the US Army, USAF, US Navy, and US Marine Corps. These functional areas make it easier for Airmen to do their jobs, both within the AF and when operating with other services within a joint environment.

Air Force Surgeon General

The AFSG advises both the SECAF and CSAF on medical matters pertaining to AF operations and readiness. A small staff that includes a BE function and two forward-operating agencies assist the AF Medical Operations Agency (AFMOA) and Air Force Medical Support Agency (AFMSA). This staff has no line authority over AF medical units in the field.

The organization of the Office of the AFSG mirrors the A-staff structure, where similar functions exist. For example, A1 is the Directorate of Manpower and Personnel at the Air Staff level. It is responsible for issues related to manpower, personnel, and services. Similarly, SG1, Force Management, is responsible for issues related to medical manpower.

The AFSG and staff plan, program, budget, develop policies, and oversee AFMS operations for both the SECAF and CSAF. The AFMSA is the AFMS operational and consultant lead for aerospace medicine, preventive medicine, clinical excellence, optimization of medical resources, BE and occupational health, and radiation protection and population health support. Many BE-specific directives originate from the Air Force Medical Support Agency Bioenvironmental Engineering Office (AFMSA/SG3PB).

Major commands

From the Air Staff level, forces are organized into major commands (MAJCOM). Each MAJCOM mirrors the organizational flow that exists at the Air Staff level. The line structure of each MAJCOM (indicated by the solid lines in figure 1–3) includes the MAJCOM commander, MAJCOM surgeon, chief, aerospace medicine operations, and MAJCOM BE officer. Each of these positions has a staff responsibility to their respective Air Staff leader (indicated by the dashed line in figure 1–3); however, they exercise no line authority over AF medical units.

The MAJCOM surgeon and staff advise the MAJCOM commander on health-related issues for their command and health impact of mission operations. The MAJCOM surgeon also interprets and enforces surgeon general policies and provides guidance to medical treatment facilities on these policies, as necessary. The MAJCOM BE provides similar guidance and assistance to installation-level BE flights. Also, at this level is a BE enlisted MAJCOM functional manager, a senior noncommissioned officer (SNCO) who serves as a liaison between installation level BE flights, MAJCOM, and the career field manager (CFM). The MAJCOM functional manager usually works directly for the MAJCOM BE but may also fill the role as an additional duty while serving at an installation level assignment.

Wing

MAJCOMs are composed of, in descending order of line responsibility, numbered air forces, wings, groups, squadrons, and flights. The wing structure resembles that of Air Staff and the MAJCOM. Beginning with the wing commander, the chain flows down to the medical treatment facility commander, squadron commander, and finally, to the flight commander.

The exact structure of each medical treatment facility (MTF) will vary across the Air Force; however, organizational structures will fit one of four models: medical wing, hospital/medical center, clinic with squadrons, and clinic plus. These structures support both garrison and deployed medical groups.

Organization at the group and squadron level

The organizational structure of each MTF depends on the mission, size, and capabilities of the organization. A medical wing is unique. It is an organization of such size and capability that it coexists with the line wing on the installation rather than coming under its command. Very few MTFs have a medical wing designation. Most MTFs within the AFMS fit either the “clinic” or “hospital/medical center” designation with a six (fig. 1–4) or four (fig. 1–5) squadron structure.

Figure 1–4. Hospital or medical center structure.

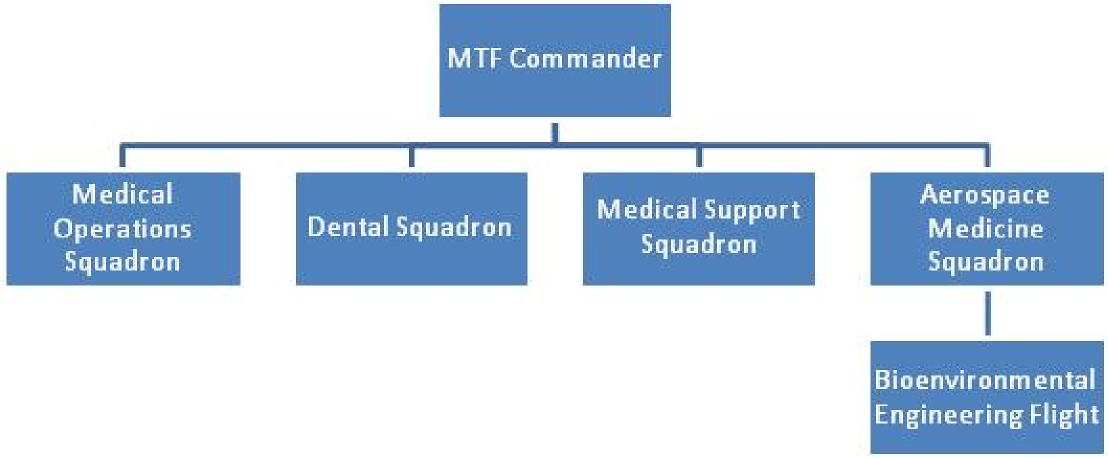


Figure 1–5. Clinic structure.

You should be familiar with services provided by each of the squadrons within the medical group. The following paragraphs identify the optimum flights that could be made available within each squadron discussed; however, it is not usual for squadrons to have all the flights listed.

Medical operations squadron

The medical operations squadron provides direct health care services for the defined population. It may include the following flights: medical services, surgical services, pediatrics, mental health, obstetrics and gynecology (OB/GYN), primary care, family practice, physical and occupational therapy, emergency services, genetics, clinical medicine, maternal/childcare, and diagnostic imaging. It also may include dental operations and aerospace medicine flights when an MTF does not have a dental squadron or an aerospace medicine squadron.

Surgical operations squadron

The surgical operations squadron provides comprehensive, specialized, surgical care to patients. Flights normally approved for this type of squadron include surgical services, operating room, OB/GYN, anesthesia, orthopedics, general surgery, and surgical specialties.

Inpatient operations squadron

An inpatient operations squadron provides inpatient clinical health care services. It may include the following flights: medical inpatient, surgical inpatient, mental health inpatient, maternal/child inpatient, critical care (includes special care, intensive care, and cardiac care), perioperative and multiservice.

Medical support squadron

This squadron provides business operations (financial and manpower), administrative support, as well as, clinical laboratory and radiology services to aid in the medical care of beneficiaries. The following are approved flights in this squadron: resource management, medical logistics, medical information services, personnel and administration, diagnostic imaging, and patient administration (optional), pharmacy, clinical laboratory, nutritional medicine, diagnostics and therapeutics, histopathology, and readiness.

Dental squadron

A dental squadron provides preventative and restorative dental care. It typically includes clinical dentistry, dental laboratory, and dental support. When applicable, it may also provide dental residency, and/or area dental laboratory flights.

Aerospace medicine squadron

This squadron supports the operational Air Force by enhancing the health of its people. This provides for ensuring a fit force, preventing disease and injury, protecting the environment, and, anticipating and responding to medical contingencies in all environments and workplaces. Flight commanders within the aerospace medicine squadron (AMDS) report to the squadron commander who reports directly to the medical group commander. The AMDS squadron commander is responsible for ensuring the aerospace medicine program (AMP) performs successfully. Like the medical group structure, the AMDS structure varies from base to base according to the mission and clinical capability of the MTF. Regardless of the organization, a number of essential elements and activities will be present at all USAF home station or deployed medical treatment facilities.

There are 13 approved flights in the AMDS. Depending upon the installation mission, the first flight will be one of four possible variations to include flight medicine, missile medicine, space medicine, or space and missile medicine. For example, you would see a missile medicine flight on an installation with a primary missile support mission. The remainder of the approved flights included: health promotion, public health, BE, aerospace physiology, aeromedical staging, occupational medicine, optometry, hyperbaric medicine, and audiology. It also may include dental operations when an MTF does not have a dental squadron but does have an aerospace medicine squadron.

002. The Aerospace and Operational Medicine Enterprise

We have established that the ability of the Air Force to conduct effective and sustained combat operations depends largely on the physical and mental health of its personnel. According to Air Force Policy Directive (AFPD) 48–1, *Aerospace & Operational Medicine Enterprise (AOME)*, the AOME mission is to optimize force health and warfighter performance. To accomplish its mission, the AOME is divided into the following five effects-based mission areas:

1. Promote and sustain a medically ready force.
2. Prevent illness and injury.
3. Restore health.
4. Optimize and sustain human performance.
5. Systematize high-reliability throughout the AOME.

The AOME effects are identical to the AFMS effects. Earlier, we talked about the AFMS mission lining up with the AF mission. These similarities continue at this level of the AFMS organization as well as your flight level. AFMS effects reach down through the layers of the organization to keep our targets aligned appropriately.

Aerospace medicine flights

Each AMDS flight provides specific capabilities to achieve the AMP effects. The following paragraphs explain the roles and responsibilities of your fellow aerospace medicine flights with which you will be working. We will discuss BE-specific responsibilities in the next section. Keep in mind, your individual unit may not have all flights; flight arrangements are dependent upon the specific mission of each AMDS. However, something to remember that when personnel from various flights work together to accomplish the mission, it is the team aerospace concept in action, directed by Air Force Manual (AFMAN) 48–146, *Occupational & Environmental Health Program Management*. This is not only helpful, but it is also essential to the success of any AMDS.

Flight medicine flight

This flight provides clinical, occupational, and preventive medical care and consultation to all key elements in the squadron, other medical squadrons, and to line units. For example, they provide flying and occupational preventive health physicals and determine fitness for flight and special operational duties. Elements may include occupational medicine, operational hyperbaric medicine, and optometry.

Space medicine and missile medicine flights, which parallel the flight medicine flight, exist at bases where there is no flying mission but rather a space mission and/or missile launch and support mission.

Health promotion flight

This flight provides programs that encourage healthy lifestyles (e.g., tobacco product cessation, exercise and fitness, nutrition, stress management, cardiovascular disease prevention, and substance abuse education). They provide health assessments and evaluations, and develop strategies to reduce mortality rates of active duty or civil servant populations.

Public health flight

This flight implements public health programs and activities devoted to preventing disease, disability, and illness in military members and their families. Included are food safety and security inspection; sanitation; medical entomology programs; vector borne, communicable, and occupational disease prevention and control; public health medical readiness activities; and promoting and providing health education and training. Elements may include community health, force health management, occupational health and education, epidemiological surveillance, communicable disease control, health risk assessment (HRA) and communication, food safety, and food facility sanitation.

Aerospace physiology flight

This flight provides human performance enhancement training, works with flight safety, and provides consultant services for flying safety activities. They also assist in aircraft mishap investigations and participate in high altitude airdrop missions. Key elements in the physiological training flight are administration, training, and maintenance.

Occupational medicine flight

This flight is devoted to prevention and management of occupational and environmental injury, illness, and disability; and the promotion of health and productivity of workers, their families, and communities. It provides initial management of occupational injuries and illnesses and directs medical monitoring efforts for the work force.

Optometry flight

This flight provides comprehensive eye care for Department of Defense (DOD) health care beneficiaries. They also manage the spectacle/gas mask inserts, contact lenses, and warfighter/aviation corneal refractive surgery programs.

Audiology flight

This flight manages the hearing conservation and hearing loss prevention programs evaluating and treating hearing disorders.

Aeromedical staging flight

The aeromedical staging flight provides medical and nursing care to patients who enter, travel in, or leave the aeromedical evacuation system. Key elements in this flight are patient support, transportation, education, risk management (RM), infection control, and nursing.

Hyperbaric medicine flight

This flight provides care and training for decompression sickness, carbon monoxide poisoning, and gas gangrene. As you can see from the preceding paragraphs, the AMP includes many activities. These activities are conducted with an integrated approach that includes officer, enlisted, and civilian personnel. You and others from the various aerospace medicine flights work together as one team—team aerospace—to accomplish the AMP mission. To illustrate this point, let us look at two hypothetical situations.

Example one

An employee of the fabrications branch receives a hearing exam during her annual physical health assessment. The test indicates a significant hearing shift or deterioration. After monitoring the audiograms, public health (PH) and BE personnel worked jointly to assess the situation. BE reviewed existing noise exposure data, surveyed new noise sources, and assessed the adequacy of engineering controls and personal protective equipment (PPE) available to workers. PH observed protective equipment donning procedures, and reviewed training documentation. In this case, the worker was not inserting her hearing protection properly. PH retrained the worker to use the proper technique to help manage current hearing loss and attempt to prevent further loss.

Example two

Your unit deploys to South America supporting humanitarian relief efforts. PH provides pre-deployment screenings and briefings before deploying. Two weeks into the deployment, the medical clinic observes a pattern of dehydration and intestinal occurrences. Patient symptoms are treated at the clinic by flight medicine, water sources and heat stress are evaluated by BE, and diet and food preparation areas are evaluated by PH in a coordinated team effort to identify and correct the threat.

So, how are AMP activities coordinated? The Aerospace Medicine Council provides the linkage for all the functions of team aerospace. The council coordinates and standardizes your activities, together with the activities of all the other personnel within team aerospace, resulting in no wasted, misdirected, or ignored efforts. We will discuss this important leading body a little later in this unit.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

001. Purpose and organization of the Air Force Medical Service

1. Describe the role of the AFSG within the AFMS.

2. List the five AFMS effects-based mission areas.

3. Describe the prevent illness and injury effects-based mission area.

4. Cite the two Air Force organization leaders and describe their individual responsibilities.

5. Cite the factors that influence the organizational structure of each MTF.

6. List the 13 approved flights within an aerospace medicine squadron.

002. The Aerospace and Operational Medicine Enterprise

1. List the five effects-based mission areas within the AOME.

2. Match the Aerospace Medicine Flight listed in column B with their corresponding responsibilities listed in column A.

Column A	*Column B*
____ (1) Provides medical care to patients who enter, travel in, or leave the aeromedical evacuation system.	a. Flight Medicine.
____ (2) Provides programs in nutrition and stress management.	b. Health Promotion.
____ (3) Manages the spectacle/gas mask inserts and warfighter/aviation corneal refractive surgery programs.	c. Public Health.
____ (4) Manages the hearing conservation and hearing loss prevention programs.	d. Aerospace Physiology.
____ (5) Manages occupational and environmental injuries and illnesses.	e. Aeromedical Staging.
____ (6) Provides clinical, occupational, and preventive medical care.	f. Occupational Medicine.
____ (7) Provides human performance enhancement training.	g. Optometry.
____ (8) Provides care and training for decompression sickness.	h. Hyperbaric Medicine.
____ (9) Implements food safety and medical entomology programs.	i. Audiology.

3. What provides the link between all the functions of *team aerospace*?

1–2. Bioenvironmental Engineering

We have looked at the AOME and studied the functional areas. Now, let us take a closer look at your area of responsibility (AOR)—BE—and see how you fit into the big picture of protecting and maintaining a healthy fighting force.

003. Mission and organization of bioenvironmental engineering

Earlier, we stated a mission statement describes an organization’s purpose; in other words, “what we are here to accomplish.” Figure 1–6 displays the BE mission along with other statements that provide strategic direction for all BE personnel.

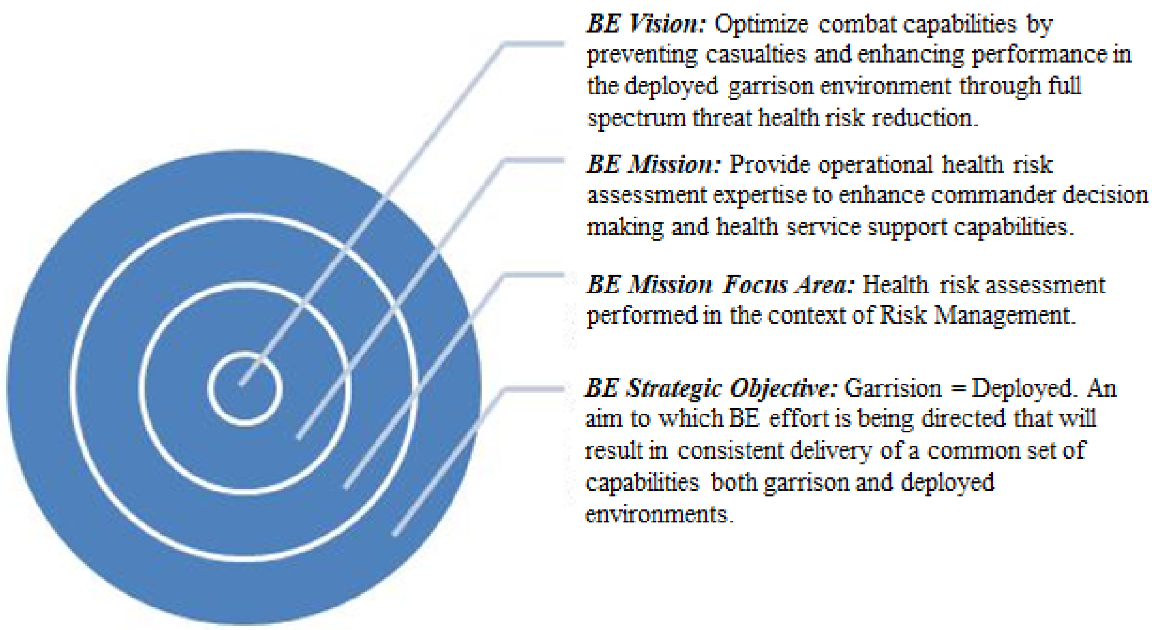


Figure 1–6. BE strategic direction.

To successfully accomplish the BE mission, each BE team member must be able to deliver a common set of capabilities applicable to both home station and deployed environments; consistent application of skills is needed in any setting. The practical application of this philosophy is:

Garrison leads to deployed

In other words, garrison leads to deployed means BE capabilities and the skills employed to achieve the capabilities are the same regardless of situation or location. Let us look at an example.

Aircraft structural maintenance activities are conducted at garrison as well as deployed locations. In fulfilling our responsibilities in support of the AFMS effects-based mission area of preventing illness and injury, we provide the capabilities to identify, analyze, and control occupational and environmental health (OEH) hazards associated with the de-painting operations of aircraft. Let us say for the purpose of this example that health threats posed by de-painting operations include inhaling heavy metal particulates and solvent vapors, and exposure to hazardous noise. These threats are identified and analyzed in the same manner whether the location is Lackland AFB (stateside) or Bagram Air Base (AB), Afghanistan (overseas).

There may be slight differences in the tactical execution of activities (emphasis and priorities assigned to accomplishing tasks) in deliberate versus crisis situations and in-garrison versus deployed; however, the skills you apply and capabilities that you provide in these situations are the same.

Bioenvironmental engineering primary capabilities

BE capabilities are essentially sub-capabilities to AFMS capabilities. They describe what BE members bring to the table to support the AFMS desired effects. The following items provide a summary of the primary BE capabilities.

Execute SGI related vulnerability assessments

Identify and assess the vulnerability of a terrorist attack on an installation and recommend measures to reduce the overall vulnerability/risk to the mission.

Conduct predictive exposure assessments

Use OEH data, intelligence products, and modeling information for predicting potential OEH exposures across the range of military operations.

Evaluate/approve potable and non-potable water systems/sources

Analyze surface, ground and/or local supplier sources and storage/distribution systems to determine health risks for garrison and deployed operations.

Execute occupational and environmental health site assessment

Executing an occupational and environmental health site assessment (OEHSA) is the process for collecting site-specific data to identify and quantify health threats in support of HRAs and to satisfy OEH surveillance requirements.

Identify OEH hazards

Effectively anticipate and recognize when chemical, biological, radiological, nuclear (CBRN) and physical health threats exist.

Analyze OEH hazards

Effectively evaluate the extent and effects of existing CBRN and physical health threats.

Control OEH hazards

Recommend measures to eliminate or control CBRN and physical health threats using health RM techniques.

Respond to OEH threats

Respond to both deliberate and crisis events.

Associate exposure with affected personnel

Document OEH hazard analysis data as part of a service member’s longitudinal exposure record.

Assist with health risk management

Advise decision makers on courses of action to minimize OEH risks while maximizing benefits for operations and missions.

The overarching aspect of the BE mission supported by these primary capabilities is performing HRAs performed in the context of RM. As a BE technician, you will use a comprehensive HRA approach to identify and analyze CBRN and physical threats in the air, water or ground; assess associated risk to human health; and recommend courses of action to eliminate or control the hazards. Your activities optimize combat capabilities by preventing illness or injuries and enhancing performance in the deployed and in-garrison environments.

As we proceed through this course, we will further explore the BE capabilities and the necessary skills you will apply throughout your career. For now, however, we need to discuss BE flight organization.

Bioenvironmental engineering flight organization

The organization and management of the BE flight can vary from base to base, reflecting several base-specific and flight-specific factors such as the mission(s) of the base, the number and type of customers served by the BE flight, the number and skill mix of BE staff working in the flight, and the preferences of the flight commander. Further, BE anticipates that the transformation to capabilities-based operations will affect organizational structure as flight operations move away from a program-specific regulatory compliance focus.

Figure 1–7 illustrates one organizational construct. Large BE flights may be oriented around two or more broad areas of related functions (i.e., occupational health surveillance, community health surveillance, readiness and training, and radiation surveillance). For instance, the flight might establish a readiness element if the unit is part of state and local response capabilities defined by agreement and plans or supports nuclear weapon storage and transport mission. If the installation has a large nuclear medicine function or radiation research mission, the unit might establish a radiation surveillance element.

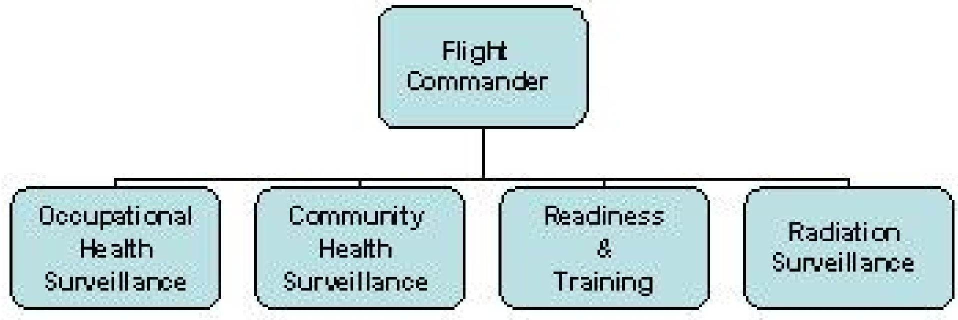


Figure 1–7. BE organizational chart.

Another organizational construct centers on teams, where individuals are assigned as managers of specific BE functional areas. They are responsible to either the flight commander or the noncommissioned officer in charge (NCOIC) for their specific functional areas; however, the reporting chain is through team leads. Additionally, this approach may be used to assign responsibility within a geographical area of the installation. Under this construct, teams accomplish all BE-related duties associated with their assigned AOR. This approach cuts across the boundaries of the traditional BE functional areas, encouraging flexibility and cross-flow of training and experience.

Regardless of the structure, BE team members are still responsible for executing explicit tasks and meeting specific OEH responsibilities. Our role in team aerospace is accomplished by promoting and maintaining the health and well-being of the operational, industrial, and community environments, enabling commanders to achieve the overall mission.

Our training prepares us to handle most problems or needs that might arise during the course of a duty day. Still, there are times we need help or input from other agencies.

004. Roles and interactions of bioenvironmental engineering with other agencies

By the nature of your work, you will occasionally need to interact with agencies and committees inside and outside the Air Force. Let us start by taking a brief look at the installation agencies with whom you may interact. Air Force Instruction (AFI) 91–202, *The US Air Force Mishap Prevention Program,* and AFI 48–145, *Occupational and Environmental Health Program,* give more detailed descriptions of each agency's involvement in OEH activities and are good sources of information. You should become familiar with these instructions.

Air Force agencies

As program partners, several agencies support OEH RM activities, to include recognition, identification, mitigation and control of OEH hazards; health education; medical examinations; injury and illness prevention and reporting; assignment of risk assessment codes (RAC) to OEH hazards in coordination with safety; and lost workday and compensation claim reduction.

Ground safety office

The installation ground safety manager is responsible for managing the occupational safety program. They conduct workplace safety inspections/assessments and report their findings to the appropriate management officials. BE and the wing safety office (SE) participate together in various installation working groups such as the Installation Hazardous Material Management Program (IHMP), the RAC program, and the confined space program team (CSPT) addressing health and safety issues. As program partners, BE team members notify the SE of any safety discrepancies noted during OEH surveillance activities.

Civil engineering environmental flight

The base environmental coordinator (BEC) manages the hazardous waste program, among other responsibilities. You will also work closely with the BEC and utilities flight to resolve issues related to the drinking water system; for example, water main breaks, water quality issues, and reporting test results.

Fire and emergency services

As first responders, the civil engineering fire department (CEF) plays an important emergency management role establishing initial command and control at a disaster scene. While fire department personnel are trained for hazardous material (HAZMAT) operations, the BE team provides expertise and advice on proper protection, hazard assessment (identification and quantification), and HRA. Specific actions will depend on the type of incident and response. CEF will also establish gross decontamination for responders and victims. BE team members must evaluate this process and advise the incident commander of any health risks to the receiving health care facility, transportation, or medical care providers. CEF also participates in IHMP and CSPT.

Civil engineering emergency management

Civil engineering emergency management (CEX) coordinates base response operation plans (OPLAN) and base comprehensive emergency management plan (CEMP) that involve BE input. They also have similar direct reading equipment and work closely with BE in joint training at least once a month. The emergency management flight plays an important role in facilitating response efforts during emergencies. The emergency management flight primarily coordinates the response elements by facilitating on-scene command, control, and communications. It also provides an initial hazard estimate in the form of a hazard plot, and in some cases, an initial detection. The BE team takes the initial assessment to the next levels (identification and quantification of the hazard). In some cases, BE uses chemical plots provided by CEX or other software to supplement the hazard identification process.

Other civil engineering agencies

Design engineers may consult with BE to ensure plans for new construction or modifications to existing facilities meet occupational safety and health requirements for potentially hazardous operations that will occur in the facility. Each Air Force Form 332, Base Civil Engineer Work Request, must be coordinated through BE before civil engineering can begin work.

Public health

PH personnel are our partners in OEH surveillance. They apply preventive and public health techniques to reduce and control the incidence of communicable diseases and occupational illnesses. Following OEH surveillance and assessment of exposures performed by BE, PH further evaluates findings for occupational examination recommendations as part of the medical surveillance program. The Occupational and Environmental Health Working Group (OEHWG) reviews and approves these recommendations. BE and PH also work together to resolve community health issues such as indoor air quality, recreational swimming pools and bathing areas; further, they collaborate on work-related illness investigations.

Air Force Medical Support Agency – bioenvironmental engineering

AFMSA/SG3PB is a field-operating agency of the AFSG. Representatives from each of the medical functions, including BE, develop policy and guidance for their respective functional areas of the AFMS. Many BE-specific occupational and environmental health directives originate from this office.

Major command – bioenvironmental engineering

As previously mentioned, each MAJCOM headquarters has its own BE officer—major command bioenvironmental engineering (MAJCOM/BE). This individual advises the command surgeon and provides guidance and assistance to installation-level BE flights. Further, the MAJCOM/BE helps interpret AFMSA policy, develops supplemental information to policy as it applies to the respective MAJCOM, and is an approval authority for variances to policy. At overseas locations, the MAJCOM/BE acts as the approving authority for drinking water laboratory certification to operate.

The major command functional manager (MFM) manages enlisted manning and training issues within the respective command. Information that the MFMs receive from the CFM is disseminated to NCOICs or superintendents at all facilities within their respective command. The MFMs also act as liaisons for the facilities by communicating concerns to the CFM. BE flight leadership must be proactive and recognize when concerns should be elevated to the MAJCOM/BE, such as certain funding matters or personnel issues, or the base receives a notice of violation for a compliance issue.

United States Air Force School of Aerospace Medicine

Along with education and training, the United States Air Force School of Aerospace Medicine (USAFSAM) provides many other analytical and consultative services. The chemistry laboratory provides chemical analytical services for OEH surveillance samples. They also provide consultative services for assessing contract laboratories, sample collection and analysis, data interpretation requirements, and field analytical equipment operations. The Environmental Safety and Occupational Health division furnishes consultation and field support in industrial hygiene, risk assessment, occupational medicine, ergonomics and noise. They provide to all AF installations many of the same BE services that you provide to your installation on a day-to-day basis. Their services help to accomplish tasks that require specialized training or knowledge otherwise left undone due to manning or resource shortages. The Air Force Center for Radiation Dosimetry manages the Air Force Personnel Ionizing Radiation Dosimetry Program and radioanalytical assessment laboratory and consultation. The USAFSAM’s Air Force Radiological Assessment Teams (AFRAT) can assess hazards when a radiological or nuclear threat exists. We will discuss AFRAT teams in more detail later in the unit.

United States Air Force Radioisotope Committee

The Nuclear Regulatory Commission (NRC) has granted a master material license to the AF for managing licensed radioactive material used by AF agencies. The USAF Radioisotope Committee (RIC) maintains the master material license, issues permits to users, and is responsible for establishing guidance pertaining to use and disposal of licensed radioactive material to ensure compliance with federal regulations. The installation’s radiation safety officer (RSO) (usually a BE officer) manages the acquisition, inventory, storage, use, transfer, disposal, and transportation of radioactive material on the installation. The RSO interfaces with the RIC on matters related to these activities.

Air Force Inspection Agency

The Air Force Inspection Agency (AFIA) provides periodic independent assessments of AF operations to SECAF, CSAF, Air Force Inspector General, and MAJCOM commanders. The Medical Operations Directorate performs health services inspections assessing medical readiness, management effectiveness, and quality of healthcare delivery at Air Force medical units—they will inspect your programs and work. Additionally, by agreement with the NRC, AFIA inspects radioactive material permits held by the USAF. The AFIA identifies critical deficiencies that exist within medical programs and recommends improvements for accomplishing the mission.

Federal agencies

A discussion of federal and civilian agencies that may be helpful to you in conducting day-to-day tasks could be endless. The idea behind mentioning these few agencies and committees and their roles is to let you know you are not alone with your important responsibilities. Whenever you need to seek guidance from an agency outside the military structure, you should not do so without your supervisor's knowledge and approval. Additionally, when dealing with commanders, make sure you notify your commander and supervisor. When interacting with these customers and organizations, treat them as you would expect to be treated.

The Environmental Protection Agency

The Environmental Protection Agency (EPA) is responsible for designing and enforcing programs that guarantee the continued safety and purity of our environment. Preventing pollution in the air, water, and soil are the agency's domain. The EPA may delegate to states the responsibility for issuing permits, and monitoring and enforcing compliance, or they may retain the right for themselves. It may be necessary to interface with federal or state EPA officials when establishing and conducting community health surveillance such as drinking water monitoring requirements and reporting a violation of a drinking water standard. BE and the base civil engineer (CE) work jointly to resolve such issues, in conjunction with EPA or state officials.

Occupational Safety and Health Administration

Occupational Safety and Health Administration (OSHA) is the Department of Labor agency that provides the regulation, guidance, and enforcement necessary to meet requirements of the Occupational Safety and Health Act. This act ensures every employee in the US receives a safe and healthful workplace. OSHA standards are used to evaluate AF workplaces and to train AF civilian and military workers. You will be involved with evaluations of workplaces and continuing education of workers exposed to the hazards identified in their respective work areas. OSHA inspectors may visit your base from time to time. You may be asked to accompany the visiting inspectors.

Meetings and work groups commonly attended by bioenvironmental engineering

Many committees, working groups, and teams will require your participation and support to accomplish the mission. Some of these assemblies are universal throughout the Air Force, while others are unique to specific bases.

Aerospace Medicine Council

The Aerospace Medicine Council (AMC) is a collective decision-making body responsible for the functional oversight of the AMP. The AMC established objectives and requirements for the base AMP; determines methods for improving the program; and periodically reviews requirements for functional areas within the AMP. The council is comprised of representatives from each flight within the AMP and chaired by the Chief of Aerospace Medicine. Council members, normally flight commanders and NCOICs, meet periodically to discuss the status of their respective functional areas and any other issues pertaining to AMP-specific resources, personnel, and training.

Occupational and Environmental Health Working Group

The OEHWG usually meets once per month to review and discuss OEH issues, such as industrial hygiene surveillance results, proposed occupational health education, and examination recommendations. The status of major OEH programs and key metrics are discussed and analyzed for trends. Normally, the BE, PH, and occupational health physician attend this meeting.

Environment, Safety, and Occupational Health Council

The Environment, Safety, and Occupational Health Council (ESOHC) is the cornerstone of the Environment, Safety, and Occupational Health Program and provides senior leadership involvement and direction. This forum meets at least semi-annually to discuss and report to the installation commander matters and solutions related to environmental programs, environmental health, fire protection, safety, and occupational health. Membership includes representatives from civil engineering, financial management, civilian personnel flight, safety, fire protection, PH, BE, and civilian employee representatives. BE-related issues discussed at the forum include such topics as the industrial hygiene program, hazard abatement and respiratory protection, the confined space program, radiation protection program, and issues with the drinking water program.

Threat working group and force protection working group

Senior BE leadership attends these forums to provide health-risk information in decision making for protecting the base. The knowledge BE team members have regarding drinking water vulnerability assessment (WVA) and toxic industrial chemical/toxic industrial material (TIC/TIM) is particularly relevant here.

005. Bioenvironmental engineering unit type codes

BE capabilities are required during all three deployment phases: an initial build-up or deployment phase (also called the “ramp-up phase”) where forces are deployed into an area of operation; sustainment phase, characterized by activities geared towards accomplishing the mission; and ramp-down or redeployment phase. Recall our earlier discussion in figure 1–7 regarding the BE Strategic Objective: *Garrison = Deployed*. The important role as health risk assessor you fulfill in-garrison continues during deployed operations. In deployed situations, the mission may depend on effective delivery of BE capabilities. Every BE team member must be ready to do their part. Let us look at a few of the unit type codes (UTC) that include BE capabilities.

Medical global reach laydown team

The medical global reach laydown (MGRL) team provides initial preventive medicine capability and limited medical care specifically for an air mobility squadron’s Tanker Airlift Control Element personnel within Air Mobility Command (AMC). The MGRL team supports AMC’s rapid global mobility contingency and emergency relief operations. The MGRL team consists of four personnel in the aerospace medicine, PH, and BE specialties, minimally equipped to provide initial capability during base laydown operations.

The MGRL team provides public health, occupational, environmental, disease surveillance, intervention, and abatement to ensure safe, healthy working and living environments. It also provides for a safe food and water supply. The team often uses expertise/experience to identify and resolve threats. Being at the start of a deployment, the MGRL team is in a position to conduct pre-deployment assessments and influence both site selection and base infrastructure during laydown operations.

The team includes one BE officer (43E3A) or BE craftsman (4B071) as a substitute. The MGRL team initiates the OEHSA process by providing initial HRA and threat control recommendations.

Preventive and aerospace medicine team

The preventive and aerospace medicine (PAM) team travels light and is extremely mobile so it can provide timely preventive medicine requirements to meet the needs of the entire population at the beddown location. The team consists of nine personnel from aerospace medicine, PH, and BE specialties in three increments (with UTCs FFPM1/2/3) to provide expertise throughout the spectrum of preventive medicine activities. The increments can deploy together or in stages. The first and second increments provide initial capability, and the third increment provides expanded capabilities and sustainment for extended operations.

Collectively, the PAM team evaluates the safety and vulnerability of local food and water sources, performs epidemiological risk assessment, evaluates local medical capabilities, performs vector/pest risk assessment, determines adequacy of local billeting and public facilities, provides medical intelligence, and performs a hazard or environmental risk assessment. It also recommends locations for the medical facilities and addresses infrastructure needs such as water and waste disposal. The PAM team provides medical input into the proper lay down of food, waste, and sanitation facilities at forward operating locations for control of disease vectors. The PAM team leader is the functional expert in casualty prevention.

The team employs the OEHSA process to perform health threat/risk assessments, health hazard surveillance, and recommend health hazard control and mitigation measures. A BE officer (43E3) and two technicians (4B071, 4B051) provide expertise in water quality, water distribution system analysis, industrial hygiene, radiation safety, waste management (biological, refuse, and human waste), hazardous material incidents, and hazardous material management. The equipment package (with UTC FFPM4) includes water, soil, air and physical hazard analysis instruments.

Medical nuclear, biological, and chemical

The medical nuclear, biological, and chemical (MNBC) team (with UTC FFGL1) consists of three BE personnel that conduct nuclear, biological, and chemical (NBC) surveillance, advise commanders on NBC health effects, threat impact, protective action posture, recovery activities, and human HRAs. The team is primarily a contingency asset deployed to, or activated at, base operating locations whenever an NBC threat is present or developing; however, it can also deploy for military support to civil authorities.

The MNBC team performs environmental sampling for CBRN agents, analyzes the data to identify and quantify human health hazards, and performs risk assessments based on sampling and analysis results. In working together with CE, the MNBC team provides mission-oriented protective posture (MOPP) recommendations to the commander. The MNBC team augments the PAM team on deployed sites in NBC threat environments and interfaces with biological augmentation, medical decontamination, theater epidemiological, and CE readiness teams. Together, these teams provide comprehensive medical NBC defense capability at a beddown location in an NBC threat environment.

The MNBC team provides support to the air base in the areas of contamination avoidance, protection, and contamination control. The team performs specialized and confirmatory sampling of suspected NBC contamination. This consists of collection, analysis and monitoring of air, soil, water and other environmental samples. When needed, the team will preserve, package, and ship samples for more comprehensive analysis. The team consists of one BE officer (43E3) and two BE journeymen (4B051). The MNBC team is assigned an equipment package (with UTC FFGL7 and allowance standard 902B), and consists of sampling, analysis and monitoring equipment for chemical, biological, and radiological hazards.

For those AFRAT UTCs that include manpower, the following table summarizes team composition. Team members have expertise in areas of health physics, environmental monitoring, and radiation measurement. AFRAT forces perform radiological assessments that include conducting dose rate measurements, measurements of air concentrations and ground depositions, and radioactive plume modeling. They will collect soil, water, air, and foodstuffs, as well as, breathing air, urine, and feces samples as appropriate.

Team Composition Summary			
AFRAT Component Teams By UTC	**BE Officer**	**BE Enlisted**	**Med Lab**
FFRN1: Med Rad/Nuc Crisis Advon Team (RCAT)	2	-	-
FFRN2: Med Rad/Nuc Surveillance Team (RST)	2	4	-
FFRN3: Med Rad/Nuc Surveillance Augmentation Team (RSAT)	2	9	-
FFRN4: Med Rad/Nuc Laboratory Team (RLT)	1	1	1
FFRN5: Med Rad/Nuc Laboratory Augmentation Team (RLAT)	1	4	2
FFRN6: Med Rad/Nuc Dosimetry Team (RDT)	1	1	1
FFRN7: Med Rad/Nuc Dosimetry Augmentation Team (RDAT)	1	1	1

Air Force Radiation Assessment Team

The AFRAT (FFRN1, FFRN2, FFRN3, FFRN4, FFRN5, FFRN6, FFRN7) is a rapid global response capability that provides the manpower, equipment and health physics expertise support to the on-scene commander following a radiation accident/incident. The AFRAT includes the advanced echelon (ADVON) team. Consequently, the mission of AFRAT is to assist in planning, measurement, assessment, and mitigation of all types of personnel, operational, and environmental risks associated with radiation/nuclear (RAD/NUC) hazards. The AFRAT is sub-divided into 10 UTCs of various equipment and personnel (BE and medical laboratory) configurations. Activation of these assets would be scaled to the specific mission needs of the incident.

AFRAT forces identify and analyze radiological hazards, assess the risks and recommend force protection measures. They provide expert guidance on what radiological threats exist, what measures can be taken to minimize troop and non-combatant exposures to radiation, and what radiation doses deployed forces actually receive. Typical deployment scenarios will include consequence management operations from nuclear weapons accidents, nuclear reactor accidents, and terrorist use of radiological dispersion devices (dirty bombs), improvised nuclear devices, or humanitarian assistance operations to countries that have experienced a nuclear exchange, incidents, or accidents.

As a UTC member, you have many responsibilities. Ensuring the team is well trained and maintaining the appropriate functional equipment are the key factors to success. Take care to routinely and critically assess capabilities and identify gaps that may be present to obtain and maintain readiness.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

003. Mission and organization of bioenvironmental engineering

1. Cite the BE mission within the AOME.

2. How does BE fulfill its responsibilities in support of the AFMS effects-based mission area of preventing illness and injury?

3. Describe the role a BE technician has in supporting the AFMS mission.

4. Regardless of the structure of the flight, what are BE team members' responsibilities, and how are they accomplished?

004. Roles and interactions of bioenvironmental engineering with other agencies

1. What organization would be notified if a safety discrepancy was noted during an OEH assessment visit?

2. Which base agency would BE team members work closely with on community health issues such as indoor air quality or recreational swimming areas?

3. Describe the role of the MAJCOM/BE, to include overseas locations.

4. When might BE personnel work together with officials from the Environmental Protection Agency, or with state officials?

5. At what meeting group would topics such as industrial hygiene surveillance results and proposed occupational health education and examination recommendations be discussed?

005. Bioenvironmental engineering unit type codes

1. Describe how the medical global reach laydown team initiates the OEHSA process.

2. Outline the areas of expertise that BE personnel would provide when assigned to the PAM team.

3. Provide a description of the MNBC team.

4. Which unit type code is primarily a contingency asset deployed to, or activated at, base operating locations whenever a chemical, biological, or nuclear threat is present or developing; however, can also deploy for military support to civil authorities?

5. Which response capability mobilizes to provide on-site manpower, equipment, and health physics support to identify and analyze radiological hazards, assess the risks, and recommend force protection measures following a radiation accident/incident?

Answers to Self-Test Questions

001

1. The AFSG is the leader of the AFMS and establishes its medical service mission, making sure it supports the Air Force mission.
2. (1) Promoting and sustaining a medically ready force.
   (2) Prevent illness and injury.
   (3) Restore health.
   (4) Optimize and sustain human performance.
   (5) Systematize high reliability throughout the Aerospace & Operational Medicine Enterprise
3. Preventive medicine activities ensure the force is available to accomplish the mission. Health services for this effect include identifying, assessing and controlling hazards from the full spectrum of health hazards encountered in garrison or deployed environments. It also includes communicating associated hazard risks so commanders understand the potential outcomes of exposure, and providing solution sets for managing hazards while continuing the mission.
4. SECAF and the CSAF. The SECAF is charged with policy and oversight of the department. The CSAF is responsible for organizing, training, and equipping AF units to meet combatant commander requirements.
5. Mission, size, and capabilities of the organization.
6. (1) Flight medicine.
   (2) Missile medicine.
   (3) Space medicine.
   (4) Space and missile medicine.
   (5) Health promotion
   (6) Public health.
   (7) Bioenvironmental engineering.
   (8) Aerospace physiology.
   (9) Aeromedical staging.
   (10) Occupational medicine.
   (11) Optometry.

(12) Hyperbaric medicine.

(13) Audiology.

It also may include dental operations when an MTF does not have a dental squadron.

002

1. (1) Promote and sustain a medically ready force.
   (2) Prevent illness and injury.
   (3) Restore health.
   (4) Optimize and sustain human performance.
   (5) Systematize high reliability through the AOME.
2. (1) f.
   (2) b.
   (3) h.
   (4) j.
   (5) g.
   (6) a.
   (7) e.
   (8) i.
   (9) c.
3. The Aerospace Medicine Council.

003

1. Provide operational HRA expertise to enhance commander decision making and health service support capabilities.
2. By providing the capabilities to identify, analyze, and control OEH hazards.
3. BE technician activities optimize combat capabilities by preventing illness or injuries and enhancing performance in the deployed and in-garrison environments.
4. Responsibilities include executing explicit tasks and meeting specific occupational and environmental health responsibilities; this is accomplished by promoting and maintaining health and well-being of the operational, industrial, and community environments, enabling commanders to achieve the overall mission.

004

1. SE.
2. PH.
3. Advises the MAJCOM’s command surgeon and provides guidance and assistance to installation-level BE flights. Further, the MAJCOM/BE helps interpret AFMSA policy, develops supplemental information to policy as it applies to the respective MAJCOM, and is an approval authority for variances to policy. At overseas locations, the MAJCOM/ BE acts as the approving authority for drinking water laboratory certification to operate.
4. When establishing and conducting community health surveillance such as drinking water monitoring requirements and reporting violations of a drinking water standard.
5. The OEHWG.

005

1. The team initiates the OEHSA process by providing initial health risk assessment and threat control recommendations.
2. Expertise in water quality, water distribution system analysis, industrial hygiene, radiation safety, waste management, hazardous material incidents, and hazardous materials management.
3. Three BE personnel that conduct nuclear, biological and chemical surveillance, advises commanders on associated health effects, threat impact, protective action posture, recovery activities, and human HRAs.
4. MNBC team.

5. AFRAT.

Complete the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field-Scoring Answer Sheet.

Do not return your answer sheet to the Air Force Career Development Academy (AFCDA).

1. (001) Who establishes the mission of the Air Force Medical Service?
   a. Air Force Surgeon General.
   b. Secretary of the Air Force.
   c. Chief of Staff of the Air Force.
   d. Major Command Surgeon General.

2. (001) Ensuring medically fit forces, providing expeditionary medics, and improving the health of all we serve to meet our nation's needs is *best* described as a part of the Air Force Medical Service's
   a. values.
   b. vision.
   c. mission.
   d. strategy.

3. (001) The prevent illness and injury effect can *best* be described as the
   a. ability to achieve Air Force Medical Service objectives.
   b. war-fighting skills the medics bring to deployment.
   c. health service support in garrison or deployed environments.
   d. defensive measures medics provide during contingency operations.

4. (001) Which Air Force Medical Service effects include identifying, assessing and controlling health hazards?
   a. Restore health.
   b. Prevent illness and injury.
   c. Optimize and sustain human performance.
   d. Promote and sustain a medically ready force.

5. (002) Optimizing force health and warfighter performance is *best* described as a part of the Aerospace & Operational Medicine Enterprise's
   a. vision.
   b. values.
   c. strategy.
   d. mission.

6. (002) All aerospace medicine squadron (AMDS) members working together to accomplish the mission *best* describes
   a. aerospace vision.
   b. aerospace mission.
   c. the team aerospace concept.
   d. the aerospace working group.

7. (002) The team aerospace concept is *best* illustrated by members of
   a. bioenvironmental engineering (BE) working together with base safety and the fire department to correct health hazards.
   b. health promotions providing stress management education to all installation agencies.
   c. public health and BE working together to prevent and manage occupational injuries.
   d. public health educating and training industrial shop workers.

8. (002) Which of the following examples *best* illustrates the team aerospace concept?
   a. Public health (PH) and bioenvironmental engineering (BE) team members working together to investigate a possible waterborne illness.
   b. A flight medicine technician performing an occupational physical exam on a fellow aerospace medicine squadron (AMDS) member.
   c. Fire department and the base safety office working with BE to correct health hazards.
   d. A health promotion technician conducting stress management classes.

9. (003) Providing health risk assessment capability to enhance a commander's decision making is part of the bioenvironmental engineering (BE)
   a. values.
   b. vision.
   c. mission.
   d. strategy.

10. (003) Which example *best* describes the bioenvironmental engineering (BE) primary capability of conducting predictive exposure assessments?
    a. Use occupational and environmental health (OEH) data for predicting potential exposures.
    b. Effectively anticipate and recognize when physical health threats exist.
    c. Recommend measures to eliminate or control physical health threats.
    d. Responds to both deliberate and crisis events.

11. (004) Which agencies would bioenvironmental engineering interface with to correct a drinking water standard violation?
    a. Air Force Inspection Agency and the Environmental Protection Agency.
    b. Air Force Medical Operations and the Air Force Inspection Agency.
    c. Civil engineering and the Environmental Protection Agency.
    d. Civil engineering and the Air Force Inspection Agency.

12. (004) Which agency would you consult for assistance when interpreting an Air Force Medical Support Agency policy?
    a. The major command's (MAJCOM) bioenvironmental engineering.
    b. United States Air Force School of Aerospace Medicine.
    c. Occupational, Safety and Health Administration.
    d. Air Force Medical Service.

13. (004) Which forum meets once per month to review, discuss, and approve issues such as industrial hygiene recommendations?
    a. Environmental, Safety and Occupational Health Council.
    b. Occupational and Environmental Health Working Group.
    c. Aerospace Occupational and Environmental Council.
    d. Aerospace Medicine Council.

14. (005) If your responsibilities at a deployed location include performing vulnerability assessments, health hazard surveillance, and drinking water sampling, then you are a member of the
    a. Medical nuclear, biological and chemical (MNBC) team.
    b. Preventive and aerospace medicine (PAM) team.
    c. Medical global reach laydown team.
    d. Air Force radiation assessment team.

15. (005) If you are deployed following a radiological incident and asked to identify the radiological environment along with providing recommendations for protective actions then, you are a member of the
    a. medical nuclear, biological and chemical (MNBC) team.
    b. preventive and aerospace medicine (PAM) team.
    c. medical global reach laydown team.
    d. Air Force radiation assessment team.

16. (005) If you are deployed for the purpose of identifying the radiological environment and recommend protective actions to insure the health and safety of personnel and the surrounding community following radiological incidents, then you are a member of which unit type code (UTC)?
    a. Medical nuclear, biological and chemical (MNBC) team.
    b. Preventive and aerospace medicine (PAM) team.
    c. Medical global reach laydown team.
    d. Air Force radiation assessment team.

Please read the unit menu for unit 2 and continue ➔

Unit 2. Chemistry

CHEMISTRY IS AN IMPORTANT part of your life. One way or another, chemistry permeates every aspect of BE. The mixing of reagents and buffers in the laboratory, the evaluation of pollution control measures, the interpretation of air sampling results, even the tracking of industrial materials all involve some form of chemistry.

What do you think when you hear the word *chemical*? Did you know that chemicals are not limited to laboratory environments? Chemicals are everywhere. Your body is a collection of chemicals, the most abundant of which is water. Therefore, we can say that when we study chemistry, we also are studying life. Figure 2–1 illustrates the various elements that comprise the field of chemistry.

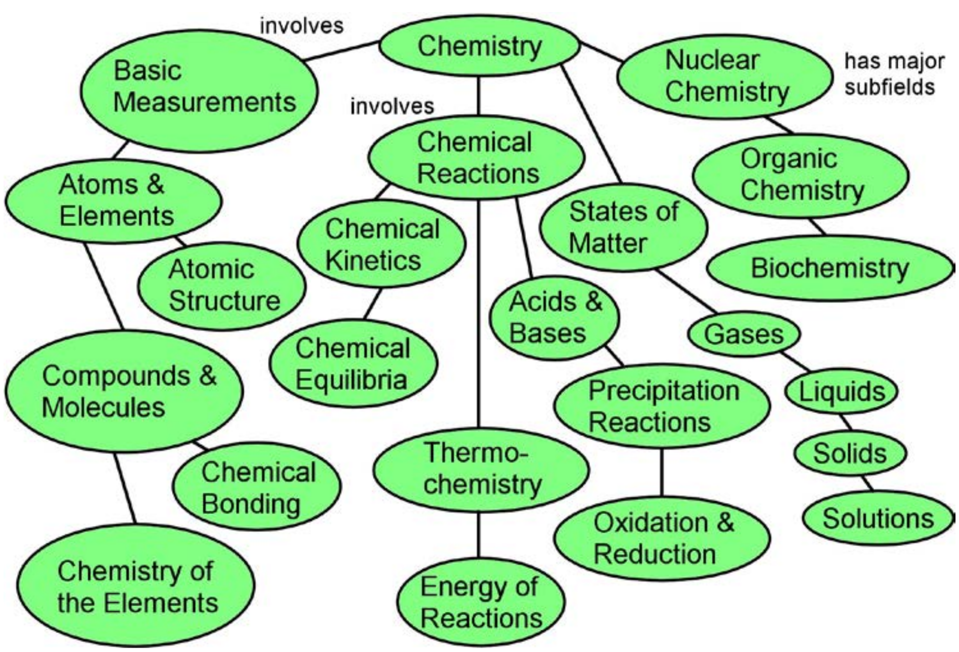


Figure 2–1. Chemistry concepts.

You already know one of the most important things about chemistry—it is a science. Chemistry is the science concerned with the composition of substances and the changes they undergo. For example, chemistry is concerned with the components of water (composition) and the interactions between water and other substances. Take a moment to review some of the more common terms and definitions that apply to chemistry's basic concepts in the glossary. You probably recall many of these terms and definitions from your high school chemistry classes. The goal of this unit is simple: to help you learn chemistry.

As we said before, chemistry is the study of substances (matter) and the changes they undergo. Everything on Earth, everything in our solar system, everything in our galaxy, and everything in the universe is made of matter. Matter is the name that scientists have given to everything that you can touch, or see, or feel, or smell.

2–1. Basic Properties of Matter

We can define matter as anything that has mass and occupies space. Notice that in this definition we use the term *mass* and not *weight*—although many people consider them one in the same. Mass is how much stuff you are made of, and it is the same whether you are on Earth, on the moon, on Mercury, or anywhere else that comes to mind. Gravity holds you on Earth; gravity pulling on your mass is your weight.

006. Physical states of matter

Matter has three basic forms: solid, liquid and gas. The physical state depends on the temperature, atmospheric pressure and specific characteristics of the particular type of matter. A solid has a definite shape and volume. When enough heat is applied to a solid, it becomes a liquid, which has definite volume but lacks shape. Of the three basic forms of matter, a liquid cannot be compressed; it, therefore, will take the shape of its container. When enough heat is applied to a liquid, it becomes a gas, which lacks both volume and shape. In contrast to a liquid, a gas can be compressed to fill a container with a smaller volume than the original volume of the gas. Upon release from the container, the gas quickly diffuses (spreads out) to fill a larger area. Some matter can actually exist in all three states whereas other matter will break down into new substances when attempting to change its physical state.

007. Composition and properties of matter

Regardless of its physical state (solid, liquid, or gas), all matter is either *homogeneous* or *heterogeneous*. The difference lies in the fact that homogeneous matter is uniform in composition and properties while heterogeneous matter is not. For example, an office consisting of all women is comparable to homogeneous matter, while a workplace of both women and men is comparable to heterogeneous matter. Figure 2–2 summarizes the organization of matter.

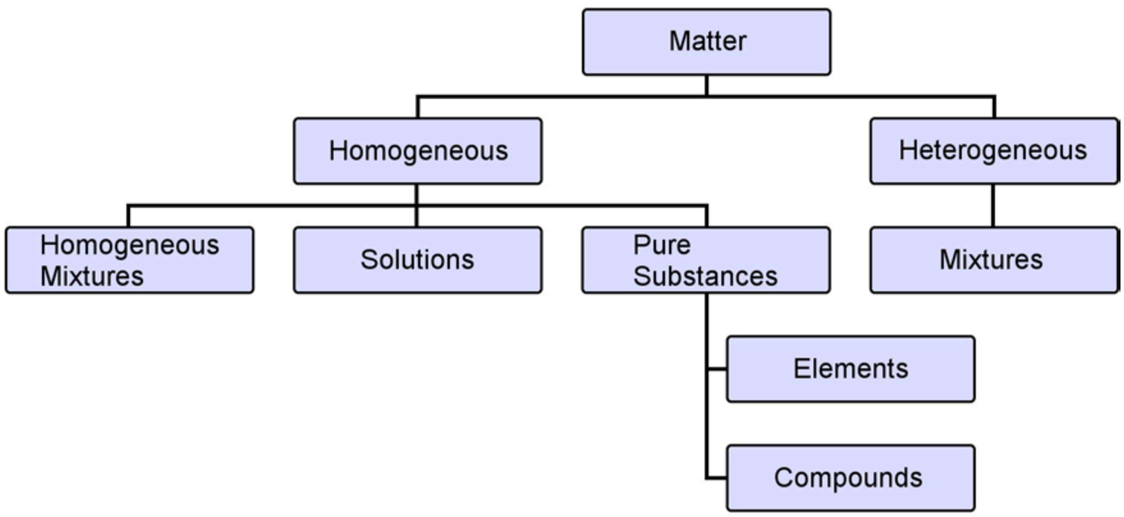


Figure 2–2. Organization of matter.

Homogenous matter divides into three categories: homogeneous mixtures, solutions, and pure substances. Mixtures of gases are generally referred to as homogeneous mixtures. Solutions are homogeneous mixtures consisting of gases, liquids, or solids dissolved in liquids.

A solution is a homogeneous mixture in which one pure substance evenly disperses in another pure substance. The dispersed substance is normally the lesser quantity and is called the solute. Whatever the substance is dispersed into possesses greater quantity and is the solvent. We typically think of a solution as having some solid dissolved in a liquid—for example, sodium hydroxide (solute) dissolved in water (solvent). The following are some common examples of solutions:

- Sugar solutions—sugar dissolved in water.
- Salt solutions—salt dissolved in water.
- Alcohol solutions—ethyl alcohol dissolved in water.
- Vinegar solutions—acetic acid dissolved in water.

In some instances, solids can dissolve in other solids to form solid solutions. A good example of a solid solution is brass, which consists of zinc dissolved in copper. Since solutions are mixtures, remember that each component retains its own properties and can be easily separated from the others; they are not in chemical combination.

Pure substances differ from homogeneous mixtures and solutions in that they have distinct and constant compositions. Further, they are divided into two groups: elements and compounds. Conversely, mixtures and solutions consist of two or more pure substances in variable proportions.

An element is a pure substance that cannot be broken down into a simpler substance by ordinary chemical means. An atom is the smallest particle of an element that possesses the chemical properties of that element. Each atom is composed of three fundamental particles that are best described in terms of their electrical charge and mass (fig. 2–3).

The proton, abbreviated p or p^+, has a *positive* electrical charge (+1) and a mass of approximately one atomic mass unit (AMU). The number of protons in a nucleus is called the *atomic number*—this number determines the element. The next particle is the neutron, abbreviated n or n^0, which has no electrical charge and a mass of approximately 1 AMU. Since protons and neutrons are both found in the nucleus of the atom, the total number of protons and neutrons within an atom is called the *mass number*. Slight variations in the number of neutrons found in the nucleus of the atom result in different atomic masses but may not affect the chemical properties of the element. The third particle of an atom is the electron. The electron, abbreviated e^-, has a negative electrical charge (–1) and a mass of 0.0005486 AMU (which is considered negligible for most practical purposes). The electrons exist in orbit around the nucleus. Each higher orbit from the nucleus represents a higher energy level of the electron.

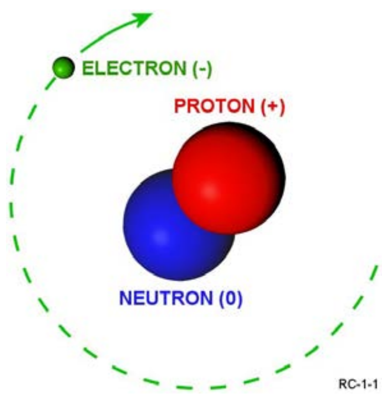


Figure 2–3. Composition of an atom.

The number of protons, neutrons, and electrons in an atom can be determined from a set of simple rules:

- The number of protons in the nucleus of the atom is equal to the *atomic number* (*Z*).
- The number of electrons in a *neutral* atom is equal to the number of protons.
- The *mass number* of the atom (*M*) is equal to the sum of the number of protons and neutrons in the nucleus.
- The number of neutrons is equal to the difference between the *M* and the *Z*.

The properties of chemical elements depend on the structure of the atom and vary with atomic number. Since the periodic table is arranged by the atomic number, elements having similar chemical properties conveniently line up in the same group.

008. Periodic table of the elements

As you can see, the periodic table is organized like a giant grid (fig. 2–4). The elements are located in specific places within the table because of the way they look and act. As previously noted, elements with similar properties are aligned in the columns called groups. The elements in each group all have the same number of valence electrons in their outer shells. The horizontal rows indicate the orbits and number of electrons in the outer shells—increasing from left to right and top to bottom. The far right column reflects inert material, better known as the noble gases. Their outer orbitals are full with electrons and have no advantage to react with anything else. Therefore, these elements are inert (not reactive).

Two major groups you should be familiar with are the alkali metals (fig. 2–4, Column IA) and the halogens (fig. 2–4, Column VIIA). The alkali group elements are considered metals—they have luster and conduct heat and electricity. All the elements within this group react vigorously with water to form a basic solution while releasing hydrogen gas. The halogens are considered non-metals and are also very reactive. They react with water to form acid compounds but release no hydrogen. Due to their high reactivity, halogens commonly combine with organic compounds to form dangerous chemicals that can be toxic to humans.

The main value of the periodic table is the ability to predict the chemical properties of an element based on its location within the table.

Shown on the following page (fig. 2–4), the periodic table shows the positive valence elements running toward the left and the negative toward the right. This is not a random arrangement. Remember that the table is arranged in order of the number of protons. Since the number of electrons equals the number of protons, you can also say that the table is arranged according to the electrons. You may have noticed by now that elements with the same valence tend to be in the same vertical columns, or groups. As you can see, the periodic table is a very clever device for showing the arrangement of electrons and, therefore, the valences and combining abilities of the elements.

Figure 2–4. Periodic table of elements.

Atomic weight

The atomic weight of an element closely relates to its mass number. They are approximately the same value. Whereas the mass number represents the combined number of protons and neutrons, the atomic weight is based on a comparison to a standard. The standard we use is based on an arbitrarily assigned value of exactly 12 AMUs for a single atom of carbon-12. All other atomic weights are based on 1/12 (1 AMU) of the carbon-12 atom. For example, the mass of the lightest isotope of hydrogen is about one (1.007825) AMU. An AMU, being about the same mass as a proton or neutron, is a very handy unit. Its mass is only 1.66×10^{-24} grams; therefore, you can see that it is much more practical to express the masses of atomic particles in AMUs.

If you take the numerical value of an atomic weight of a given element and simply add the unit grams to it, you have the gram atomic weight. To show the relationship of grams and AMU, you can say that one gram of any element contains 6.02×10^{23} AMU.

Valence

The electrons determine the ways elements combine with each other. Electrons are arranged in orbits called shells at varying distances from the nucleus. For any given atom, there are a definite number of electrons a shell can hold. There can be no more than two in the innermost shell (the shell closest to the nucleus), no more than eight in the second shell, and never more than eight in the outermost shell. It is this outermost or outer shell we are mainly interested in—this is where most of the reaction activity takes place.

If an outer shell contains all of the possible electrons it can hold, it is considered full—or satisfied; meaning the atom will not combine with any other. This is defined as being inert. All inert elements appear on the right side of the periodic table. These include the noble elements such as helium, neon, argon, krypton, xenon, and radon. Each has its outer shell completely full—so they will not give, receive, or share electrons with another element. This brings us back to the topic of a valence, which is the number of electrons (called valence electrons) an atom will give, receive, or share with another in a chemical reaction to become more stable and have a full shell.

Valence can be positive or negative. Just as eight is the magic number for a satisfied outer shell, one-half that number (four) is the critical point for determining a positive or negative valence. Any element with more than four outer electrons has a negative valence. This means that the number of electrons is close to eight but lacks (negative) just a few. It will receive electrons from an element with a positive valence to fill the gap. An element with fewer than four outer electrons has a positive valence. It can be viewed as having a slight excess (positive) of electrons that it will give up. This is somewhat like saying that the previous shell was filled up and a few were left over to start a new shell. Figure 2–5 shows the formation of a water molecule (H_2O) from oxygen (valence –2) and hydrogen (+1). Note that it takes two hydrogen atoms to match oxygen's –2 valences.

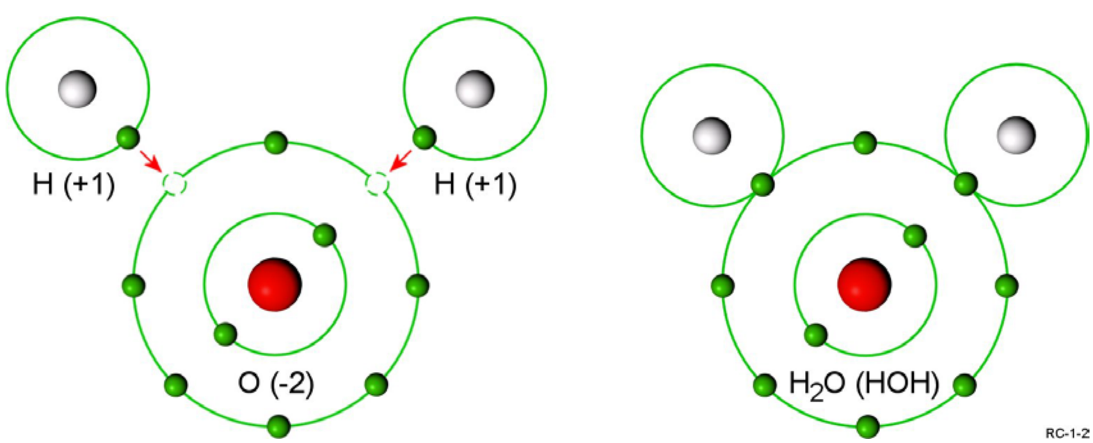


Figure 2–5. Formation of water (H_2O).

So what happens when the valence is exactly four?

Taking carbon as the best example, a valence of four can be positive or negative depending on the combined element. The valence of carbon is –4 when it combines with hydrogen (which has a valence of +1) to form methane (CH_4) (fig. 2–6).

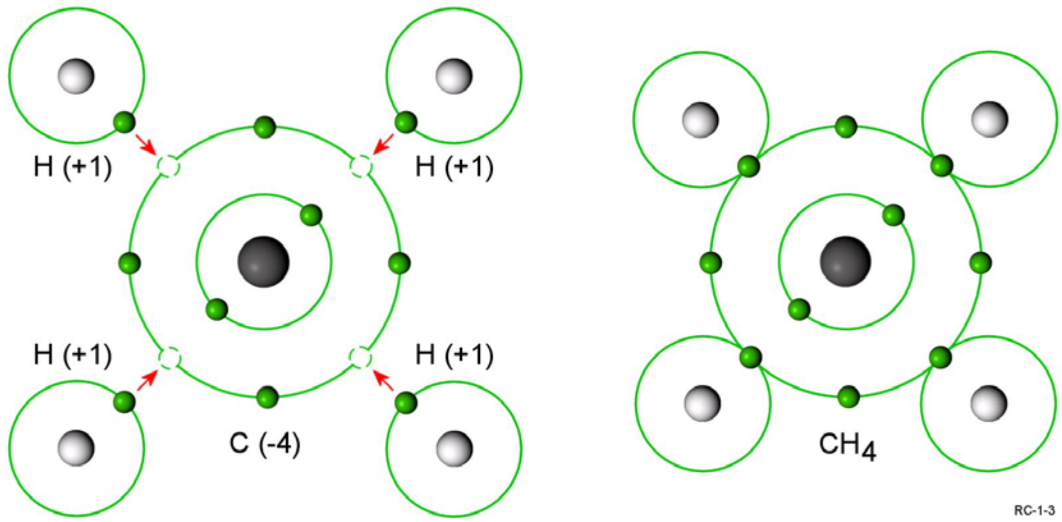


Figure 2–6. Formation of CH_4.

Figure 2–7 shows carbon exhibiting a positive valence when it combines with fluorine to form carbon tetrafluoride (CF_4).

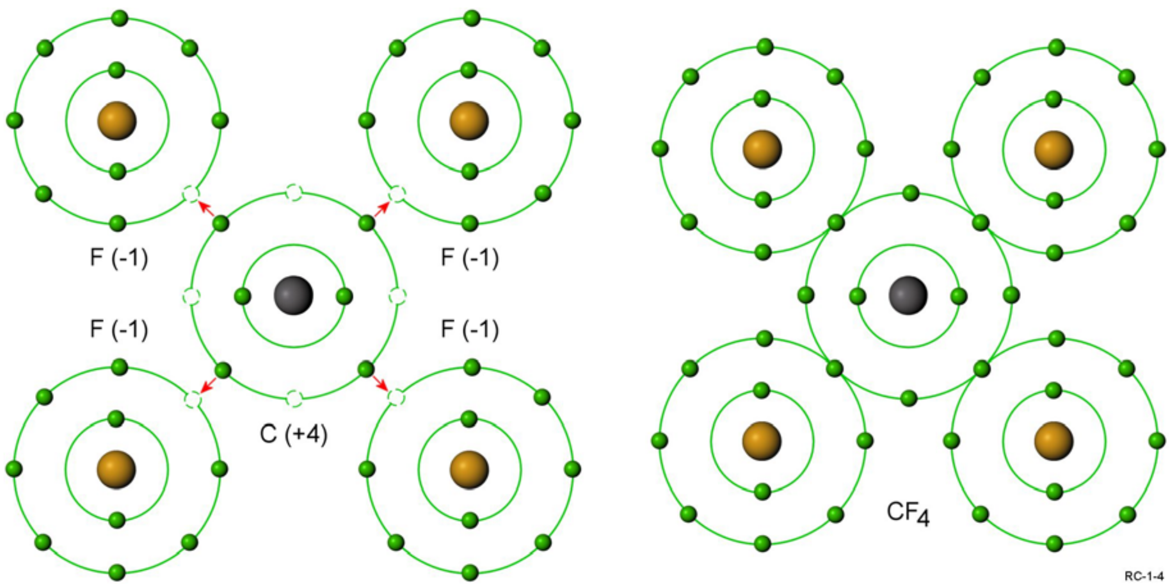


Figure 2–7. Formation of CF_4.

009. Structure of compounds

Elements form compounds to become more stable. A compound is composed of any two elements that combine chemically. When the elements join, the atoms lose their individual properties and possess different properties from the elements that now make up the compound. Water, salt, and sugar are examples of compounds. A given compound has its own distinctive set of properties that are often very different from the elements it was made from. A good example is combining of the gases hydrogen and oxygen to form the liquid water.

Chemical bonds are the attractive forces that hold atoms together. Ionic bonds and covalent bonds are the two general types of bonds between atoms in a compound. These bonds form through interactions among the valence electrons of the atoms in the compound. The formation of compounds and molecules depends not only on the existence of unfilled energy levels in many elements but also on the ionization energy of the atoms involved. The ionization energy of an atom is the amount of energy required to remove only the most loosely bound electron from the atom. The remaining portion of the atom is then a cation—a positively charged ion—because the atom now has more protons than electrons.

The counterpart of ionization energy is an atom's electron affinity, which is the amount of energy given off when an atom gains an extra electron. By picking up an extra electron, the atom is now called an anion—a negatively charged ion because the atom now has more electrons than protons with a net negative charge. Ionization energy and electron affinity are important concepts because they help us understand bonding between atoms. For example, atoms gain, lose, or share electrons in the act of bonding. The ionization energy helps a chemist understand what happens when an atom loses an electron, while electron affinity helps describe what happens when an atom gains an electron.

Formulas

The science community uses formulas to describe the arrangement of compounds. Their symbols and the numbers of each atom show the number of component elements by the subscripts. A symbol without a subscript means that there is only one element in that combination.

Molecular

This type of formula uses chemical symbols with subscript numbers to indicate the number of atoms of each element. Examples include O_2 for molecular oxygen, O_3 for ozone, CH_4 for methane, and C_6H_6 for benzene.

Empirical

If the substance does not exist as molecules, empirical formulas show the relative proportions of the constituents. Examples include NaCl for sodium chloride, HCl for hydrogen chloride, and NaF for sodium fluoride.

Structural

This type of formula identifies the location of chemical bonds between the atoms of a molecule. A structural formula consists of symbols for the atoms connected by short lines that represent chemical bonds—one, two, or three lines standing for single, double, or triple bonds, respectively. Structural formulas are particularly useful for showing how isomers differ. Figure 2–8 shows the structural formula for CH_4 and acetylene (C_2H_2).

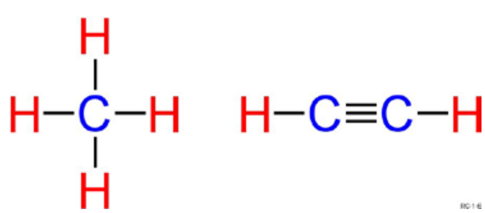


Figure 2–8. Structural formula for CH_4 and C_2H_2.

Organic chemistry

What do pencils and living tissue have in common? They both contain carbon in one form or another. Carbon is the basis of all living things and many nonliving things. Carbon is at the core of many products we use every day, from natural fibers such as cotton and wool, to drugs like aspirin and penicillin. Organic compounds fall into two broad categories: hydrocarbons and derivatives of hydrocarbons (halogen, oxygen, etc.). Figure 2–9 summarizes the classification of organic compounds.

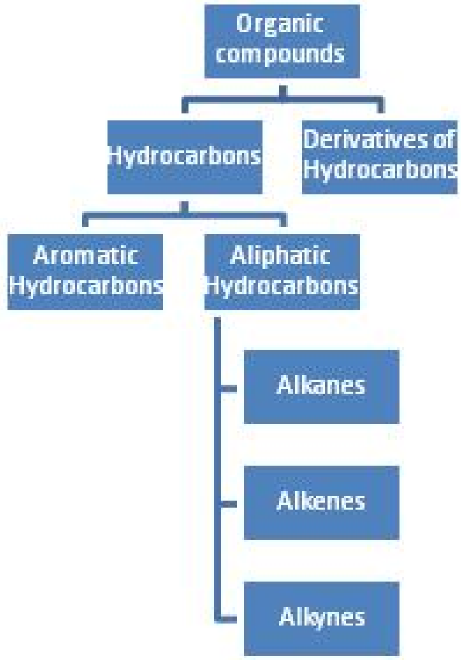


Figure 2–9. Classification of organic compounds.

Hydrocarbons

Hydrocarbons make up one of the most basic and important chemical families. As the name implies, hydrocarbons are organic compounds that contain only the elements carbon and hydrogen. The organic compounds in oil and coal are largely hydrocarbons. Hydrocarbons divide into groups based on the structure of the compounds: aliphatic hydrocarbons and aromatic hydrocarbons.

Aliphatic hydrocarbons

The carbon atoms of an aliphatic hydrocarbon arrange themselves in open chains; that is, they join each other in one continuous string. Methane, the simplest member of this group, contains one carbon atom and four hydrogen atoms, and the empirical formula is CH_4. The empirical formula shows the type and number of atoms in the molecule, but it does not show their relation to each other. You can see in figure 2–10 this relationship in the structural formula.

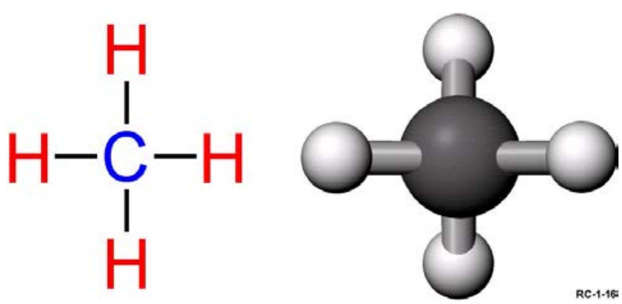


Figure 2–10. Structural formula of CH_4.

The lines joining the atoms represent their valences and are called bonds. Each line represents a shared electron. The arrangement shown by the structural formula is what determines the properties of a hydrocarbon. If one hydrogen atom is removed from CH_4, the remaining CH_3 constitutes what is known as the methyl group. It cannot exist alone but is present in many compounds.

Ethane (C_2H_6) is the next higher member of this series and contains two carbon atoms. As an aliphatic hydrocarbon, ethane shows the open chain formation in its structural formula (fig. 2–11). Note that so far we are dealing with only single bonds between carbon atoms (shown by the single lines). This will become important later in distinguishing aliphatic hydrocarbons. As we saw with methane, removing one hydrogen atom from C_2H_6 makes it an ethyl radical, C_2H_5.

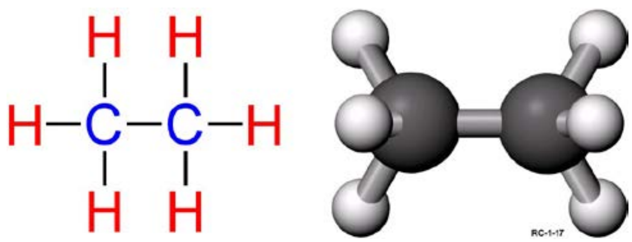


Figure 2–11. Structural formula of C_2H_6.

Adding more and more carbon atoms, we progress up the series to propane (C_3H_8), butane (C_4H_{10}), pentane (C_5H_{12}), and so on. Starting with pentane, the prefix 'penta' denotes the number of carbon atoms. You will hear these single-bonded aliphatics referred to as the methane series, alkane series, paraffinic hydrocarbons, or saturated-aliphatic hydrocarbons. The last one in particular is of special interest. A saturated aliphatic hydrocarbon is one that contains carbon atoms combined with the maximum number of hydrogen atoms. The carbon valences are satisfied (saturated) with hydrogen.

An unsaturated aliphatic hydrocarbon does not have all of its carbon valences satisfied as the alkanes did. Such compounds combine more readily with others; that is, they are more chemically reactive than saturated compounds. This condition is due to adjacent carbon atoms having two or three bonds as opposed to the single bonds of the saturated aliphatics. The simplest member of the double-bonded group is ethylene (C_2H_4), which demonstrates this concept (fig. 2–12).

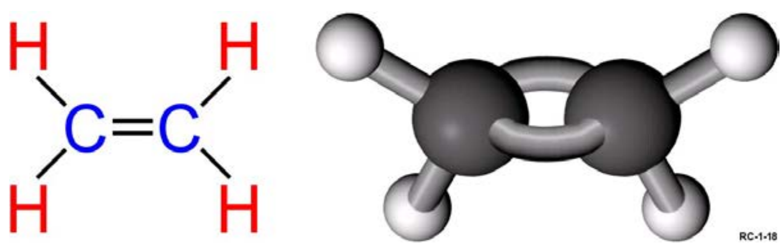


Figure 2–12. Structural formula of C_2H_4.

Unsaturated aliphatic compounds with the double carbon bonds are known collectively by any of the following three titles: ethylene series, olefins, and alkenes. Alkenes get their names by dropping the *–ane* ending of an alkane (such as ethane) and adding *–ene* as in ethene, another proper name for ethylene. Two more examples are propene (propylene) which comes from the word propane, and butene (butylene) which comes from the word butane. An unsaturated aliphatic compound with three bonds between carbon atoms is typified by acetylene (C_2H_2), (fig. 2–13).

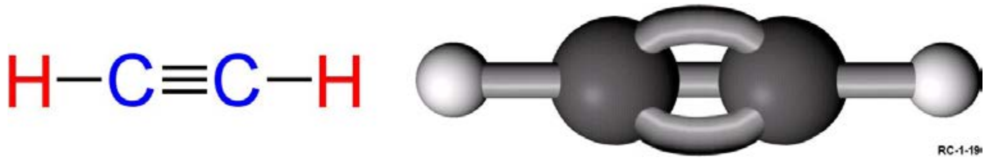


Figure 2–13. Structural formula of C_2H_2.

The members of this series are called alkynes, or the acetylene series. Alkynes are named similarly to the alkenes, except that the *–ane* ending is replaced with *–yne*. Since ethane means the same thing as the more commonly known ethylene, ethyne is the same as acetylene. Other alkynes include propyne (methylacetylene) and butyne (ethylacetylene).

Aliphatic hydrocarbons are used widely in industry, principally as fuels, solvents, lubricants, and as chemical intermediates in the manufacture of other substances. Some are relatively nontoxic, acting simply as asphyxiants, while the rest tend to act mainly as central nervous system (CNS) depressants. Liquid types getting into the lungs can result in very serious effects such as edema and bleeding in the lungs. Since they are fat solvents (aliphatic means fatty), they also have a defatting action on the skin that produces dermatitis after prolonged contact. The many breakdowns of the aliphatics and the various names applied to them can be confusing. The key to identifying them, which also distinguishes their properties, is the structural formula: single carbon bonds for saturated compounds (alkanes) and double or triple bonds for the unsaturated compounds (alkenes and alkynes).

Aromatic hydrocarbons

The use of the term aromatic is due to the fact that many of these substances have fragrant or pungent odors. However, this is not a distinctive property of aromatics since other chemicals have odors. Therefore, we cannot attach any great significance to this class name. However, we can consider the arrangement of the carbon atoms to be significant. We use the structural formula again to classify this group. The compounds we have discussed so far were all of the open chain type. Aromatic hydrocarbons have their carbon atoms arranged in a closed chain, or ring formation. The simplest member of this series is C_6H_6 (fig. 2–14).

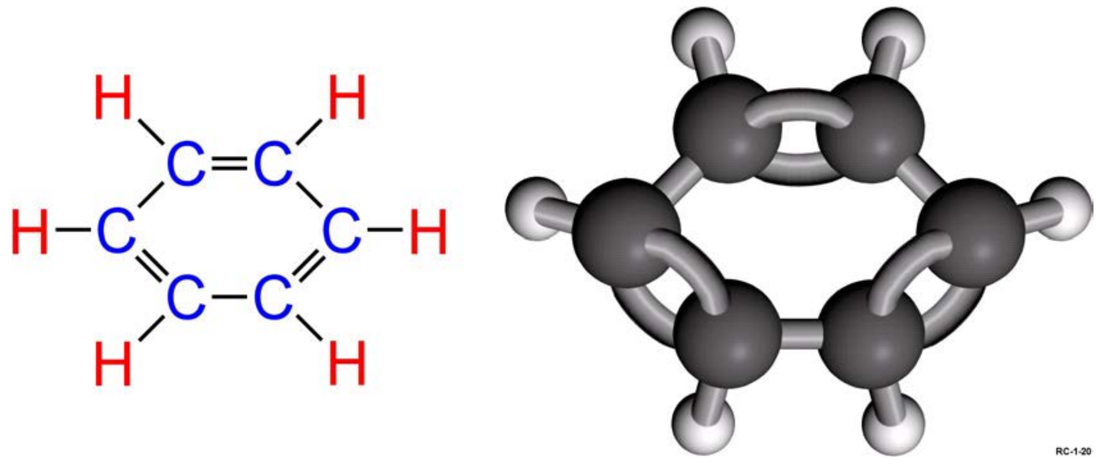


Figure 2–14. Structural formula of C_6H_6.

As with the aliphatics, the structure determines the properties of this group. Aromatic compounds are considered generally more toxic than the aliphatics. They produce similar effects but also tend to attack the liver and kidneys. Benzene, in particular, is a potent carcinogen. A few other examples of this series are toluene, xylene, cumene, and styrene, all with similar properties. These chemicals can be found in such diverse products as paints, strippers, and glues, and in the manufacturing of dyes, explosives, and perfumes.

Petroleum distillates

The process of identifying the contents of a barrel or drum of industrial chemicals can be a painstaking experience. For example, if you find the main ingredient is petroleum distillates, you might try looking at the references based on national stock numbers (NSN) to identify the chemical only to find that naphtha is listed (a flammable oil containing various hydrocarbons). While this breaks it down a little more, it could still be any of a large variety of substances. Knowing something about petroleum distillates can help you find out what the substance is. This will enable you to determine the potential effects, exposure limits, and interpretation of sample results.

Petroleum distillates can be identified to some extent by their boiling ranges. Our main interest is that range between the gases and heavy liquids where we find the light to medium solvents. These are often lumped together under the general term petroleum naphtha. Naphtha's boiling ranges start at above 30 degrees (˚) Celsius (C) for the lightest and ending at somewhere a little over 200˚C for the heaviest. There is little consistency from one reference to another on just what the boiling range is for a particular chemical. Depending on the reference, you may find petroleum ether ranging from 20-60˚C to 40-70˚C. The next less volatile compound might be called light naphtha, or benzine (not benzene), and have a range of about 60-100˚C.

Confusing as this can be (and trade names add even more to the confusion), there are ways to discover what some of these chemicals are. You may be able to find the flash point on the container or by looking up the stock number. You may be able to find information such as an average molecular weight or the specific gravity. These are just some of the ways of finding out what chemical you are trying to sample; there are likely others you will think of.

NOTE: An important point to remember when using chemical properties: in order to identify a substance, there are many times when you must convert units before any comparison can be made. Celsius to Fahrenheit and specific gravity to pounds per gallon are typical conversions.

Halogen derivatives (halogenated hydrocarbons)

Substances in this group are formed by combining the parent hydrocarbon with a halogen. Halogens are very reactive elements and include fluorine, chlorine, bromine, and iodine. The compounds are named by adding one of the following prefixes to the hydrocarbon name: fluoro-, chloro-, bromo-, or iodo-. Sometimes you might see a prefix for just one halogen such as with monochloro-. When more than one of a certain halogen is attached, you have difluoro- (2), trifluoro- (3), and so on. For example, adding two chlorine atoms to a certain alkane yields dichloromethane (methylene chloride); adding three gives trichloromethane (chloroform). In the case of more than one type of halogen, dichlorofluromethane has two chlorine atoms and one fluorine atom. Halogenated hydrocarbons are found on every AF base and their uses range from dry cleaning to refrigerants and propellants. Most of these compounds are very toxic as demonstrated by the fact that many, such as dichlorodiphenyltrichloroethane (DDT), are pesticides.

Oxygen derivatives

Oxygen-containing hydrocarbons include a wide variety of familiar groups. Alcohols are described first because so many other compounds are made from them. Alcohols are recognized by the *–ol* ending, which replaces the *–e* on the parent alkane. The following are the most common members of this group:

- Methanol (methyl alcohol).
- Ethanol (ethyl alcohol).
- 2-propanol (isopropyl alcohol).

A little harder to recognize as alcohols are ethylene glycol (antifreeze) and glycerol (glycerin). Their toxicities range from relatively nontoxic for ethanol to serious illness and some reported deaths from methanol.

Although phenols are structurally similar to alcohols, they are derivatives of aromatic hydrocarbons rather than alkanes. There are very penetrating, irritating materials that are quite toxic once inside the body yet are more appropriately used in disinfectants, dyes, resins, and plastics. Phenol (carbolic acid), cresol, xylenol, and naphthol fall under the general term phenols.

Ethers are prepared from alcohols; in the case of the best known, ethyl ether, the alcohol it comes from is ethanol. Ethers are relatively inert compared to alcohols, but they can produce serious toxic effects on the body. Ethyl ether, in particular, is a potent anesthetic that also causes respiratory irritation. Other major effects of ethers in general are pulmonary edema, liver, and kidney damage. They are used mainly as solvents. Some of the other types of ethers are ethylene glycol monomethyl ether (2-methoxyethanol) and epoxy compounds such as ethylene oxide.

Aldehydes and ketones are related groups that are also prepared from alcohols. Formaldehyde, the simplest aldehyde, comes from methanol, the simplest alcohol. A few of the products that contain aldehydes are antiseptics, embalming fluids, perfumes, and flavorings. They are strongly irritating and can damage the lungs. Formaldehyde is especially important to take note of because it is a suspected carcinogen. The ketones, acetone, methyl ethyl ketone (MEK), and methyl isobutyl ketone (MIBK) are important alcohol derivatives that illustrate the *–one* ending of this group. They are typically less toxic than aldehydes and are used mainly as solvents and strippers. Some surprising examples of familiar substances that belong to these groups are those found in flavorings; these include vanilla and cinnamon, both of which are aldehydes, and oil of spearmint, a ketone.

Carboxylic acids and esters are also related groups that we come across in our work. Carboxylic acids are named by replacing the *–eon* with *–oic*. Examples include methanoic acid (formic acid – found in ants) and ethanoic acid (acetic acid – a component of vinegar). They are prepared from either alcohols or aldehydes and are extremely irritating to the upper respiratory system. Further, they are used in wool dyes, photographic chemicals, insecticides, and acetate esters such as acetic acid. Esters are reaction products of carboxylic acids and alcohols and are commonly used as paint thinners in the AF. Many have very pungent or pleasant odors, which are even used in the making of perfumes and flavorings. While primarily irritants, they have high concentrations that can cause headaches, drowsiness, and unconsciousness. Common esters that you may see are ethyl acetate, n-butyl acetate, and amyl acetate, also called banana oil.

Miscellaneous compounds

While the majority of chemicals most likely seen in industrial areas include hydrocarbons and their derivatives, there are other important groups. In particular, nitrogen-containing compounds make up a vast group with widely varying properties. Some are hydrocarbon derivatives such as the amides and some are inorganic. Important nitrogen compounds include ammonia and its many related chemicals—hydrazine, sodium azide, and cyanides. Most substances in this group are extremely toxic and are used in pesticides, explosives, reagents, fertilizers, and photocopying chemicals. Terms such as nitrate, nitrite, and nitrile are easy to identify as nitrogen compounds. For others, you should look at combined forms of names that include amine, amino, ammonium, azine, and cyano, among others.

While many toxic metals could be discussed within this lesson, mercury, lead, and chromium compounds stand out as the most significant to us. Mercury in its pure form, such as found in barometers, is not highly toxic in acute (short-term) doses. Chronic effects typically involve disturbances of the CNS. Compounds of mercury, such as mercuric oxide, are much more toxic than the elemental form.

Lead and chromates are sometimes combined and most often encountered in paint pigments. Lead can cause painful disturbances of the gastrointestinal tract, as well as anemia and kidney damage. Chromium compounds can cause sores of the skin and nose, and some kidney damage. They are classified by valence (chromium II, III, and VI) and only certain insoluble chromium VI compounds are cancer-causing chemicals. The difficulty in assessing various types of chromium compounds is that they can be mixed together. This accounts for the extra care needed in handling some chromium compounds.

Although this has by no means been a complete discussion of the various chemical families, we have covered a majority of substances you are likely to find in the industrial workplace. If you understand the chemical relationships that place compounds into distinct groups, you can easily determine their hazards. This can be very helpful when comparing an unknown chemical to one that you know.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

006. Physical states of matter

1. Cite the three basic forms of matter.

2. What basic form of matter has a definite volume but lacks shape?

3. What basic form of matter *cannot* be compressed but will take the shape of its container?

4. What basic form of matter can take the shape of a container smaller than its original volume?

007. Composition and properties of matter

1. Define homogeneous matter.

2. Define heterogeneous matter.

3. How do pure substances differ from homogeneous mixtures?

4. What does the atomic number of an atom represent?

5. What does the mass number of an atom represent?

008. Periodic table of the elements

1. What is the name of the vertical columns within the periodic table that hold elements with the same number of valence electrons in their outer shell?

2. Where are the noble gases located within the periodic table?

3. What is the main value of the periodic table?

4. What value is approximately the same and closely related to the atomic weight of an element?

5. Define inert.

009. Structure of compounds

1. Define compound.

2. Cite the two general types of bonds that occur between atoms in a compound.

3. Define cation.

4. Define anion.

5. What represents the chemical bonds between two atoms in a structural formula?

6. Match the term in column B with the correct description from column A. Each term in column B may be used only once.

Column A	*Column B*
____ (1) Formed by combining the parent hydrocarbon with a halogen.	a. Aliphatic hydrocarbons.
____ (2) Their carbon atoms are arranged in a closed chain, or ring formation.	b. Aromatic hydrocarbons.
____ (3) Prepared from alcohols and are relatively inert compared to alcohols.	c. Petroleum distillates.
____ (4) Can be identified to some extent by their boiling ranges.	d. Halogens.
____ (5) Derivatives of aromatic hydrocarbons and are structurally similar to alcohols.	e. Phenols.
____ (6) Their carbon atoms are arranged in open chains.	f. Ethers.

2–2. Solutions

By definition, a solution is a homogeneous mixture in which one pure substance is evenly dispersed in another pure substance. A solution consists of a solute (the lesser quantity) dissolved in a solvent (the greater quantity). The concentration is the measure of how much solute is contained in a given amount of solvent or solution.

010. Calculate solution strengths

The terminology of solutions is often confusing. Terms that describe the qualities of solution such as standard, unsaturated, saturated and supersaturated are often misused. For that reason, we will provide a foundation here.

- Standard solution—The concentration is known in a standard solution. Further, standard solutions are used as references to calculate the concentration of other solutions.
- Unsaturated solution—In this solution, the solvent does not contain all of the solute it is capable of dissolving. This is temperature specific, because the solubility (ability to dissolve) of most substances varies with temperature.
- Saturated solution—In contrast to an unsaturated solution, a saturated solution is one in which the maximum possible amount of solute is dissolved at some specified temperature.
- Supersaturated solution—More solute is dissolved in this solution than would ordinarily be possible for a specified temperature. Supersaturated solutions are typically highly unstable.

A weak concentration of a solution can have one effect, while a stronger concentration may give way to an entirely different result. Remember, the concentration is the measure of how much solute is contained in a given amount of solvent or solution. Therefore, it is important for you to have an understanding of the most frequently used quantitative methods for expressing the concentrations of solutions. These include percent by mass, molarity, normality, and molality.

Percent by mass

Percent by mass is the measure of the concentration of a solution; it is calculated as the mass of solute divided by the mass of solution, with the result multiplied by 100.

$$\text{\% by mass} = \frac{mass\ of\ solute}{mass\ of\ solution} \times 100$$

This is a simple solution type. For example, a 10 percent solution denotes 10 grams of solute per 100 grams solution. For a 10 percent sodium hydroxide solution, for instance, you use 10 percent sodium hydroxide and 90 percent water (100 percent total solution). Consider the following examples involving percent by mass.

EXAMPLE 1.1

Calculate the percent by mass of NaCl if 15.0 grams of sodium chloride dissolves in enough water to make 150 grams of solution.

$$\frac{15.0\ grams\ NaCl}{150\ grams\ solution} \times 100 = 10.0\ parts\ NaCl\ per\ 100\ parts\ of\ solution$$

$$Answer = 10\%\ NaCl$$

EXAMPLE 1.2

Calculate the percent by mass of NaCl if 12.0 *grams* of sodium chloride dissolves in 60.0 grams of water.

You are given the mass of the solute and so you will need to determine the mass of the solution in order to fill in the equation.

$$12.0\ grams + 60.0\ grams = 72.0\ grams\ (mass\ of\ solution)$$

Thus, you can calculate the percent by mass of sodium chloride.

$$\frac{12.0\ grams\ \ NaCl}{72.0\ grams\ solution} \times 100\ = \ 16.7\%\ NaCl$$

$$Answer = 16.7\%\ NaCl$$

EXAMPLE 1.3

Calculate the number of grams of water that must be added to 10.0 grams of sodium hydroxide to prepare a 2.0 percent aqueous sodium hydroxide solution.

$$\frac{2\%\ sodium\ hydroxide}{100\%\ solution} \times \frac{10\ grams\ sodium\ hydroxide}{?\ grams\ solution} = 500\ grams\ total\ solution$$

$$500\ grams - 10\ grams = 490\ grams\ water$$

Molar solutions

For some solutions, we have to take into account the combining of substances in definite proportions. If we ignore this, we may not get the reactions we are looking for and our results will be in error. Molar solutions require that we use molecular weights. This type of solution is prepared by adding certain multiples of moles (molecular weight in grams) of solute to one liter of solvent.

$$M\ = molarity = \frac{moles\ of\ solute}{liter\ of\ solution}$$

To find how many grams of solute are in one mole, calculate the molecular weight of the substance. Use the periodic table to find the atomic weights of the constituent atoms, determine how many of each atom is in the compound, and sum. Example 1.4 illustrates finding the molecular weight of calcium hydroxide [$Ca(OH)_2$] from the atomic weights of calcium, oxygen, and hydrogen. Note that $(OH)_2$ signifies there are two oxygen atoms and two hydrogen atoms:

EXAMPLE 1.4

Ca = 40 grams × 1= 40 grams

O = 16 grams × 2 = 32 grams

H = 1 gram × 2 = 2 grams

Total = *74 grams*, the molecular weight of $Ca(OH)_2$, or one mole.

Consider another example.

EXAMPLE 1.5

H = 1 gram × 3 = 3 grams

P = 31 grams × 1 = 31 grams

O = 16 grams × 4 = 64 grams

Total: 98 grams, the molecular weight of phosphoric acid (H_3PO_4).

Now, add the 98 grams of H_3PO_4 to a container, fill to one liter with solvent, and you have a one molar solution. For multiples of one molar, simply multiply the molarity (M) (such as 0.1M, 1.0M, 5M, etc.) by the molecular weight. For example, a 5M solution of H_3PO_4 would be 98 grams × 5M = 490 grams per liter.

Normality

When a solution involves a reaction of acids with bases, it is often preferred to express the concentration in terms of normality. Normality (N) is the number of equivalents (eq) of solute per liter of solution.

$$N = normality = \frac{equivalents\ of\ solute}{liter\ of\ solution}$$

Mixing equal volumes of solutions having the same normality will result in the complete reaction of their solutes. For example, a liter of one normal (1N) HCl solution will completely neutralize a liter of one normal (1N) sodium hydroxide (NaOH) solution – a base. Notice that in HCl there is one mole of hydrogen ions (H^+). In NaOH, there is one mole of hydroxide ions ($OH^–$), which combines perfectly with the H^+. The definition of normality is similar to the definition of molarity; for example, in normality we use equivalents while in molarity we use moles. This brings up the concept of equivalents and equivalent weights.

Equivalents are the number of *moles* of a substance that will combine with another substance; whereas, *equivalent weights* are the number of *grams* that will combine completely with each other.

The key to understanding normality is knowing the number of equivalent weights present in the solute. With these values, we simply calculate the molecular weight, count the number of H^+ or $OH^–$ molecules present in the formula, and divide the molecular weight by the number of H^+ or $OH^–$. Let us consider some examples so you can see the concept in practice.

EXAMPLE 1.6

Equivalent weight of H_3PO_4 (note three moles of H^+) from its molecular weight of 98 grams:

$$\frac{molecular\ weight}{moles\ of\ H} = \frac{98}{3} = 32.67\ grams$$

EXAMPLE 1.7

Equivalent weight of $Ca(OH)_2$ (note two moles of $OH^–$) from its molecular weight of 58 grams:

$$\frac{molecular\ weight}{moles\ of\ OH} = \frac{58}{2} = 29\ grams$$

Add the equivalent weight in grams to a container and fill to one liter for a 1N solution. For a 2N solution, multiply the equivalent weight by two. For 5N, multiply by five, and so forth.

One more way to define an equivalent weight is to say that it is an element's atomic weight (or a compound's molecular weight) divided by its valence (disregarding whether it is positive or negative, for the moment). This is illustrated by two moles of hydrogen (valence 1) combining completely with one mole of oxygen (valence 2) to form H_2O. Thus, hydrogen's equivalent weight is 1 gram (atomic weight 1/1) and oxygen's equivalent weight is 8 grams (atomic weight 16/2). Another example is the carbonate radical (CO_3), which has a valence of 2 –2 and a molecular weight of 60 grams. Dividing the molecular weight by the valence equals 30 grams – the equivalent weight.

Molality

At times, you may find it more convenient to measure the mass of the solvent rather than the volume of the solution. In such cases, molarity and normality are not useful. Molality (m) is the number of moles of solute per kilogram of solvent.

$$m = molality = \frac{moles\ of\ solute}{kilogram\ of\ solvent} = {grams\ of\ solute}\Big/{kilogram\ of\ solvent}$$

To express a concentration in units of molality, you must know the *mass* of the solute and the mass (not the volume) of the *solvent*. Let us look at an example.

EXAMPLE 1.8

Find the amount of solute required to make a 1m solution of glycerol ($C_3H_8O_3$).

The molecular weight of $C_3H_8O_3$ is 92 grams. The molality of the solution must express the concentration of glycerol as mol/kg of water. Therefore, 92 grams of $C_3H_8O_3$ added to one kilogram (1000 grams) of solvent will yield a 1 molal solution. Note the difference between molar and molal solutions.

011. Acids and bases

The discussion of normal solutions laid a good foundation for acids and bases, which are very common substances in our lives. The following table lists some common substances and their acid or base ingredients.

Substance	Ingredient
	Acids
Vitamin C	Ascorbic acid
Sour Milk	Lactic acid
Food Preservative	Benzoic acid
Lemon, lime, tomato	Citric acid
Eye wash	Boric acid
	Bases
Window cleaner	Ammonia solution
Drain cleaner	Sodium hydroxide
Milk of magnesia	Magnesium hydroxide
Plaster	Calcium hydroxide

Strengths of acids and bases

Different acids can have very different abilities to donate an H^+ ion. Just as some people are stronger than others, some acids are stronger than other acids. Hydrochloric acid is a strong acid because it is very effective in accomplishing the transfer of an H^+ ion to water; however, acetic acid is a weak acid because it is much less able to do the job. Likewise, there are also strong and weak bases. Strong bases dissolve in water to give solutions high concentrations of OH^-. Weak bases dissolve in water and generate only modest concentrations of hydroxide ions in the solution. The most common strong bases are soluble hydroxide compounds like sodium hydroxide and potassium hydroxide. The most important class of weak bases includes nitrogen-containing compounds similar to ammonia.

Water

We have defined strong and weak acids and bases in terms of their behavior in water. Water is an excellent solvent for the formation of ions. Water (HOH or H_2O) is always dissociating. This means that its components, H^+ and OH^-, which we will now call hydrogen ions and hydroxyl ions, are always separating and recombining. In pure water, the concentrations remain equal. An acid such as HCl (the H right up front indicates an acid) added to water contributes H^+ ions, upsetting the balance. There is actually a reaction in the water that removes the H^+ from the HCl. With more H^+ than OH^-, you have a solution that is on the acidic side. On the other hand, adding a base like NaOH contributes OH^- ions, making the solution more basic (often called alkaline). There are more OH^- ions than H^+ in this case. How acidic or basic a solution may be is one of the major concerns in lab tests.

Potential of hydrogen

A solution's potential of hydrogen (pH) value is a quantitative way of expressing the acidic or basic nature of a solution. The phrase "potential of hydrogen" is rarely, if ever, used; the abbreviation pH is consistently used in its place. The scale we use for pH is actually an indication of the number of moles of the hydrogen ion in one liter. Solutions with a pH below 7 are acidic, while solutions with a pH above 7 are considered basic (fig. 2–15). For example, recall from an earlier lesson that ethanoic acid (acetic acid) is a component of vinegar. Although not identified on figure 2–15, vinegar usually possesses a pH value of 2.4. On the opposite spectrum, sodium hydroxide lye normally possesses a pH of approximately 14. The lower the pH number, the higher the hydrogen ion concentration. A solution is neutral when the hydrogen ion concentration and the hydroxide concentration are equal – which corresponds to a pH of *7*.

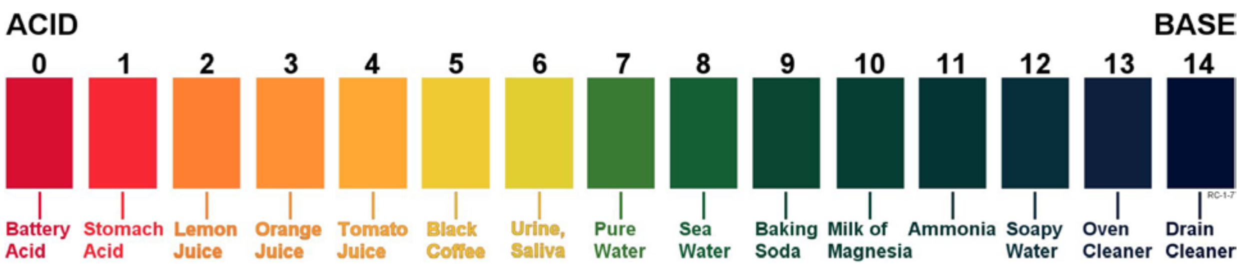


Figure 2–15. The pH scale.

Buffers

Normally, acids and bases cannot exist in a solution without reacting with each other. A buffer solution is a solution that contains substantial amounts of both a weak acid and its conjugate base so that it resists change in its pH. For a buffer of less than pH 7, we use a weak acid and a salt of that acid, such as acetic acid and sodium acetate, each in relatively high concentrations. For a buffer of more than pH 7, you would use a weak base, such as ammonium hydroxide and a salt of the weak base, such as ammonium chloride – again in relatively higher concentrations. Salts will dissolve in water to produce ions; namely, a cation and an anion.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

010. Calculate solution strengths

1. Match the term in column B with the correct description from column A. Each term in column B may be used only once.

Column A	*Column B*
____ (1) Maximum possible amount of solute is dissolved at some specified temperature.	a. Concentration.
____ (2) Measure of how much solute is contained in a given amount of solvent or solution.	b. Equivalents.
____ (3) Solvent does not contain all of the solute it is capable of dissolving.	c. Molality.
____ (4) Number of moles of solute per kilogram of solvent.	d. Standard solution.
____ (5) More solute is dissolved than would ordinarily be possible at a specified temperature.	e. Unsaturated solution.
____ (6) Used as reference to calculate the concentration of other solutions.	f. Saturated solution.
____ (7) Number of moles of a substance that will combine with another substance.	g. Supersaturated solution.

2. For a mixture of 10 percent sodium hydroxide and 90 percent water, which is the solute and which is the solvent?

3. How much water (in *grams*) must be added to 12 *grams* of sodium hydroxide to prepare a 4 percent aqueous sodium hydroxide solution?

4. If you have 20 *grams* of sodium chloride dissolved in 65 *grams* of water, what is the mass of solution?

5. How many grams per liter are needed for a 5 molar solution of a compound with a molecular weight of 56?

011. Acids and bases

1. Is a solution with more hydrogen ions than hydroxyl ions more acidic or basic?

2. Identify the following substances as “A” for acids or “B” for bases.

_______a. Vinegar

_______b. Ammonia

_______c. Lye

_______d. Tomato juice

_______e. Ocean water

_______f. Coffee

3. When is a solution considered neutral?

4. Define buffer solution.

2–3. Gases

Gases react to environmental changes in predictable ways. If we change the temperature of a gas, we can predict the changes to its volume and pressure-using principles known as gas laws. To best understand these laws, you will need to know more about pressure and molecular volume.

012. Calculate gas laws

Pressure is defined as force per unit area. All gases exert at least a small amount of pressure. The pressure that supports a column of mercury at a height of 76.0 centimeters (cm) at 0˚C at sea level is called standard pressure. Standard pressure can be expressed in the following units:

- 14.7 pounds per square inch (psi).
- 76.0 centimeters of mercury (cm Hg).
- 760 millimeters of mercury (mm Hg).
- 760 torr (1 torr = 1 mm of mercury).
- 29.92 inches of mercury (in Hg).
- 1.00 atmosphere (atm).
- 1.013×10^5 pascals (Pa).
- 1013 millibars (mbar).

NOTE: While standard pressure is a useful measure in many cases, much of the world, and thus, many gases, are found at higher elevations. Atmospheric pressure decreases as altitude increases (approximately 25 torr/1,000 ft).

Molecular volume

The gram molecular weight of a substance – one mole – will always have the same number of molecules. Known as Avogadro’s number, it is 6.022×10^{23} molecules/mole. This applies to all forms of a compound (solid, liquid, and gas); however, gaseous substances have one more unique quality. Not only does a mole always have the same number of molecules, it also always occupies the same volume at a given temperature and pressure. Any gas will fill a volume of 22.4 liters at standard temperature and pressure (STP). For chemistry, STP is 0˚C and 1 atm of pressure. Since the volume is based on a mole of gas having a definite number of molecules, we call it molecular volume.

Typically, the molecular weight is expressed in grams while the gram molecular volume is expressed in liters. In certain kinds of work, such as air sampling, you will hear the term normal temperature (25˚C) used. The gram molecular volume at 25˚C and 1 atm is 24.45 liters. One mole of any chemical contains 6.022×10^{23} molecules and occupies 24.45 liters at normal temperature. If we change the temperature or pressure, the volume also changes. For example, one mole of O_2 (32 grams) contains

6.022×10^{23} molecules. At 0˚C and 1 atm, O_2 occupies 22.4 liters, while at 25˚C and 1 atm, it occupies 24.45 liters (fig. 2–16).

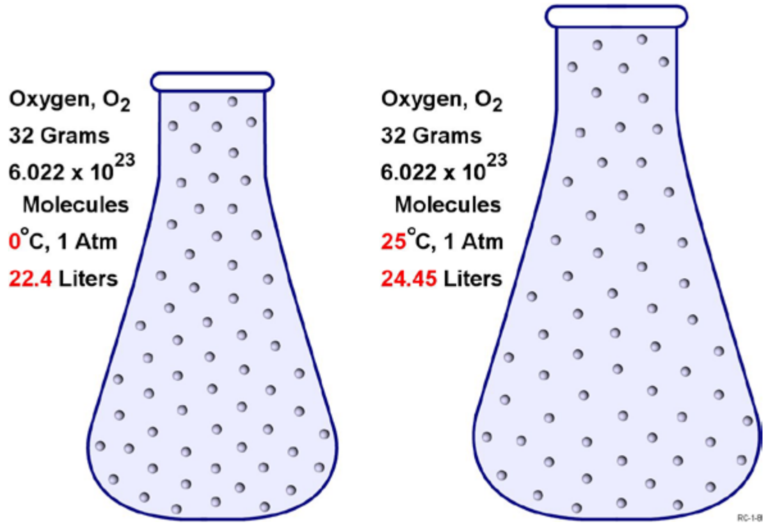


Figure 2–16. Oxygen's gram molecular volume.

Where ventilation principles are concerned, still another reference is used: 70˚F and 1 atm – more commonly 29.92 in Hg. When using Fahrenheit, you must use pound moles (molecular weight in pounds) and the molecular volume in cubic feet (ft^3) as standard units of measurement. One-pound mole of gas occupies 387 ft^3 at 70˚F and 29.92 in Hg.

Gas laws

Gas molecules are always moving closer together or farther apart with temperature and pressure changes. It is possible to predict what volume of a gas you will have through some very simple calculations. If you have a fixed volume, such as in a gas cylinder, you can even calculate the temperature or pressure inside the cylinder. This concept directly relates to molecular volume. The fact that a certain number of grams of gas occupy a definite volume that changes only with temperature and pressure leads us to the most basic of the gas laws.

1. **Boyle's Law:** The effect of pressure change on the volume of a gas at a constant temperature.
2. **Charles's Law:** The effect of temperature change on the volume of a gas at a constant pressure.
3. **Gay-Lussac's Law:** The effect of temperature change on the pressure of a gas at a constant volume.

Boyle's Law

Boyle's Law states that a gas volume is inversely proportional to its pressure—at constant temperature. Inversely proportional means that an increase in one variable results in a decrease in the other variable; similarly, a decrease in one variable results in an increase in the other variable. For example, if the pressure on a given gas is doubled, the volume will be halved. In turn, if the pressure is halved, the volume will be doubled. Thus, we have the following:

- As pressure decreases, volume increases.
- As pressure increases, volume decreases.

The following is the mathematical equation for Boyle's Law:

$$PV = k$$

Where:

P = the pressure of the system.

V = the volume of the gas.

k = a constant value representative of the pressure and volume of the system.

Boyle's Law is commonly used to predict the result of introducing a change, in volume and pressure only, to the initial state of a fixed quantity of gas. The before and after volumes and pressures of the fixed amount of gas, where the before and after temperatures are the same are related by the following equation:

$$P_1V_1 = P_2V_2$$

Figure 2–17 provides a demonstration of how Boyle's Law works using a tire pump. With no effort on the pump handle, the pressure (P_1V_1) is the same as standard atmospheric pressure (1 atm or 760 torr). The gas (air) molecules are spaced normally and you have 500 milliliters (ml). Pushing the handle doubles the pressure (P_2V_2) and the molecules are packed more closely together. This doubling of pressure reduces the volume to 250 ml from 500 ml (volume is halved).

Boyle's Law applies when temperature is constant; however, sometimes pressure remains constant while temperature changes. To predict volume changes in such cases, we rely on Charles's Law.

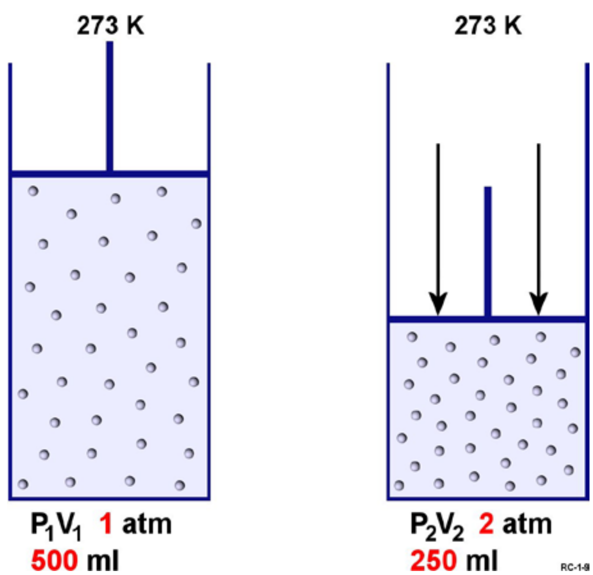


Figure 2–17. Boyle's Law.

Charles's Law

Charles's Law deals with volumes in relation to temperature. This law is based on the principle that, at constant pressure, the volume of a fixed mass of a given gas is directly proportional to the temperature in Kelvin (an absolute temperature scale). Therefore, if the Kelvin temperature is doubled at a constant pressure, the volume will also be doubled; similarly, if the Kelvin temperature is halved at a constant pressure, the volume will also be halved. Thus, we have the following:

- As temperature increases, the volume of the gas increases.
- As temperature decreases, the volume of the gas decreases.

The following is the mathematical equation for Charles's Law:

$$\frac{V}{T} = k$$

Where:

V = the volume of the gas.

T = the temperature of the gas (measured in Kelvin).

k = the constant.

This equation states that the volume divided by the Kelvin temperature is equal to a constant at constant pressure. Because k is a constant, we can equate different conditions of temperature and volume for the same mass of a gas at constant pressure.

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

or

$$V_1 \times T_2 = V_2 \times T_1$$

Figure 2–18 provides a demonstration of Charles's Law. As the temperature is increased, the kinetic energy of the molecules is increased. This results in an increase in the volume in order to keep the pressure constant.

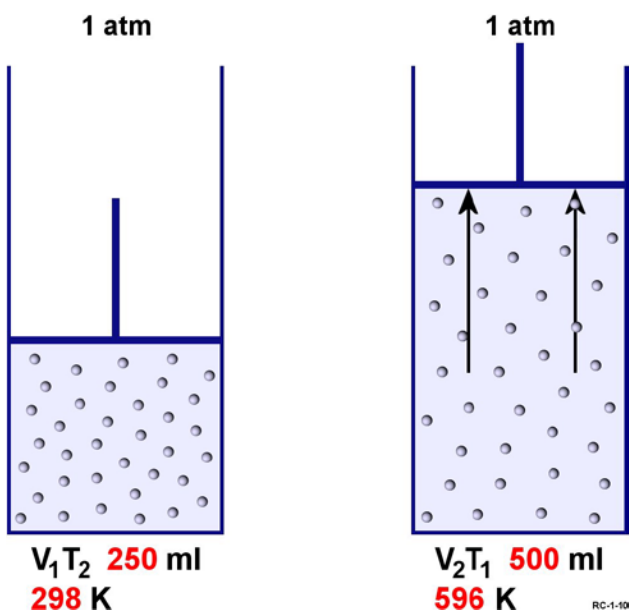


Figure 2–18. Charles' Law.

Gay-Lussac's Law

Figure 2–19 provides a demonstration of Gay-Lussac's Law. Under this law, at a constant volume, the pressure of a fixed mass of a given gas is directly proportional to the Kelvin temperature. Therefore, if the Kelvin temperature is doubled at a constant volume, the pressure will also be doubled; similarly, if the Kelvin temperature is halved, the pressure will also be halved. Thus, we have the following:

- As pressure increases, the temperature increases.
- As pressure decreases, the temperature decreases.

The following is the mathematical equation for Gay-Lussac's Law:

$$\frac{P}{T} = k$$

Where:

P = the pressure of the gas.

T = the temperature of the gas (measured in Kelvin).

k = the constant.

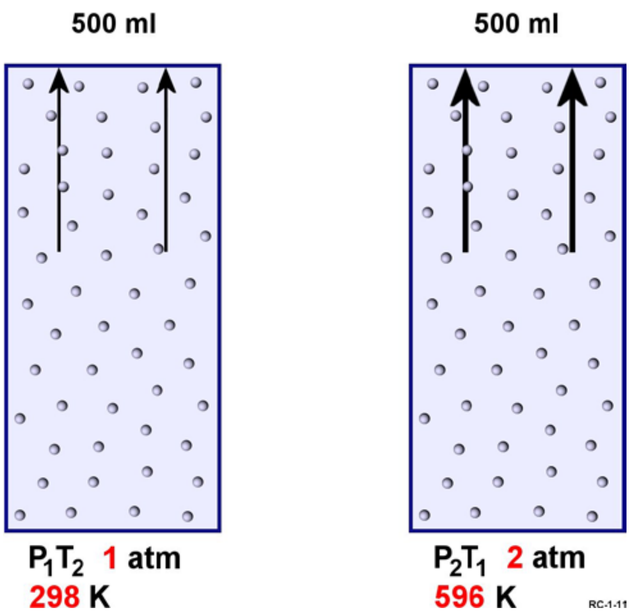


Figure 2–19. Gay-Lussac's Law.

This law holds true because temperature is a measure of the average kinetic energy of a substance; as the kinetic energy of a gas increases, its particles collide with the container walls more rapidly, thereby exerting increased pressure. Simply put, if you increase the temperature you increase the pressure. For comparing the same substance under two different sets of conditions, the law can be written as follows:

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

or

$$P_1T_2 = P_2T_1$$

Putting the previous three laws together, we get the combined gas law:

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

or

$$P_1V_1T_2 = P_2V_2T_1$$

Ideal gas equation

In the gas laws of Boyle, Charles, and Gay-Lussac, the mass of gas and one of the three variables – temperature, pressure, or volume are fixed. Using a new equation, the ideal gas equation, we can vary not only the temperature, pressure, and volume but also the mass of the gas. We can state the ideal-gas equation mathematically as follows:

$$PV = nRT$$

Where:

P = pressure in atmospheres.

V = volume in liters (l).

n **=** number of gram moles.

R = 0.08205 liter atm mol $^{-1}K^{-1}$ $\dfrac{liter \times atm}{mol \times K}$ $=$ a constant.

T = temperature in Kelvin (K).

Note the units for each part of the formula. The pressure must be expressed in atmospheres, the volume in liters, and the temperature in Kelvin. Obviously, moles are expressed as moles.

Because of this, if the information is given in any other units, you will have to convert to the appropriate units of measurement. For example, pressure can be stated in inches of mercury or milliliters of mercury (torr). Knowing that 29.92 in Hg = 760 torr = 1 atm, you can easily convert. Consider the following examples.

EXAMPLE 1.9

Given a pressure of 646 torr, determine the corresponding atm (recalling that 760 torr is equivalent to 1 atm).

Ratio: $\dfrac{646\,torr}{760\,torr} = \dfrac{?}{1\,atm}$

Cross-multiplying: $646\,torr \times 1\,atm = ? \times 760\,torr$

Dividing: $\dfrac{646\,torr \times 1\,atm}{760\,torr}$

Answer: $0.85\,atm$

What if your volume is in cubic meters (m^3) instead of liters? Again, you will need to convert.

EXAMPLE 1.10

Given a volume of 0.15 m^3, convert to liters (recalling that 1000 liters is equivalent to one cubic meter).

Ratio: $\dfrac{1000\,liters}{?} = \dfrac{1\,m^3}{0.15\,m^3}$

Cross-multiplying: $? \times 1\,m^3 = 1000\,liters \times 0.15\,m^3$

Dividing: $\dfrac{1000\,liters \times 0.15\,m^3}{1\,m^3}$

$$\textbf{Answer: } 150\,liters$$

Now, let us take a look at an example involving moles and grams.

EXAMPLE 1.11

How many moles are in 12.8 grams of a gas with a molecular weight of 32 grams (one mole)?

$$\textbf{Ratio: } \frac{1\,mole}{?} = \frac{32\,grams}{12.8\,grams}$$

$$\textbf{Cross-multiplying: } ? \times 32\,grams = 1\,mole \times 12.8\,grams$$

$$\textbf{Dividing: } \frac{1\,mole \times 12.8\,grams}{32\,grams}$$

$$\textbf{Answer: } 0.4\,moles$$

The temperature must be in Kelvin before working any gas law calculation. This means that its zero point has absolutely no heat, and is the theoretical point at which all molecular activity stops. For a temperature given as 25˚C, you will need to add 273 in order to convert the temperature to Kelvin (0˚C = 273˚K).

This brings us to the constant – R. You can see that simply using the constant (R) is much easier than the term: liter atm/mol K (none of the units cancel). The term does tell exactly, however, what units to use in the formula. To see how this formula is used, let us work through another example.

EXAMPLE 1.12

Calculate the volume of 32 grams of oxygen (one mole) at 25˚C and 760 torr.

$$\textbf{Original equation: } PV = nRT$$

$$\textbf{Solving for V: } \frac{PV}{P} = \frac{nRT}{P}$$

Where:

n = 1 mol.

R = 0.08205 liter atm mol.

T = 273˚ K (0˚ C) [Where 273˚ K + 25˚ K = 298˚ K].

P = 1 atm.

$$V = \frac{1\,mol \times 0.08205\,liter\ atm\ mol^{-1}K^{-1} \times 298\,K}{1\,atm}$$

$$V = 24.451\,liters \text{ (rounded)}$$

It is helpful to see how the units of measurement cancel to end up with liters.

$$V = \frac{nRT}{P} = mol\left[\frac{atm}{mol}\ \frac{liter}{K}\right]\frac{K}{atm}$$

You can rearrange this formula to find whatever you need. You can find the number of moles (and therefore the number of grams) of a sample if you know the volume, temperature, and pressure of the gas. Rearranging another way, you can calculate either the temperature or pressure of your sample. Further, if you start with a volume at certain conditions of temperature and pressure, you can calculate what the volume will be at other conditions. That is what you must do in many cases to determine the actual volume.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

012. Calculate gas laws

1. Define pressure.

2. What does inversely proportional mean?

3. What does directly proportional mean?

4. Given a pressure of 580 *torr*, what will be the *pressure in atmospheres*?

5. How many moles are in 16 *grams* of a gas with a molecular weight of 32 *grams* (one mole)?

Answers to Self-Test Questions

006

1. Solid, liquid, and gas.
2. Liquid.
3. Liquid.
4. Gas.

007

1. Homogeneous matter is uniform in composition and properties.
2. Heterogeneous matter is not uniform in composition and properties.
3. Pure substances differ from homogeneous mixtures and solutions in that they have distinct and constant compositions. Further, they are divided into two groups: elements and compounds. Conversely, mixtures and solutions consist of two or more pure substances in variable proportions.
4. The number of protons in the nucleus of an atom.
5. The number of protons and neutrons in the nucleus of an atom.

008

1. Groups.
2. Far right column.
3. Its ability to predict the chemical properties of an element based on its location within the table.
4. The element’s mass number.

5. It is when an outer shell contains all of the possible electrons it can hold and is considered full or satisfied. This means the atom will not combine with any other.

009

1. A compound is composed of any two elements that combine chemically.
2. Ionic bonds and covalent bonds.
3. A cation is a positively charged ion, meaning that the atom has more protons than electrons.
4. An anion is a negatively charged ion, meaning that the atom has more electrons than protons.
5. Short lines.
6. (1) d.
   (2) b.
   (3) f.
   (4) c.
   (5) e.
   (6) a.

010

1. (1) f.
   (2) a.
   (3) e.
   (4) c.
   (5) g.
   (6) d.
   (7) b.
2. Sodium hydroxide is the solute and water is the solvent.
3. 288 grams of water needed for 12 grams of sodium hydroxide.

   Where: In a 4 percent solution, there are 4 grams of sodium hydroxide for every 96 grams of water (100 grams of solution – 4 grams of sodium hydroxide = 96 grams of water); thus you can calculate the number of grams of water needed for 12 grams of sodium hydroxide as:

$$12\, grams\, of\ sodium\, hydroxide \times \frac{96\, grams\, of\ water}{4\, grams\, of\ sodium\, hydroxide} = 288\, grams$$

4. 85 grams.

   Where: 20 grams + 65 grams = 85 grams (mass of solution).
5. 280 grams.

   Where: 56 grams $\times$5 M = 280 grams per liter.

011

1. Acidic.
2. a. Acid.
   b. Base.
   c. Base.
   d. Acid.
   e. Base.
   f. Acid.
3. A solution is neutral when the hydrogen ion concentration and the hydroxide concentration are equal (pH of 7).
4. A buffer solution is a solution that contains substantial amounts of both a weak acid and its conjugate base so that it resists change in its pH.

012

1. Force per unit area.
2. An increase in one variable results in a decrease in the other variable; similarly, a decrease in one variable results in an increase in the other variable.
3. An increase in one variable results in an increase in the other variable; similarly, a decrease in one variable results in a decrease in the other variable.
4. 0.76 atm, where 760 *torr* is equivalent to 1 *atm*. The following is mathematical proof:

$$\textbf{Ratio: } \frac{580\,torr}{760\,torr} = \frac{?}{1\,atm}$$

$$\textbf{Cross-multiplying: } 580\,torr \times 1\,atm = ? \times 760\,torr$$

$$\textbf{Dividing: } \frac{580\,torr \times 1\,atm}{760\,torr} = 0.76\,atm \text{ (answer)}$$

5. 0.5 moles. The following is the mathematical proof:

$$\textbf{Ratio: } \frac{1\,mole}{?} = \frac{32\,grams}{16\,grams}$$

$$\textbf{Cross-multiplying: } ? \times 32\,grams = 1\,mole \times 16\,grams$$

$$\textbf{Dividing: } \frac{1\,mole \times 16\,grams}{32\,grams} = 0.5\,moles \text{ (answer)}$$

Complete the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field-Scoring Answer Sheet.

Do not return your answer sheet to the Air Force Career Development Academy (AFCDA).

17. (006) What change in the physical state occurs when sufficient heat is applied to a liquid?
    a. Dissolves.
    b. Contracts.
    c. Turns to gas.
    d. Becomes a solid.

18. (006) Which of the physical states of matter lacks both volume and shape?
    a. Solid and liquid.
    b. Gas and liquid.
    c. Liquid only.
    d. Gas only.

19. (007) If matter is uniform in composition and properties then it is considered to be
    a. heterogeneous.
    b. homogeneous.
    c. covalent.
    d. binary.

20. (007) Which example *best* describes a solution?
    a. Methane gas combined with carbon dioxide gas.
    b. Ethyl alcohol dissolved in water.
    c. Beaker of sodium hydroxide.
    d. Container of argon gas.

21. (007) The number of protons in the nucleus of an atom is equal to the
    a. electron number.
    b. electron weight.
    c. atomic number.
    d. atomic weight.

22. (007) The mass number of an atom is equal to the sum of the number of
    a. neutrons, electrons and protons.
    b. neutrons and electrons.
    c. protons and electrons.
    d. protons and neutrons.

23. (008) Where are the noble gases located within the periodic table?
    a. Far right column.
    b. Far left column.
    c. Bottom row.
    d. Top row.

24. (008) Due to their high reactivity, what commonly combines with organic compounds to form dangerous chemicals that can be toxic to humans?
    a. Metals.
    b. Alkalis.
    c. Halogens.
    d. Noble gases.

25. (009) Elements form compounds in an attempt to
    a. become more stable.
    b. disperse energy.
    c. become inert.
    d. gain energy.

26. (009) A *cation* has a positive charge because the atom has
    a. more neutrons than protons.
    b. fewer neutrons than protons.
    c. more protons than electrons.
    d. fewer protons than electrons.

27. (009) It is important to understand the chemical relationships that place compounds into distinct groups so you can more easily determine the
    a. percent by mass of the compounds.
    b. saturation rate of the compounds.
    c. concentration of the compounds.
    d. hazards of the compounds.

28. (010) If 50 grams of sodium chloride dissolves in enough water to make 500 grams of solution, what is the percent by mass?
    a. .1 percent.
    b. 10 percent.
    c. 25 percent.
    d. 50 percent.

29. (011) A solution with a potential of hydrogen (pH) of 3 is considered
    a. buffered.
    b. alkaline.
    c. neutral.
    d. acidic.

30. (011) What type of solution contains large amounts of both a weak acid and its conjugate base so that it resists change in its potential of hydrogen (pH) level?
    a. Buffer.
    b. Alkaline.
    c. Neutral.
    d. Acidic.

31. (012) What is the molecular weight of a substance based on one mole?
    a. 6.022×10^{21}.
    b. 6.022×10^{22}.
    c. 6.022×10^{23}.
    d. 6.022×10^{24}.

32. (012) Gay-Lussac’s law states that at a constant volume the pressure of a fixed mass of a given gas is directly proportional to the temperature (in Kelvin); therefore, as pressure
    a. decreases, temperature increases.
    b. increases, temperature increases.
    c. decreases, temperature remains constant.
    d. increases, temperature remains constant.

Student Notes

Please read the unit menu for unit 3 and continue ➔

Unit 3. Anatomy and Physiology

HUMAN BEINGS ARE perhaps the most complex organisms on this planet. Understanding how your environment can affect the human body is an important step for you in gaining comprehensive scientific knowledge of the BE career field. Two complementary branches of science, anatomy and physiology, provide the critical concepts that help us understand the human body. The human body is a single structure; however, it is made of billions of smaller structures of four major kinds: cells, tissues, organs, and systems.

In this unit, we will expand on all of these concepts as we progress allowing you to expand your knowledge of the various physiological systems that compose the human body, how each system functions, and how their functions concern the BE career field.

3–1. The Structure and Function of Cells and Tissues

Cells have long been recognized as the simplest units of living matter that can maintain life and reproduce themselves. The human body, which is made of numerous cells, begins as a single, newly fertilized cell. Tissues are somewhat more complex units than cells. By definition, a tissue is an organization of a great many similar cells with varying amounts and kinds of nonliving, intercellular substance between them.

013. Cells within the human body

A cell is the smallest functioning unit of life that is capable of independent existence. Cells are the basic units of the human body and the basic structural and functional units of living organisms. Therefore, when you define cell properties you are in fact defining the properties of life. The adult human body contains approximately 75 trillion cells. Although cells differ in size and shape, they all have a common structure. Each body tissue and organ is actually a mixture of many different cells held together by intercellular supporting structures. Each type of cell is specially adapted to perform one particular function for the body as a whole. For example, red blood cells transport gases to body tissue, nerve cells carry impulses, and white blood cells serve as part of the body's defense mechanism. Further, they must serve themselves by metabolizing nutrients for the cell's existence, and they must reproduce themselves for future generations.

Cell structure

The cell has three basic parts: the plasma membrane, the cytoplasm, and the nucleus (fig. 3–1).

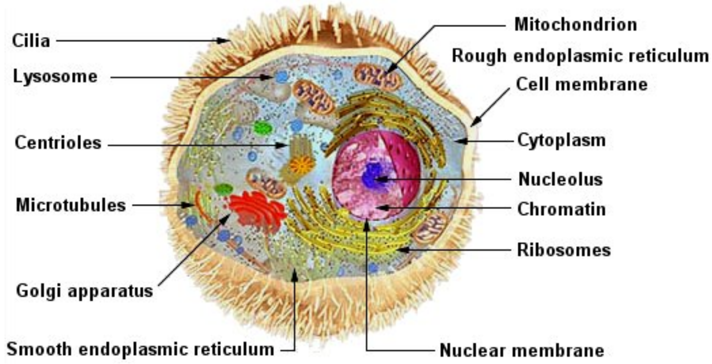


Figure 3–1. Basic cell structure.

Plasma membrane

The plasma membrane is the outermost layer of the cell and serves to separate and protect a cell from its surrounding environment. The membrane is composed mainly of lipids and proteins. Embedded within this membrane are a variety of other molecules that act as channels and pumps, allowing for the movement of different molecules in and out of the cell.

Cytoplasm

With the exception of the nucleus, the cytoplasm contains all of the living substances of the cell. It is a clear liquid and is alive with constant cellular activity. All the functions for cell expansion, growth and replication occur in the cytoplasm of a cell. The word metabolism—often used in discussions regarding the human body—actually refers to the activity that occurs in the cytoplasm of each cell. Within the cytoplasm are structures called organelles that are always surrounded by a protective membrane. The function of the cytoplasm and the organelles that reside within the cytoplasm are critical for a cell's survival. The following table lists the components found within the cytoplasm and provides a brief description of each.

Component	Description
Endoplasmic reticulum	A tubular system within the cell that transports molecules.
Ribosomes	Important for the processing of proteins, both within the cell itself and in other parts of the body.
Golgi apparatus	Located near the nucleus and responsible for distributing proteins the ribosomes processed.
Mitochondria	Principal source of cellular energy. Contains the enzymes involved with electron transport and the citric and fatty acid cycles.
Lysosomes	Tiny membranous sacs that contain enzymes used to break down protein, carbohydrates, acids, and foreign substances that may enter the cell.
Peroxisomes	Found most commonly in cells of the liver and kidneys. Mainly serve to break down toxic substances.
Centrosomes	Vital for cellular reproduction. Centrosomes distribute chromosomes, which carry deoxyribonucleic acid (DNA) information to newly forming cells.
Cilia and flagella	Tiny projections that extend outward from cell surfaces. Responsible for cell movement and the movement of cell products.
Vesicles	Membranous sacs that vary in size. Vesicles are actually an extension of the cell membrane that folds inward into the cytoplasm.

Component	Description
Microfilaments and microtubules	Microfilaments are responsible for cell contraction. Microtubules serve as an internal cell 'skeleton' that helps maintain the shape of a cell.

Nucleus

The nucleus is located near the center of the cell. It is responsible for directing all cellular activity – serving as the 'brain' of the cell. The nucleus determines how the cell will function, as well as the basic structure of that cell. Within each nucleus are chromosome protein structures. The chromosome is important because attached to it are genes, which determine an individual's characteristics. The chromosomes' genes not only control heredity from parents to children but the daily functions of the cells. This nucleic acid, or DNA, is the coded model for the formation of another nucleic acid, ribonucleic acid (RNA), which spreads through the cells and controls the formation of different body structures. Scientists estimate that there are well over a million genes in the nucleus of a single human cell. They duplicate before cell reproduction, one set going to each daughter cell.

Cell division

Individual cells have the capacity to grow and multiply. The series of changes that occur within a cell from its formation until it reproduces is known as the cell life cycle. In other words, the life cycle is the process involving the growth of a cell until it divides and becomes two new cells. Therefore, cell division is the process by which new cells are formed for growth, repair, and replacement in the body. This process includes division of the nuclear material and division of the cytoplasm.

Somatic cells reproduce by mitosis, which results in two cells that are identical to the one parent cell. Interphase is the period between successive cell divisions, and is the longest part of the cell cycle. The successive stages of mitosis are prophase, metaphase, anaphase, and telophase (fig. 3–2). Meiosis is a special type of cell division that occurs in the production of the gametes (egg or sperm cells).

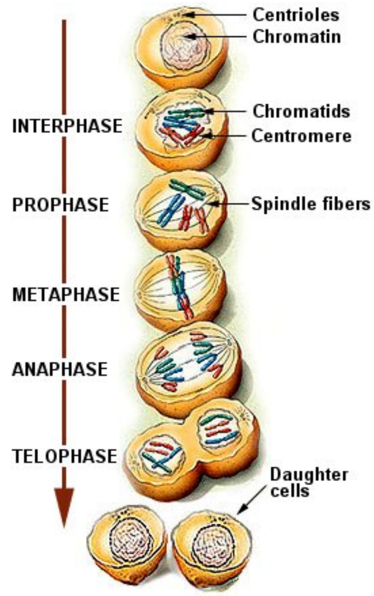


Figure 3–2. Mitosis.

DNA replication and protein synthesis

Proteins are synthesized in the cytoplasm function as structural materials, enzymes that regulate chemical reactions, hormones, and other vital substances. DNA in the nucleus directs protein synthesis in the cytoplasm. A gene is the portion of a DNA molecule that controls the synthesis of one specific protein molecule. Messenger RNA carries the genetic information from the DNA in the nucleus to the sites of protein synthesis in the cytoplasm.

Bioenvironmental engineering concerns

Overexposure to ionizing radiation damages the cell. This radiation can react with the water molecules in the cells to create hydroxides that are very toxic to cell life. Ionizing radiation can cause the DNA to inhibit proper cell division or pass on incomplete genetic information during cell division. It also can alter the DNA by changing the coded information causing mutations (mutagenic effect). The cells that reproduce most rapidly are the ones affected most by exposure to ionizing radiation. These are blood, intestinal, reproductive, and cancer cells.

014. Tissues within the human body

Tissues are groups of cells that have similar structure and function. There are four main tissue types in the body, and each is designed for a specific purpose or general function. These include covering, support, movement, and control. This lesson considers each type of tissue and membranes, and discusses BE concerns.

Types of tissue

The four main tissue types in the body are epithelial (covering), connective (support), muscle (movement), and nervous control).These four main types of tissue interweave to form the fabric of the human body.

Epithelial tissue

Epithelial tissues are widespread throughout the body. They form the covering of all body surfaces, line body cavities and hollow organs, and are the major tissue in glands. In its role as an interface tissue, epithelium performs a variety of functions, which include protection, secretion, absorption, excretion, filtration, diffusion, and sensory reception.

The cells in epithelial tissue are tightly packed together with very little intercellular matrix—a nonliving material that fills the spaces between cells. Because the tissues form coverings and linings, the cells have one free surface that is not in contact with other cells. Opposite the free surface, the cells attach to underlying connective tissue by a non-cellular basement membrane. This membrane is a mixture of carbohydrates and proteins secreted by the epithelial and connective tissue cells.

Epithelial cells may be squamous, cuboidal, or columnar in shape and can be arranged in single (simple) or multiple (stratified) layers (fig. 3–3).

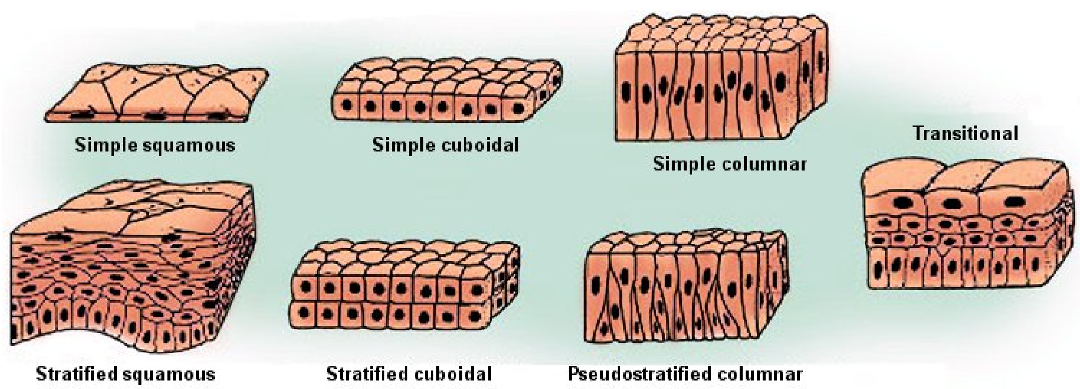


Figure 3–3. Types of epithelium.

Simple cuboidal epithelium is found in glandular tissue and in the kidney tubules. Simple columnar epithelium lines the stomach and intestines. Pseudostratified columnar epithelium lines portions of the respiratory tract and some of the tubes of the male reproductive tract. Transitional epithelium can be distended or stretched. Glandular epithelium is specialized to produce and secrete substances.

Connective tissue

Connective tissue is the most abundant and widely distributed of the primary tissues. Connective tissue does much more than just connect body parts—it has many forms and functions. Its major functions include binding and support, protection, insulation, and as blood (transportation of substances within the body). Whereas all other primary tissues are composed mainly of cells, connective tissues are largely nonliving extracellular matrix, which separates, often widely, the living cells of the tissue. Because of its matrix, connective tissue is able to bear weight, withstand great tension, and endure abuses—such as physical trauma and abrasion—that no other tissue would be able to tolerate.

The types of connective tissue include loose connective tissue, adipose tissue, dense fibrous connective tissue, elastic connective tissue, cartilage, osseous tissue (bone), and blood (fig. 3–4).

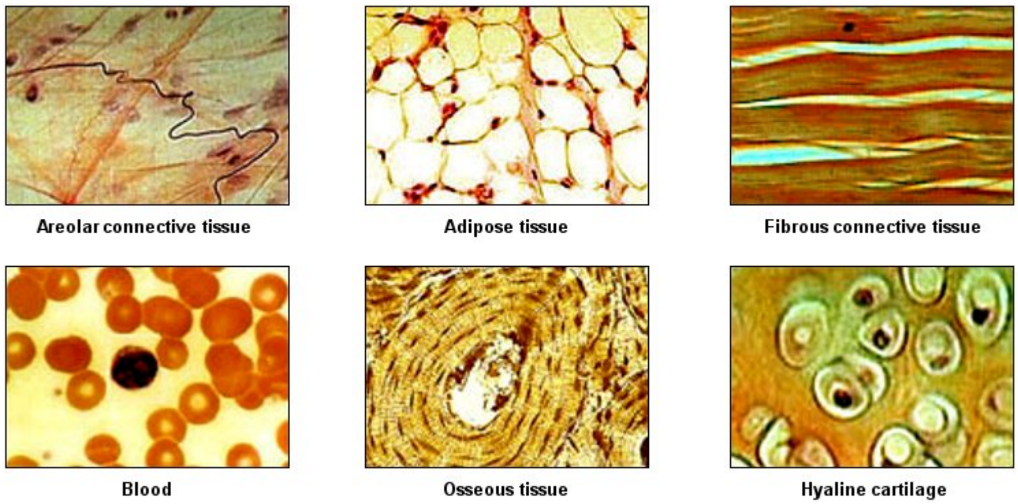


Figure 3–4. Types of connective tissue.

Muscle tissue

Muscle tissue is composed of cells that have the special ability to shorten or contract in order to produce movement of the body parts. This tissue is highly cellular and is well supplied with blood vessels. The cells are long and slender, often called muscle fibers, and usually arranged in bundles or layers, surrounded by connective tissue. Actin and myosin are contractile proteins in muscle tissue. Muscle tissue can be categorized into skeletal muscle tissue, smooth muscle tissue, and cardiac muscle tissue.

Nervous tissue

Nervous tissue is found in the brain, spinal cord, and nerves, and is responsible for coordinating and controlling many body activities. It stimulates muscle contraction, creates an awareness of the environment, and plays a major role in emotions, memory, and reasoning. To do all these things, cells in nervous tissue need to be able to communicate with each other by way of electrical nerve impulses. Nervous tissue is made of two principle types of cells: supporting cells and neurons.

Neurons are the excitable nerve cells that transmit electrical signals and possess three principal parts, including the cell body, the dendrites, and one axon. The main part of the cell, the part that carries on the general functions, is the cell body. Dendrites are extensions of cytoplasm that carry impulses to the cell body. An extension called an axon carries impulses away from the cell body. Nervous tissue also includes cells that do not transmit impulses but instead support the activities of the neurons.

Membranes

Body membranes are thin sheets of tissue that cover the body, line body cavities, and cover organs within the cavities in hollow organs. They can be categorized as either epithelial or connective tissue membranes.

Epithelial membranes

Epithelial membranes consist of epithelial tissue and the connective tissue attached. The two main types of epithelial membranes are the mucous membranes and serous membranes.

Mucous membranes

Mucous membranes are epithelial membranes that consist of epithelial tissue that attaches to an underlying loose connective tissue. These membranes line the body cavities that open to the outside. Mucous membranes line the entire digestive tract. Other examples include the respiratory, excretory, and reproductive tracts.

Serous membranes

Serous membranes line body cavities that do not open directly to the outside, and they cover the organs located in those cavities. A thin layer of serous fluid secreted by the epithelium covers and lubricates the serous membranes, reducing friction and abrasion when organs in the thoracic or abdominopelvic cavity move against each other or the cavity wall.

Connective membranes

Connective tissue membranes contain only connective tissue. Synovial membranes and meninges belong to this category.

Synovial membranes

Synovial membranes are connective tissue membranes that line the cavities of the freely movable joints such as the shoulder, elbow, and knee. Like serous membranes, they line cavities that do not open to the outside; however, unlike serous membranes, they do not have a layer of epithelium. Synovial membranes secrete synovial fluid into the joint cavity, and this lubricates the cartilage on the ends of the bones so that they can move freely and without friction.

Meninges

Meninges are connective tissue covering the brain and spinal cord within the dorsal cavity providing protection for these vital structures.

In essence, these membranes are all continuous multicellular sheets comprised of a least two primary tissue types: an epithelium bond to an underlying layer of connective tissue. Thus, these membranes are simple organs. Tissues that are grouped together to perform a common function are called organs. In other words, an organ is a structure composed of different types of tissues that perform a particular function. Further, when organs are grouped together to perform a specific function, they are part of an organ system.

Bioenvironmental engineering concerns

Epithelial tissue plays an important role in absorption, excretion, filtration and secretion. Chemicals found in the workplace may affect these tissue functions. The epithelium of the skin protects underlying tissues from mechanical and chemical injury and bacterial invasion. It also contains nerve endings that respond to various stimuli (pressure, heat, pain, etc.) acting at the skin surface. When tissues are injured, inflammatory and immune responses kick in. Many of these normal responses occur in the body's connective tissues.

The nervous tissue of the brain, spinal cord and nerves is critical to controlling our body's functions. It is highly sensitive to certain chemicals, including ethanol and methyl mercury, which can have an adverse effect on this tissue type. Once chemicals are absorbed in the bloodstream, blood carries them to different organs of the body—a specialized type of connective tissue. Due to some tissues, including the kidney and liver, being well perfused, they are most likely exposed to chemicals circulating in the blood.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

013. Cells within the human body

1. Define cell.

2. Describe the general structure and function of the plasma membrane of a cell.

3. Cite the special functions that occur within the cytoplasm of a cell.

4. Describe the general function of the nucleus.

5. Explain cell division and why it is important.

014. Tissues within the human body

1. Define tissue and cite the four major types of tissue found in the human body.

2. What are the functions of epithelial tissue (epithelium)?

3. Explain how the structure of connective tissue contributes to its function.

4. Describe the function of muscle tissue.

5. Describe the general structure and function of nervous tissue.

3–2. The Structure and Function of the Major Organ Systems

Organs are more complex units than tissues. An organ is an organization of several different kinds of tissues so arranged that together they can perform a special function. For example, the stomach is an organization of muscle, connective, epithelial, and nervous tissues. Muscle and connective tissues form its wall, epithelial and connective tissues form its lining, and nervous tissue extends throughout both its wall and its lining.

Systems are the most complex of the component units of the human body. A system is an organization of varying numbers and kinds of organs so arranged that together they can perform complex functions for the body.

015. The major organ systems that make up the human body

An organ system is a group of organs that work together to perform complex functions for the body. Ten major systems compose the human body:

1. Skeletal.
2. Muscular.
3. Nervous.
4. Endocrine.
5. Cardiovascular.
6. Lymphatic.
7. Respiratory.
8. Digestive.
9. Urinary.
10. Reproductive.

Before we begin our discussion on the major systems that compose the human body, we will take a moment to recall the five basic human senses: sight, smell, taste, touch, and hearing. Each of the senses consists of specialized cells that have receptors for specific stimuli. These cells have links to the nervous system and therefore to the brain. Sight is probably the most developed sense in humans, followed closely by hearing. In this lesson, we will limit our discussion to the senses of sight, hearing and touch.

Sight

In the eyes, the organ of sight, we have special sensory dendrites that let us perceive different colors and shapes, which is how we see. The eye is a hollow ball, or globe, containing various structures for specific functions (fig. 3–5). The eyeball, itself, has three layers of tissue.

Sclera

The outer layer is the sclera, the white protective covering that surrounds the eyeball entirely except for a small segment covered by the cornea. The sclera is resistant to stretching and tearing, and it gives strength to the fluid-filled eyeball. If this outer layer is cut or penetrated, the eye’s fluid content can leak out. You can compare this leak to letting the air out of a tire. Very soon, a tire with a hole in it will collapse; so will the eye.

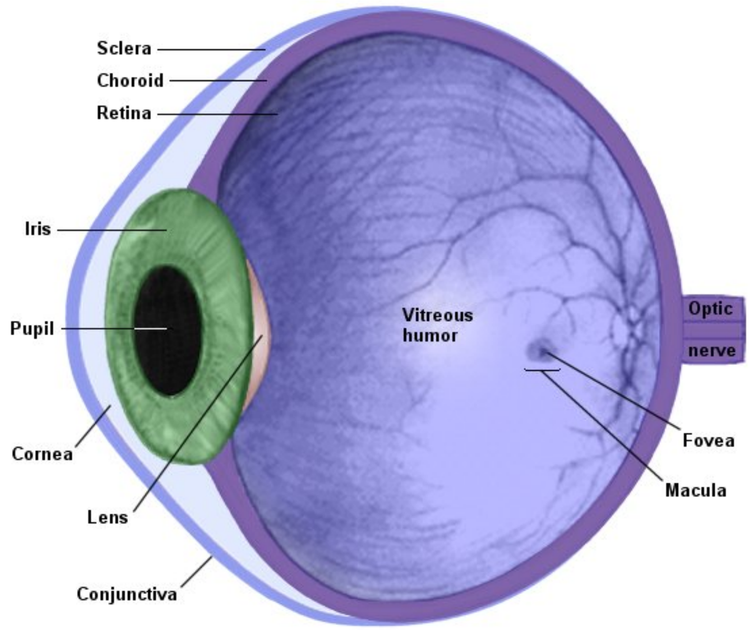


Figure 3–5. Human eye.

Choroid, iris, and ciliary body

The eye's middle layer consists of the choroid, the iris, and ciliary body. The choroid is a highly vascular layer that supplies the eye with nutrition and lines the posterior part of the eye. The iris is a thin, circular membrane that gives the eye its color. Like a camera's shutter, it covers the pupil—the opening through which light rays pass. The ciliary body makes movement of the lens possible. The lens is a transparent body just behind the pupil; its function is to focus light on the retina. It focuses the image we see on the retina. Occasionally, the lens loses its transparency; a condition called a cataract.

Retina

The innermost layer of the eye is the retina, a delicate membrane that receives images. When an object is viewed, the eye's lens system projects an image on the retina nerve endings. When light falls on the nerve endings, impulses are generated and relayed through the optic nerve to the brain where they are integrated and interpreted as visual images.

Bioenvironmental engineering concerns

Nonionizing radiation (radar microwave) exposure to the unprotected eye can cause cataracts if the radiation level is intense enough. Since the lenses of the eyes have very few blood vessels, it cannot dissipate the heat adequately to handle this kind of radiation. Hence, cataracts form on the lens. This 'cooking' of the lens is comparable to what happens when you cook an egg white. Ultraviolet radiation (such as that produced by arc welding) causes sunburned eyeballs. In this case, the ultraviolet radiation creates a photochemical reaction in the very outside layer of the eye that kills the cells there, hence, called the sunburned effect. Lasers can cause annoying glare and mild bleaching of the photoreceptors (similar to seeing spots when you look at a very bright light) up to massive, permanent damage to the retina.

Hearing

Hearing, one of our five senses, helps keep us aware of changes in our environment. The ear, the hearing organ, is divided into three parts: the external ear, the middle ear, and the inner ear (fig. 3–6).

External ear

The external ear consists of a flap, or modified trumpet called the auricle, and the ear canal. The auricle picks up or collects the sound waves (like a catcher's mitt) and directs them through the ear canal to the eardrum, or tympanic membrane.

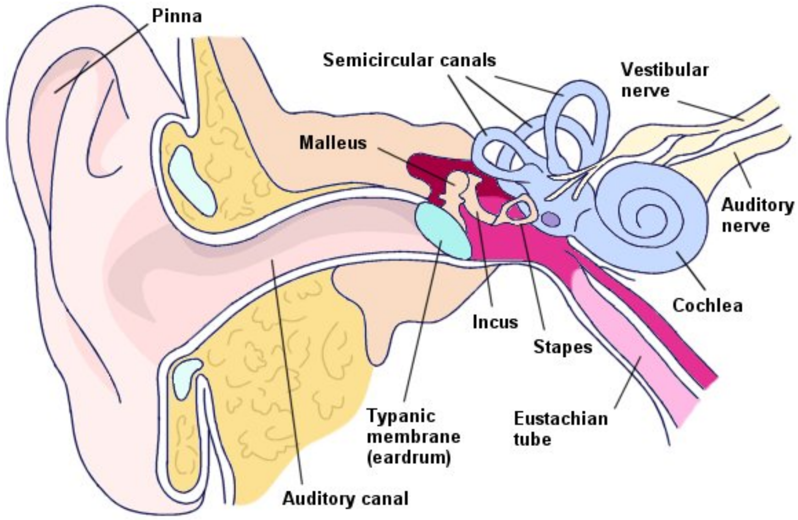


Figure 3–6. Human ear.

Middle ear

The middle ear is in a cavity of the temporal bone that is lined with mucous membrane, contains the tympanic membrane, the Eustachian tube, and three tiny ear bones called ossicles. The tympanic membrane separates the external ear from the middle ear. It receives sound vibrations from the external ear and transmits them to the ear ossicles. The Eustachian tube connects the middle ear cavity with the pharynx. Its function is to equalize the air pressure in the ear with that of the atmosphere. This pressure adjustment is especially important during air flight and under water. Unless the pressure is equalized, the eardrum might burst.

Inner ear

The inner ear, or labyrinth, is a series of complicated canals in a hollow part of the temporal bone. It contains the receptors for both hearing and equilibrium. The receptor for hearing is the Corti, contained inside a fluid-filled shell-like structure called the cochlea. Vibrations reach this structure from the external ear by way of the ossicles. Their vibrations cause movement of the fluid within the cochlea, which stimulates the sensory nerve endings in the organ of Corti. From the organ of Corti, the nerve impulses are relayed by the acoustic nerve to the hearing center in the temporal lobe of the brain.

Bioenvironmental engineering concerns

The cochlea's sensory nerve endings are sound frequency specific. Exposing the unprotected ear to enough volume of sound for long enough (the louder the sound, the faster the effect) makes the sensory nerve endings lose their ability to sense sound. This loss of sound perception can be temporary or permanent.

Touch

The skin is the sense organ that covers the whole body and the sense of touch is distributed over the entire body. Skin protects the body from invasion by bacteria and other harmful microorganisms, helps keep a constant body temperature, prevents water loss, excretes wastes, receives four kinds of sensations, produces a vitamin, and absorbs certain drugs and other chemical substances. It has a remarkable ability to heal itself. To carry out all these functions, the skin must be tough, and pliable, selectively permeable, and well supplied with nerves and sensory receptors, blood vessels, and glands. The sweat and sebaceous glands, the hair, and nails are all derivatives of the skin. Skin is made of two major layers, an innermost dermis and an outermost epidermis. These are further divided into several smaller layers (fig. 3–7).

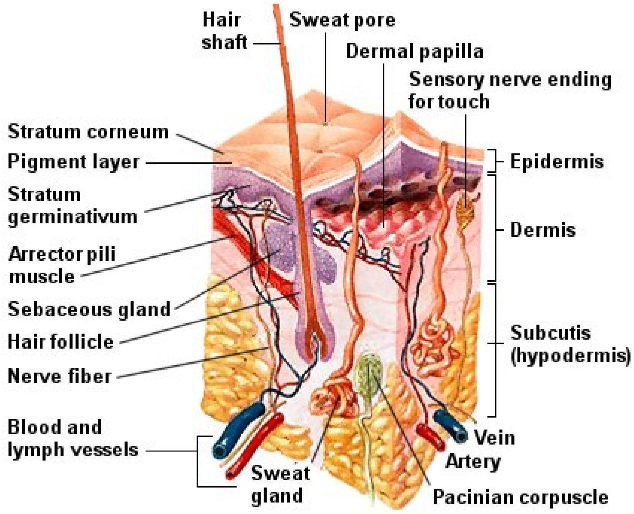


Figure 3–7. The skin.

Epidermis

There are several layers of the epidermis. Although these layers resemble dry, clear, overlapping scales, they develop part of the accessory skin organs. In addition, their overlapping arrangement prevents the passage of almost every known variety of germs. The cells in the first two layers are dead or dying, while those in the two deeper layers are alive and constantly dividing. The cells in the outermost layer have no nuclei and contain the hornlike protein material called keratin. They are constantly worn away and shed but are replaced by cells from another layer. The three upper layers of the epidermis could not exist without the lower layers. There the cells multiply and slough off when they reach the outer layers.

Dermis

This is the inner of the two main layers of epithelial cells. It is also known as the true skin. Within the dermis are capillaries, nerve endings, and skin pigment. Capillaries nourish these cells, which multiply rapidly and push toward the epidermis. Because of this constant activity, minor injuries to the dermis are quickly repaired without leaving a scar. The nerve endings respond to pressure, pain, and changes in temperature. Pigment cells give the skin its color.

Accessory skin organs

You must realize that epithelial cells are not all arranged in flat, smooth layers but may lie in pockets within the subcutaneous fatty tissue. Sebaceous glands about the hair shaft secrete an oily substance, sebum, which keeps the skin soft and pliable. Sweat glands are tubular organs imbedded in the dermis. The perspiration, or sweat, they excrete is carried to the skin surface through ducts and out through skin openings called pores. Hair is composed of modified epithelial cells. The hair root is imbedded in the fatty subcutaneous tissue and nourished by dermal capillaries. The hair shaft rises up through the hair follicle—the tube in which it grows. Alongside each follicle is a special tissue called erector muscle. Since the hair grows at a slight angle, whenever the dermal nerve endings are stimulated by cold or other special stimuli, the erector muscle is also stimulated. This forces the hair to straighten and gives the skin the appearance of goose flesh.

By now, you may have figured out that the skin's three main functions are protection, temperature regulation and excretion. As previously mentioned, the overlapping arrangement of the epidermal and dermal cells prevents the passage of almost every known variety of disease germs. Dermal cells reassure protection by their ability to replace injured or diseased tissue. Further protection to the body comes when the skin acts as an organ for sensation. The nerve endings in the dermis perceive heat, cold, pressure, and pain. Once the nerves react to these stimuli, the nervous and muscular systems use reflex action to prevent serious injury.

Body temperature regulation

Not only does the skin detect heat and cold, it helps regulate body temperature. According to which stimulus they receive, capillaries within the dermis dilate to let warm blood come near the skin surface to lose its heat or constrict to decrease the amount of blood at the skin surface and conserve heat within the body. The skin also secretes perspiration from the sweat glands as the body temperature rises. Perspiration escapes from the pores, evaporates on the skin surface, and produces a cooling effect.

Perspiration contains salt, acids, urea, and carbon dioxide. Its evaporation on the skin surface is a means of excreting these waste products from the body. An average of a quart daily may be excreted, but the amount varies considerably with the temperature, humidity, and amount of physical activity. Perspiration is continuous, but it may be so slow and it may evaporate so quickly that it goes unnoticed.

Bioenvironmental engineering concerns

Most accidents or incidents in industrial areas involve the skin in one form or another. Contact dermatitis (inflammation of the skin from exposure to chemicals, ultraviolet radiation, heat, etc.) is a common occupational disease within the Air Force. Why is this condition so prevalent? Part of the answer is obvious. The skin, as a mode of entry, is the largest area exposed to toxic chemicals and infectious agents. The rest of the answer involves the use (or maybe the nonuse) of protective equipment, controlling the toxins in the workplace, and health education of the industrial worker, supervisor, and our own medical staff as to the importance of recognizing and preventing exposure.

016. The skeletal system

As humans, we rely on our sturdy internal frame. The human skeletal system consists of bones, cartilage, ligaments and tendons and accounts for about 20 percent of our body’s weight. The living bones in our bodies use oxygen and give off waste products during metabolism. They contain active tissues that consume nutrients, require a blood supply, and change shape or refashion in response to variations in mechanical stress. The main function of bones is to provide a rigid framework, our skeleton, to support and protect the soft organs of the body.

The skeleton supports the body against the pull of gravity. The large bones of the lower limbs support the trunk when standing. The skeleton also protects the soft body parts. For example, the fused bones of the cranium surround the brain to make it less vulnerable to injury; vertebrae surround and protect the spinal cord; and bones of the rib cage help protect the heart and lungs of the thorax. Bones also work together with muscles as simple mechanical lever systems to produce body movement. Hematopoiesis, the formation of blood cells, mostly takes place in the red marrow of the bones. Red marrow functions in the formation of red blood cells, white blood cells, and blood platelets.

Divisions of the skeleton

The adult human skeleton typically consists of 206 named bones, which can be grouped into two divisions: the axial skeleton and appendicular skeleton.

Axial skeleton

The 80 bones of the axial skeleton form the vertical axis of the body. They include the bones of the head, vertebral column, ribs and breastbone (sternum).

Appendicular skeleton

The appendicular skeleton consists of 126 bones and includes the free appendages and their attachments to the axial skeleton. The free appendages are the upper and lower extremities, or limbs, and their attachments that are called girdles.

Joints

A joint is where two bones come together. In terms of the amount of movement they allow, there are three types of joints: immovable, slightly movable, and freely movable. Most joints in the adult body are freely movable joints. In this type of joint, the ends of the opposing bones are covered with cartilage and are separated by a space called the joint cavity. The components of the joints are enclosed in a dense fibrous joint capsule. The outer layer of the capsule consists of the ligaments that hold the bones together. The inner layer is the synovial membrane, which secretes synovial fluid into the joint cavity for lubrication. Because all freely movable joints have a synovial membrane, they are sometimes called synovial joints (fig. 3–8).

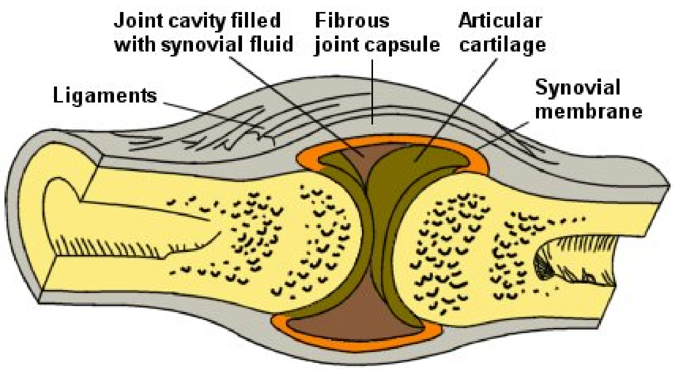


Figure 3–8. Synovial joints.

Bioenvironmental engineering concerns

Often the most overlooked part of the skeletal system is bone marrow. The blood-forming cells of the bone marrow are among the most radiosensitive cells in the body. If a large percentage of such cells are killed, as can happen when intensive irradiation of the whole body occurs, the normal replacement of circulating blood cells is impaired.

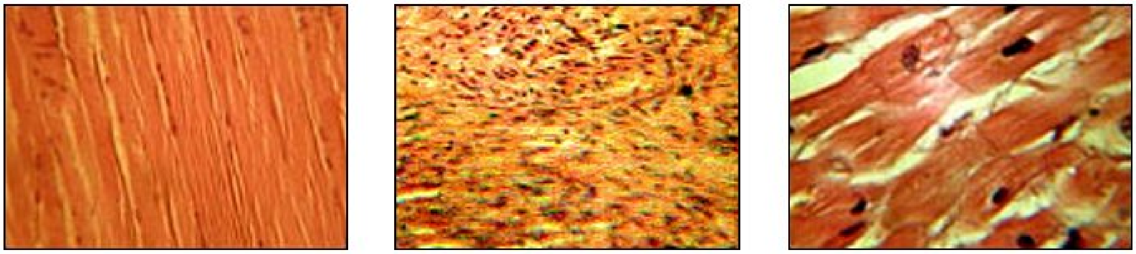
017. The muscular system

The muscles of the body work with the skeletal system to provide movement and support. The muscular system is composed of specialized cells called muscle fibers with a chief function of contractibility. Muscles, where attached to bones or internal organs and blood vessels, are responsible for movement. Nearly all movement in the body is the result of muscle contraction. The integrated action of joints, bones, and skeletal muscles produces obvious movements such as walking and running. Skeletal muscles also produce more subtle movements that result in various facial expressions, eye movements, and respiration.

In addition to movement, muscle contraction also fulfills some other important functions in the body, such as posture, joint stability, and heat production. The skeletal muscles are continually making fine adjustments that hold the body in stationary positions. The tendons of many muscles extend over joints, contributing to joint stability. Heat production, to maintain body temperature, is an important by-product of muscle metabolism. Nearly 85 percent of the heat produced in the body is the result of muscle contraction.

Muscle types

Skeletal (striated), smooth, and cardiac (fig. 3–9) are the three types of muscle within the body.



Skeletal muscle | Smooth muscle | Cardiac muscle

Figure 3–9. Types of muscle tissue.

Skeletal

It is cylindrical, multinucleated, and striated. The basic unit is the muscle fiber. Each muscle acts independently of neighboring muscle fibers to produce skeletal movements. The peripheral portion of the central nervous system controls the skeletal muscles. Thus, these muscles are under conscious, or voluntary, control.

Smooth

Smooth muscle is spindle shaped, has a single, centrally located nucleus, and lacks striations. It is found in the walls of hollow internal organs such as blood vessels, the gastrointestinal tract, bladder, and uterus. Smooth muscle contracts slowly and rhythmically, is under control of the autonomic nervous system, thus acts involuntarily.

Cardiac

Found in the walls of the heart, cardiac muscle has one central nucleus, like smooth muscle. However, it is also striated, like skeletal muscle. The cardiac muscle cell is rectangular in shape. The contraction of cardiac muscle, under control of the autonomic nervous system, is involuntary, strong, and rhythmical.

Bioenvironmental engineering concerns

Movement, the ability to lift, and worker strength are all affected by the muscular system. Some tasks place workers at risk of developing musculoskeletal disorders. As the name implies, musculoskeletal disorders include problems involving the muscular and skeletal systems. Hand-arm vibration syndrome, back disorders, and carpal tunnel syndrome are just a few examples of these disorders.

018. The nervous system

The nervous system is the major controlling, regulatory, and communicating system in the body. It is the center of all mental activity including thought, learning, and memory. Together with the endocrine system, the nervous system is responsible for regulating and maintaining homeostasis. Through its receptors, the nervous system keeps us in touch with our environment, both external and internal.

Like other systems in the body, the nervous system is composed of organs, principally the brain, spinal cord, nerves, and ganglia—mass of nerve cells external to the brain or spinal cord. These, in turn, consist of various tissues, including nerve, blood, and connective tissue. Together these carry out the complex activities of the nervous system. The various activities of the nervous system can be grouped together as three general overlapping functions: sensory, integrative, and motor.

Although the nervous system is very complex, there are only two main types of cells in nerve tissue: the neuron and the neuroglia. The neuron is the actual conductive nerve cell that transmits impulses and is the structural unit of the nervous system. The neuroglia (which means nerve glue) are nonconductive and provide support system for the neurons.

Neurons

Neurons, or nerve cells, carry out the functions of the nervous system by conducting nerve impulses. They are highly specialized and amitotic. This means that if a neuron is destroyed, it cannot be replaced because neurons do not go through mitosis. Figure 3–10 illustrates the structure of a typical neuron. Each neuron has three basic parts: cell body (soma), one or more dendrites, and a single axon.

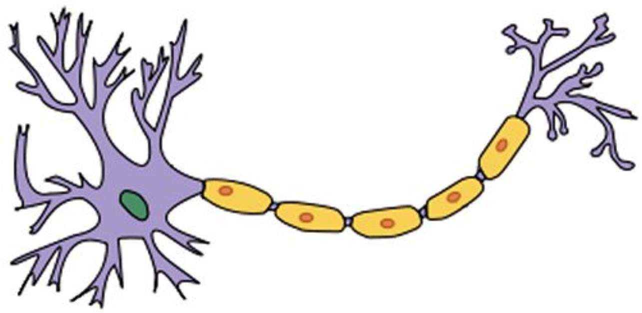


Figure 3–10. Structure of a typical neuron.

Cell body

In many ways, the cell body is similar to other types of cells. It has a nucleus with at least one nucleolus and contains many of the typical cytoplasmic organelles. It lacks centrioles, however. As centrioles function in cell division, the fact that neurons lack these organelles is consistent with the amitotic nature of the cell.

Dendrites

Dendrites and axons are cytoplasmic extensions, or processes, that project from the cell body. They are sometimes referred to as fibers. Dendrites are usually, but not always, short and branching, which increases their surface area to receive signals from other neurons. The number of dendrites on a neuron varies.

Axon

Each neuron has a single axon. The axon may be very short in some neurons, while it may be long in others; this accounts for nearly the entire length of the neuron. Any long axon is called a nerve fiber. Functionally, the axon is the conducting region of the neuron; for example, it generates nerve impulses and transmits them, typically away from the cell body.

Neuroglia

Neuroglia cells do not conduct nerve impulses, but instead, they support, nourish, and protect the neurons. Neuroglia cells are far more numerous than neurons and, unlike neurons, are capable of mitosis. There are six types of neuroglia—four in the central nervous system and two in the peripheral nervous system. Each type provides a unique supportive function for the neurons.

Organization of the nervous system

The nervous system as a whole is divided into two subdivisions: the central nervous system and the peripheral nervous system. Each subdivision has structural and functional characteristics that distinguish it from the other.

Central nervous system

The central nervous system is made of the brain and spinal cord. Because they are so vitally important, the brain and spinal cord are encased in bone for protection. The brain is in the cranial vault while the spinal cord is in the vertebral canal of the vertebral column. The central nervous system functions as the major signal receptor and integration (information processing) site for the nervous system.

Peripheral nervous system

The organs of the peripheral nervous system are the nerves and ganglia. Cranial nerves and spinal nerves extend from the central nervous system to peripheral organs such as muscles and glands. Ganglia are collections of nerve cell bodies outside the central nervous system.

The peripheral nervous system is further divided into a sensory division and a motor division. The sensory division transmits impulses from peripheral organs to the central nervous system. The motor division transmits impulses from the central nervous system out to the peripheral organs to cause an effect or action.

Bioenvironmental engineering concerns

Certain toxic substances can interfere with the nervous system's operation. The two major groupings of these toxics are central nervous system depressants and stimulants. Central nervous system depressants depress the autonomic nervous system – a subdivision of the peripheral nervous system. The autonomic nervous system consists of visceral motor nerve fibers that regulate the activity of smooth muscles, cardiac muscles, and glands. Some of the best examples of central nervous system depressants are organic solvents. Central nervous system stimulants excite acetylcholine production, which stimulates the smooth muscles. Cholinesterase, an enzyme in blood plasma, immediately neutralizes the effects of acetylcholine. Nerve agents and organophosphate pesticides inhibit cholinesterase from doing its job, and the nerve continues to stimulate the muscles. This can eventually lead to paralysis and possibly death.

019. The endocrine system

The endocrine system and the nervous system function together in the regulation of body activities. The nervous system acts through electrical impulses and neurotransmitters to cause muscle contraction and glandular secretion. The endocrine system acts through chemical messengers called hormones that influence growth, development, and metabolic activities. There are two major categories of glands in the body—exocrine and endocrine.

- Exocrine glands have ducts that carry their secretory product to a surface. These glands include the sweat, sebaceous, and mammary glands, and the glands that secrete digestive enzymes.
- The endocrine glands do not have ducts to carry their products to a surface and are called ductless glands. The secretory products of endocrine glands are called hormones and are secreted directly into the blood and then carried throughout the body where they influence only those cells that have receptor sites for that hormone.

Hormones are chemical substances, secreted by cells into the extracellular fluids, which regulate the metabolic function of other cells in the body. Chemically, hormones can be classified as either protein or steroids. All of the hormones in the human body, except the sex hormones and those from the adrenal cortex, are proteins or protein derivatives. Hormones are very potent substances; very small amounts of a hormone may have profound effects on metabolic processes. Because of this potency, hormone secretion must be regulated within very narrow limits in order to maintain homeostasis in the body.

Endocrine glands and their hormones

The endocrine system is made of the endocrine glands that secrete hormones. Although there are eight major endocrine glands scattered throughout the body, they are still considered to be one system because they have similar functions, similar mechanisms of influence, and many important interrelationships. Each of the glands within the endocrine system secretes specific hormones. These hormones either travel short distances to nearby cells or are released into the bloodstream to travel to other parts of the body. Cells that receive the hormones and act as receptors are called target cells. Figure 3–11 illustrates the major glands that comprise the endocrine system.

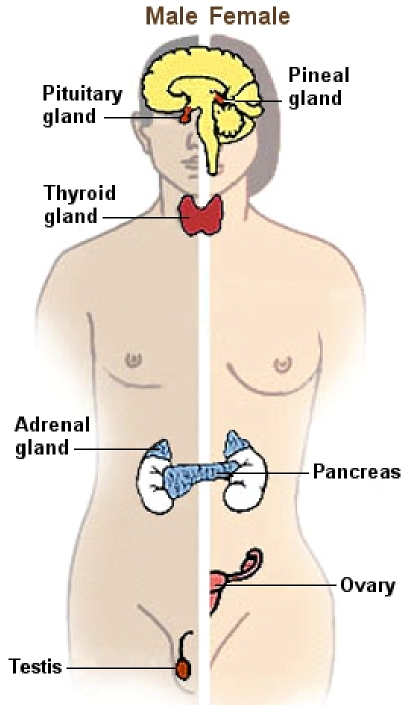


Figure 3–11. Major glands of the endocrine system.

Pituitary gland

The pituitary gland is a small gland about 1 cm in diameter. This tiny gland secretes at least nine hormones. It is located at the bases of the brain and is attached to the hypothalamus. There are two distinct regions in the gland: the anterior lobe and the posterior lobe. The pituitary gland is also referred to as the body's master gland because of the controlling effect it has on the other glands.

Thyroid gland

The thyroid gland is a highly vascular organ that is located in the neck. It consists of two lobes, one on each side of the trachea, just below the larynx (voice box). The two lobes are connected by a narrow band of tissue called the isthmus. Internally, the gland consists of follicles, which produce thyroxine and triiodothyronine hormones. Both of these require iodine for their synthesis.

Adrenal gland

The adrenal gland is paired with one gland located near the upper portion of each kidney. Each gland is divided into an outer cortex and an inner medulla. The hypothalamus of the brain influences both portions of the adrenal gland but by different mechanisms. The adrenal cortex is regulated by negative feedback involving the hypothalamus while the medulla is regulated by nerve impulses from the hypothalamus.

Pancreas

The pancreas is a long, soft organ that lies posterior to the stomach. This gland has an exocrine portion that secretes digestive enzymes that are carried through a duct to the duodenum. The endocrine portion consists of the pancreatic islets, which secrete glucagons and insulin. Alpha cells in the pancreatic islets secrete the hormone glucagons in response to a low concentration of glucose in the blood.

Gonads

The gonads, the primary reproductive organs, are the testes in the male and the ovaries in the female. These organs are responsible for producing the sperm and ova, but they also secrete hormones and are considered endocrine glands. In addition to the major endocrine glands, other organs have some hormonal activity as part of their function. These include the thymus, stomach, small intestines, heart, and placenta.

Bioenvironmental engineering concerns

There is concern amongst the scientific community about the effects of some chemicals on the endocrine system. These chemicals are believed to disrupt the endocrine system by acting like, inhibiting, or altering the body's natural hormones and are sometimes referred to as endocrine disruptors. Dinitro-o-cresol, an insecticide, is an example of a chemical with the endocrine system as the target organ.

020. The cardiovascular system

The cardiovascular system is sometimes called the blood-vascular system or simply the circulatory system. It consists of the heart and a closed system of vessels called arteries, veins, and capillaries (fig. 3–12). As the name implies, the heart pumps the blood that is contained in the circulatory system around the closed circle, or circuit of vessels, as it continuously passes through the various circulations of the body.

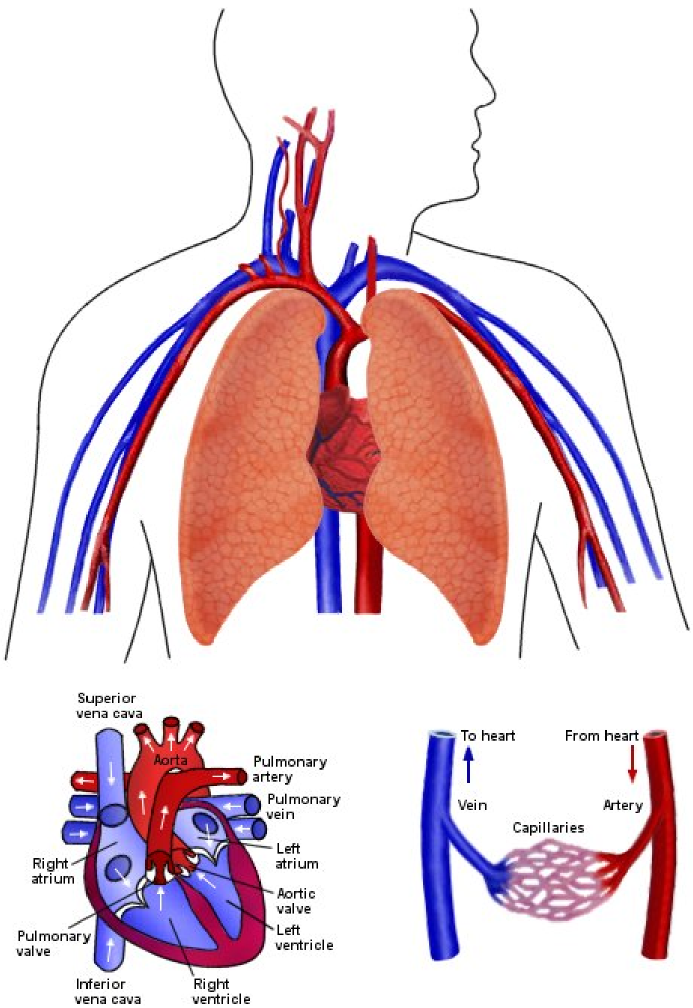


Figure 3–12. Cardiovascular system.

The vital role of the cardiovascular system in maintaining homeostasis depends on the continuous and controlled movement of blood through the thousands of miles of capillaries that permeate every tissue and reach every cell in the body.

Heart

The heart is a muscular pump that provides the force necessary to circulate the blood to all the tissues in the body. Its function is vital; to survive, the tissues need a continuous supply of oxygen and nutrients, while metabolic waste products must be eliminated. Deprived of these necessities, cells soon undergo irreversible changes that lead to death. While the blood is the transport medium, the heart is the organ that keeps the blood moving through the vessels.

Blood

Blood is the fluid of life, transporting oxygen from the lungs to body tissue and carbon dioxide from body tissue to the lungs. Blood is the fluid of growth, transporting nourishment from digestion and hormones from glands throughout the body. Blood is the fluid of health, transporting disease fighting substances to the tissue and waste to the kidneys. Because it contains living cells, blood is alive. Red blood cells and white blood cells are responsible for nourishing and cleansing the body. Without blood, your body would stop working.

Classification and structure of blood vessels

Blood vessels are the channels through which blood is distributed to body tissues. Based on their structure and function, blood vessels are classified as arteries, capillaries, or veins.

Arteries

They carry blood away from the heart. Blood is pumped from the ventricles into large elastic arteries that branch repeatedly into smaller and smaller arteries until the branching results in microscopic arteries called arterioles. Arterioles play a key role in regulating the blood flow into the tissue capillaries.

Capillaries

They are the smallest and most numerous of the blood vessels and form the connection between the vessels that carry blood away from the heart (arteries) and the vessels that return blood to the heart (veins). The primary function of capillaries is the exchange of materials between the blood and tissue cells.

Veins

Veins carry blood toward the heart. After passing through the capillaries, blood enters the smallest veins, called venules, from which it flows into progressively larger and larger veins until it reaches the heart. As the walls of veins are thinner and less rigid than arteries, veins can hold more blood. Almost 70 percent of the total blood volume is in the veins at any given time.

The blood vessels of the body are functionally divided into two distinctive circuits: pulmonary circuit and system circuit. The pump for the pulmonary circuit, which circulates blood through the lungs, is the right ventricle. The left ventricle is the pump for the systemic circuit, which provides the blood supply for the tissue cells of the body.

Bioenvironmental engineering concerns

Once toxic substances have entered the bloodstream, the circulatory system plays an important role in distributing them throughout the body where they may cause harmful effects, depending on the target organ. In addition, the circulatory system also plays a role in the elimination of toxic substances. Further, the circulatory system plays a key role in providing oxygen to the tissues. Some agents, such as argon and methane, displace oxygen in the inspired air, resulting in inadequate oxygen in the blood. Other substances, such as carbon monoxide, bind with hemoglobin in red blood cells, ultimately resulting in insufficient oxygenation of tissues. Still other substances may affect the blood cells themselves, resulting in varying blood abnormalities.

021. The lymphatic system

The lymphatic system has three primary functions. First, it returns excess interstitial fluid to the blood. Of the fluid that leaves the capillary, about 90 percent is returned. The 10 percent that does not return becomes part of the interstitial fluid that surrounds the tissue cells. Small protein molecules may "leak" through the capillary wall and increase the osmotic pressure of the interstitial fluid. This further inhibits the return of fluid into the capillaries, and fluid tends to accumulate in the tissue spaces. If this continues, blood volume of tissue fluid increases, resulting in swelling (edema). Lymph capillaries pick up the excess interstitial fluid and proteins and return them to the venous blood. After the fluid enters the lymph capillaries, it is called lymph.

The second function of the lymphatic system is the absorption of fats and fat-soluble vitamins from the digestive system and the subsequent transport of these substances to the venous circulation. The mucosa that lines the small intestine is covered with fingerlike projections called villi. There are blood capillaries and special lymph capillaries, called lacteals, in the center of each villus. The blood capillaries absorb most nutrients, but the fats and fat-soluble vitamins are absorbed by the lacteals. The lymph in the lacteals has a milky appearance due to its high fat content.

The third and probably most well-known function of the lymphatic system is defense against invading microorganisms and disease. Lymph nodes and other lymphatic organs filter the lymph to remove microorganisms and other foreign particles. Lymphatic organs contain lymphocytes that destroy invading organisms.

Physiology of the lymphatic system

The lymphatic system consists of a fluid (lymph), vessels that transport the lymph, and organs that contain lymphoid tissue.

Lymph

Lymph is fluid similar in composition to blood plasma. It is derived from blood plasma as fluids pass through capillary walls at the arterial end. As the interstitial fluid begins to accumulate, it is picked up and removed by tiny lymphatic vessels and returned to the blood. As soon as the interstitial fluid enters the lymph capillaries, it is called lymph. Returning the fluid to the blood prevents edema and helps to maintain a normal blood volume and pressure.

Lymphatic vessels

Lymphatic vessels, unlike blood vessels, only carry fluid away from the tissues. The smallest lymphatic vessels are the lymph capillaries (fig. 3–13), which begin in the tissue spaces as blind-ended sacs. Lymph capillaries are found in all regions of the body except the bone marrow, central nervous system, and tissues, such as the epidermis, that lack blood vessels. The wall of the lymph capillary is composed of endothelium in which the simple squamous cells overlap to form a simple one-way valve. This arrangement permits fluid to enter the capillary but prevents lymph from leaving the vessel.

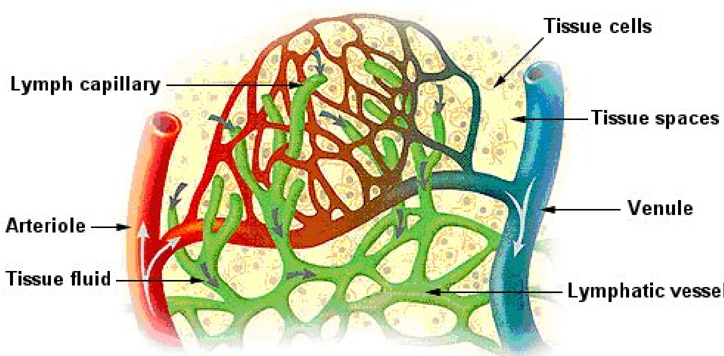


Figure 3–13. Lymph capillaries in the tissue spaces.

The microscopic lymph capillaries merge to form lymphatic vessels. Small lymphatic vessels join to form larger tributaries, called lymphatic trunks, which drain large regions. Lymphatic trunks merge until the lymph enters the two lymphatic ducts. The right lymphatic duct drains lymph from the upper right quadrant of the body. The thoracic duct drains all the rest.

Like veins, the lymphatic tributaries have thin walls and valves to prevent backflow of blood. Unlike the heart in the cardiovascular system, there is no pump in the lymphatic system. The pressure gradients to move lymph through the vessels come from the skeletal action, respiratory movement, and contraction of smooth muscle in vessel walls.

Lymphatic organs

Lymphatic organs are characterized by clusters of lymphocytes and other cells, such as macrophages, enmeshed in a framework of short, branching connective tissue fibers. The lymphocytes originate in the red bone marrow with other types of blood cells and are carried in the blood from the bone marrow to the lymphatic organs. When the body is exposed to microorganisms and other foreign substances, the lymphocytes proliferate within the lymphatic organs and are sent in the blood to the site of the invasion. This is part of the immune response that attempts to destroy the invading agent. The lymphatic organs include lymph nodes, tonsils, spleen, and the thymus.

Lymph nodes

Lymph nodes are small bean-shaped structures that are typically less than 2.5 cm in length. They are widely distributed throughout the body along the lymphatic pathways where they filter the lymph before it is returned to the blood. Lymph nodes are not present in the central nervous system; instead, there are three superficial regions on each side of the body where lymph nodes tend to cluster. These are the inguinal nodes in the groin, the auxiliary nodes in the armpit, and the cervical nodes in the neck.

Tonsils

Tonsils are the clusters of lymphatic tissue just under the mucous membranes that line the nose, mouth and throat (pharynx). The three groups of tonsils include pharyngeal, palatine, and lingual tonsils. The pharyngeal tonsils are located near the opening of the nasal cavity into the pharynx. When these tonsils become enlarged, they may interfere with breathing. The palatine tonsils are the ones that are located near the opening of the oral cavity into the pharynx. Lingual tonsils are located on the posterior surface of the tongue, which also places them near the opening of the oral cavity into the pharynx. Lymphocytes and macrophages in the tonsils provide protection against harmful substances and pathogens that may enter the body through the nose or mouth.

Spleen

This is the largest lymphatic organ in the body. The spleen filters blood in much the way that the lymph nodes filter lymph. Lymphocytes in the spleen react to pathogens in the blood and attempt to destroy them. Macrophages then engulf the resulting debris, the damaged cells, and the other large particles. The spleen, along with the liver, removes old and damaged red blood cells (erythrocytes) from the circulating blood. Like other lymphatic tissue, it produces lymphocytes, especially in response to invading pathogens. The sinuses in the spleen are a reservoir for blood.

Thymus

The primary function of the thymus is the processing and maturation of special lymphocytes called T-lymphocytes or T-cells. While in the thymus, the lymphocytes do not respond to pathogens and foreign agents. After the lymphocytes have matured, they enter the blood and go to other lymphatic organs where they help provide defense against disease. The thymus also produces the hormone thymosin, which stimulates the maturation of lymphocytes in other lymphatic organs.

Bioenvironmental engineering concerns

Exposures to infectious agents as well as some chemical agents can result in the body mounting different immune responses. For example, an exaggerated immune response, or hypersensitivity, may result due to exposure to biological or chemical agents, to include isocyanates, chromium, and latex. Suppression of the immune system can result from exposure to organophosphates, organic solvents such as benzene, and metals such as lead.

022. The respiratory system

Whenever the respiratory system is mentioned, people typically think of breathing; however, breathing is only one of the activities of the respiratory system. The body cells need a continuous supply of oxygen for the metabolic processes that are necessary to maintain life. The respiratory system works with the circulatory system to provide this oxygen and to remove the waste products of metabolism. It also helps to regulate the pH level within the blood.

Respiration is the sequence of events that results in the exchange of oxygen and carbon dioxide between the atmosphere and the body cells. Pulmonary ventilation is commonly referred to as breathing. It is the process of air flowing into the lungs during inhalation and out of the lungs during exhalation. The human body requires a constant supply of air and gases at the cellular level to carry on the chemical processes that are vital to life.

All of the organs of the upper and lower respiratory system, as well as the accessory structures, combine to permit the process of respiration to take place. This continuing process of inhalation and exhalation is primarily involuntary and continues even when you are asleep. There is a degree of conscious control over breathing; however, this control is limited by chemical changes in the blood.

The controlling factor is not the oxygen requirement, as you might think, but the carbon dioxide level in the blood. For example, when you exercise more, oxygen is used, and more carbon dioxide is produced. The increase in carbon dioxide is what makes you start breathing faster and deeper. This increased breathing rate brings in more oxygen to meet the new oxygen requirements. The respiratory center stimulates the nerves that control respiratory movements, the respiratory rate increases, and the body rids itself of the excess carbon dioxide.

Conducting passages

The respiratory conducting passages are divided into the upper and lower respiratory tracts (fig. 3–14). The upper respiratory tract includes the nose, pharynx, and larynx. The lower respiratory tract consists of the trachea, bronchial tree, and lungs. These tracts open to the outside and are lined with mucous membranes.

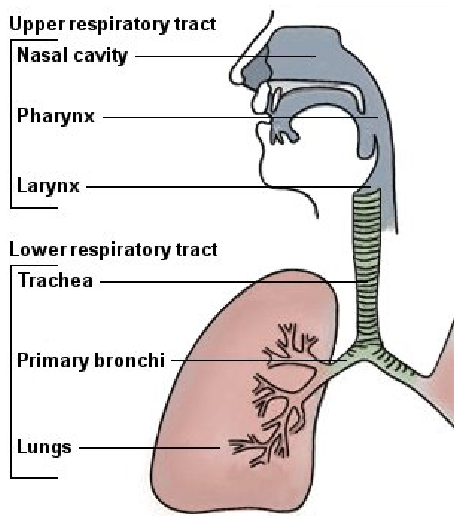


Figure 3–14. Respiratory system.

Bioenvironmental engineering concerns

The respiratory system is one of the major entry modes of contaminated or toxic substances. Unprotected exposures to toxic substances can cause what is termed “occupational illnesses.” For example, inhaling dust that contains crystalline free silica (from grinding or sandblasting operations) may cause an occupational illness called silicosis. In silicosis, the lymph nodes in the lungs trap particles and become enlarged, eventually obstructing bronchioles and causing loss of vital capacity. Asbestosis is another form of occupational illness. Asbestosis results from inhaling asbestos fibers (from asbestos insulation removal or installation). The asbestos fibers lodge in the bronchioles, where they can cause irritation and eventually create an obstruction. Exposure to major air pollutants can affect the respiratory system, particularly within susceptible population group, such as the very young, the chronically ill, and the very old.

023. The digestive system

The digestive system includes the digestive tract and its accessory organs, which process food into molecules that can be absorbed and utilized by the cells of the body. Food is broken down, bit by bit, until the molecules are small enough to be absorbed and the waste products are eliminated. The digestive tract, also called the gastrointestinal tract, consists of a long continuous tube that extends from the mouth to the anus. It includes the mouth, pharynx, esophagus, stomach, small intestine, and large intestine. The tongue and teeth are accessory structures located in the mouth. The salivary glands, liver, gallbladder, and pancreas are major accessory organs that have a role in digestion. These organs secrete fluids into the digestive tract.

Regions of the digestive system

The chief goal of the digestive system is to break down proteins, fats, and starches, which cannot be absorbed intact into amino acids, fatty acids, and glucose that can be absorbed across the wall of the tube and into the circulatory system for dissemination throughout the body.

Regions of the digestive system can be divided into two main parts: the alimentary tract and accessory organs (fig. 3–15). The alimentary tract of the digestive system is composed of the mouth, pharynx, esophagus, stomach, small and large intestines, rectum and anus. Associated with the alimentary tract are the following accessory organs: salivary glands, liver, gallbladder, and pancreas.

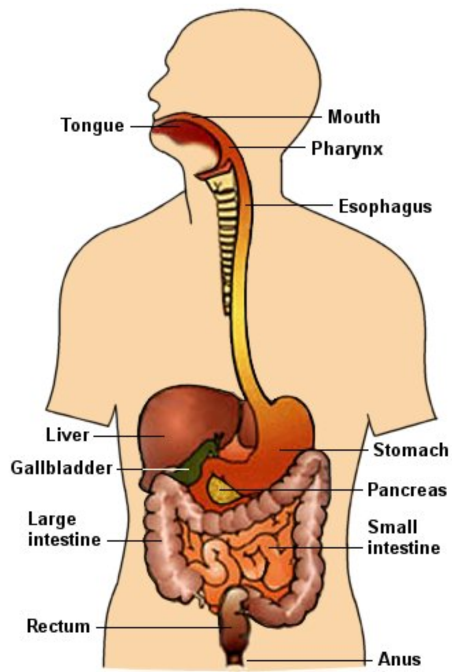


Figure 3–15. Digestive system.

Bioenvironmental engineering concerns

The liver, the largest organ in the body, plays the most important role in metabolizing toxicants. Many hazardous substances can damage the liver and effects will vary depending on the agent. For example, beryllium, cadmium, and selenium can cause necrosis or death of the liver cells. Manganese and toluenediamine cause changes that can impair bile production or secretion that affects removing toxicants. Other agents may induce hepatitis—inflammation of the liver.

024. The urinary system

The principal function of the urinary system is to maintain the volume and composition of body fluids within normal limits. One aspect of this function is to rid the body of waste products that accumulate because of cellular metabolism; as a result, it is sometimes referred to as the excretory system.

The urinary system maintains an appropriate fluid volume by regulating the amount of water that is excreted in the urine. Other aspects of its function include regulating the concentrations of various electrolytes in the body fluids and maintaining normal pH levels within the blood. In addition to maintaining fluid homeostasis in the body, the urinary system controls red blood cell production by secreting the hormone erythropoietin. The urinary system also plays a role in maintaining normal blood pressure by secreting the enzyme renin.

Components of the urinary system

The urinary system consists of the kidneys, ureters, urinary bladder, and the urethra (fig. 3–16). The kidneys form the urine and account for the other functions attributed to the urinary system. The ureters carry the urine away from the kidneys to the urinary bladder, which is a temporary reservoir for the urine. The urethra is a tubular structure that carries the urine from the urinary bladder to the outside.

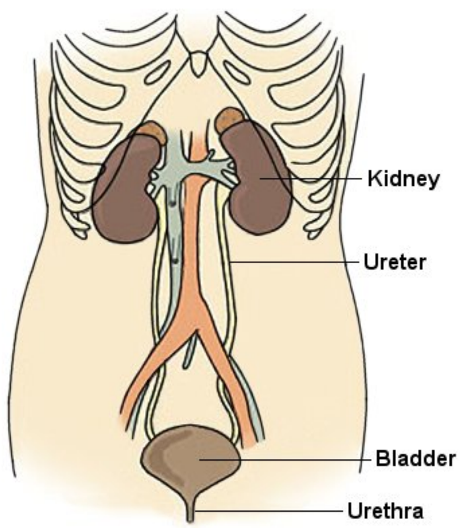


Figure 3–16. Urinary system.

The kidneys are the primary organs of the urinary system. The kidneys are the organs that filter the blood, remove the wastes, and excrete the wastes in the urine. They are the organs that perform the functions of the urinary system. The other components are accessory structures to eliminate the urine from the body.

Bioenvironmental engineering concerns

Certain toxic substances normally filtered out of the blood by the kidney can damage the kidney if they are stored or concentrated. Substances that cause renal damage include most of the heavy metals (inorganic lead, mercury, chromium, uranium, cadmium, and arsenic), some of the halogenated hydrocarbons (carbon tetrachloride, trichloroethylene, and trichlorethane), and some of the aromatic hydrocarbons (benzene and toluene).

025. The male and female reproductive systems

Other systems in the body, such as the endocrine and urinary systems, work continuously to maintain homeostasis for survival of the individual. Unlike other body systems, the male and female reproductive systems are devoted completely to the reproduction of offspring and are not necessarily vital to the individual's own survival. An individual may live a long, healthy, and happy life without producing offspring, but if humankind is to continue, at least some individuals must produce offspring. The major function of the reproductive system is to ensure survival of the species. Within the context of producing offspring, the reproductive system has four functions:

1. Produce egg and sperm cells.
2. Transport and sustain these egg and sperm cells.
3. Nurture the developing offspring.
4. Produce hormones.

These functions are divided between the primary and secondary reproductive organs. The primary organs consist of the ovaries and testes. These organs are responsible for producing the egg and sperm cells and for producing hormones. These hormones function in the maturation of the reproductive system, the development of sexual characteristics, and have important roles in regulating the normal physiology of the reproductive system. All other organs, ducts, and glands in the reproductive system are considered secondary, or accessory, reproductive organs. These structures transport and sustain the egg and sperm cells and nurture the developing offspring.

Male

The male reproductive system, like that of the female, consists of those organs whose function is to reproduce. The anatomy of the male reproductive system consists of the testes, the penis, a network of excretory ducts, accessory glands, and semen.

Female

The organs of the female reproductive system produce and sustain the female sex cells, transport these cells to a site where they may be fertilized by sperm, provide a favorable environment for the developing fetus, move the fetus to the outside at the end of the development period, and produce the female sex hormones. The female reproductive system includes the ovaries, fallopian tubes, uterus, vagina, accessory glands, and external genital organs.

Bioenvironmental engineering concerns

As stated previously, ionizing radiation exposure can damage the cell's DNA, resulting in genetic mutations (mutagenic effect). This type of radiation also can cause a teratogenic effect. A teratogen is a substance that causes birth defects in the offspring without posing a significant hazard of toxicity to the mother. Exposure to certain chemicals can also affect the unborn child. For example, methyl mercury ingestion by a pregnant woman can produce cerebral palsy in offspring, even though the mother is symptom free.

In summary, the human being is truly a very complex organism. The combined contributions of cells, tissues, organs, and organ systems help maintain stability in the internal environment, which is required for survival.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

015. The major organ systems that make up the human body

1. Cite the five basic human senses.

2. What is the function of the sclera within the eye?

3. Describe the function of the Eustachian tube within the ear.

4. Cite the seven functions of skin.

016. The skeletal system

1. Describe the function of bones within the skeletal system.

2. Describe the role of vertebrae within the skeletal system.

3. Cite the two divisions of the skeletal system and describe the structure of each.

4. Describe the function of the synovial membrane within joints.

017. The muscular system

1. Describe the relationship between the skeletal system and the muscles of the body.

2. Match the term in column B with the correct description from column A. Each term in column B may only be used once.

Column A	*Column B*
____ (1) Produces skeletal movement.	a. Cardiac muscle.
____ (2) Contraction is involuntary, strong, and rhythmical.	b. Smooth muscle.
____ (3) Extends over joints, contributing to joint stability.	c. Skeletal muscle.
____ (4) By-product of muscle metabolism.	d. Tendons.
____ (5) Contraction is slow and rhythmical.	e. Heat production.

018. The nervous system

1. Cite the three general, overlapping functions of the nervous system.

2. Match the term in column B with the correct description from column A. Each term in column B may only be used once.

Column A	*Column B*
____ (1) The conducting cell that transmits impulses and the unit of the nervous system.	a. Axon.
____ (2) Nonconducting and provides a support system for the neurons.	b. Motor division.
____ (3) The conducting region of the neuron.	c. Ganglia.
____ (4) Collections of nerve cell bodies outside the central nervous system.	d. Neuron.
____ (5) Transmits impulses from peripheral organs to the central nervous system.	e. Sensory division.
____ (6) Transmits impulses from the central nervous system out to the peripheral organs to cause an effect or action.	f. Neuroglia.

019. The endocrine system

1. Describe the relationship between the nervous system and the endocrine system.

2. Match the term in column B with the correct description from column A. Each term in column B may only be used once.

Column A	*Column B*
____ (1) These glands have ducts that carry their secretory product to a surface.	a. Pituitary.
____ (2) Ductless glands.	b. Endocrine.
____ (3) Regulate the metabolic function of other cells in the body.	c. Gonads.
____ (4) Referred to as the body's master gland.	d. Pancreas.
____ (5) Receives hormones and act as receptors.	e. Target cells.
____ (6) Produces the hormone thyroxine.	f. Exocrine.
____ (7) Secretes digestive enzymes.	g. Hormones.
____ (8) Produces the sperm and ova.	h. Thyroid.

020. The cardiovascular system

1. Describe the basic structure of the cardiovascular system.

2. Describe the role of the heart within the cardiovascular system.

3. Match the term in column B with the correct description from column A.

Column A	*Column B*
____ (1) Transports disease fighting substances to the tissue and waste to the kidneys.	a. Veins.
____ (2) Transports blood away from the heart.	b. Blood.
____ (3) Transports blood toward the heart.	c. Blood vessels.
____ (4) Regulate blood flow into the tissue capillaries.	d. Arteries.
____ (5) Primary function is the exchange of materials between the blood and tissue cells.	e. Arterioles.
____ (6) Channels through which blood is distributed to body tissues.	f. Capillaries.

021. The lymphatic system

1. Cite the three primary functions of the lymphatic system.

2. Describe the response of the lymphatic system when the body is exposed to microorganisms or other foreign substances.

022. The respiratory system

1. Describe the relationship between the circulatory system and the respiratory system.

2. Describe the act of breathing.

023. The digestive system

1. Describe the basic structure of the digestive system.

2. Cite the main purpose of the digestive system.

024. The urinary system

1. Cite the primary function of the urinary system.

2. Describe the role of the kidneys within the urinary system.

025. The male and female reproductive systems

1. Explain the difference between the reproductive system and the other body systems.

2. Cite the four functions of the reproductive system.

Answers to Self-Test Questions

013

1. A cell is the smallest functioning unit of life that is capable of independent existence.
2. The outermost layer of the cell, the membrane is composed mainly of lipids and proteins; it serves to separate and protect a cell from its surrounding environment.
3. Cell expansion, growth and replication.
4. The nucleus determines how the cell will function, as well as the basic structure of the cell.
5. It is the process by which new cells are formed for tissue growth, repair, replacement, and maintenance in the body. This process includes division of the nuclear material and division of the cytoplasm.

014

1. Tissues are groups of cells that have a similar structure and function. The four major types of tissue found in the body are epithelial, connective, muscle, and nervous.
2. (1) Protection.
   (2) Secretion.
   (3) Absorption.
   (4) Excretion.
   (5) Filtration.
   (6) Diffusion.
   (7) Sensory reception.
3. The matrix of connective tissue makes it able to bear weight, withstand great tension, and endure abuses that other tissue types would not be able to tolerate.
4. Muscle tissue has the special ability to shorten or contract in order to produce movement of the body parts.
5. Nervous tissue is found in the brain, spinal cord, and nerves. It is responsible for coordinating and controlling many body activities. Nervous tissue is comprised of supporting cells and neurons and is responsible for coordinating and controlling many body activities.

015

1. (1) Sight.
   (2) Smell.
   (3) Taste.
   (4) Touch.
   (5) Hearing.
2. It provides strength to the fluid-filled eyeball.

3. It equalizes the air pressure in the ear with that of the atmosphere. If the pressure is not equalized, the eardrum could burst.
4. (1) Protects the body from invasion by bacteria and other harmful microorganisms.
   (2) Helps keep a constant body temperature.
   (3) Prevents water loss.
   (4) Excretes wastes.
   (5) Receives sensations.
   (6) Produces a vitamin.
   (7) Absorbs certain drugs and other chemical substances.

016

1. Bones provide a rigid framework, which supports and protects the soft organs of the body.
2. Vertebrae surround and protect the spinal cord.
3. (1) The axial skeleton consists of 80 bones that form the vertical axis of the body. They include the bones of the head, vertebral column, ribs and breastbone (sternum).
   (2) The appendicular skeleton consists of 126 bones and includes the free appendages and their attachments to the axial skeleton. The free appendages are the upper and lower extremities, or limbs, and their attachments that are called girdles.
4. The synovial membrane secretes synovial fluid into the joint cavity for lubrication.

017

1. The muscles of the body work with the skeletal system to provide movement and support.
2. (1) c.
   (2) a.
   (3) d.
   (4) e.
   (5) b.

018

1. (1) Sensory.
   (2) Integrative.
   (3) Motor.
2. (1) d.
   (2) f.
   (3) a.
   (4) c.
   (5) e.
   (6) b.

019

1. These systems function together in the regulation of body activities.
2. (1) f.
   (2) b.
   (3) g.
   (4) a.
   (5) e.
   (6) h.

(7) d.
(8) c.

020

1. It consists of the heart and a closed system of vessels called arteries, veins, and capillaries.
2. It is a muscular pump that provides the force necessary to circulate the blood to all the tissues in the body.
3. (1) b.
   (2) d.
   (3) a.
   (4) e.
   (5) f.
   (6) c.

021

1. (1) Return excess interstitial fluid to the blood.
   (2) Absorption of fats and fat-soluble vitamins from the digestive system and the subsequent transport of these substances to the venous circulation.
   (3) Defense against invading microorganisms and disease.
2. Lymph nodes and other lymphatic organs filter the lymph to remove microorganisms and other foreign particles. Lymphatic organs contain lymphocytes that destroy invading organisms.

022

1. The body cells need a continuous supply of oxygen for the metabolic processes that are necessary to maintain life—the respiratory system and circulatory system work together to provide this oxygen and to remove the waste products of metabolism. It also helps to regulate the pH of the blood.
2. Breathing (pulmonary ventilation) is the process of air flowing into the lungs during inhalation and out of the lungs during exhalation.

023

1. It consists of a long continuous tube that extends from the mouth to the anus; this includes the mouth, pharynx, esophagus, stomach, small intestine, and large intestine.
2. Break down proteins, fats, and starches, which cannot be absorbed intact into amino acids, fatty acids, and glucose that can be absorbed across the wall of the tube and into the circulatory system for dissemination throughout the body.

024

1. Maintain the volume and composition of body fluids within normal limits.
2. The kidneys are the primary organs of the urinary system and filter the blood, remove the wastes, and excrete the wastes in the urine.

025

1. The male and female reproductive systems, which are devoted completely to the reproduction of offspring, are not necessarily vital to the individual's own survival.
2. (1) Produce egg and sperm cells.
   (2) Transport and sustain egg and sperm cells.
   (3) Nurture the developing offspring.
   (4) Produce hormones.

Complete the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field-Scoring Answer Sheet.

Do not return your answer sheet to the Air Force Career Development Academy (AFCDA).

33. (013) The purpose of the plasma membrane within a cell is to
    a. promote electron transport and the citric and fatty acid cycles.
    b. separate and protect a cell from its surrounding environment.
    c. break down toxic substances, and distribute carbohydrates and proteins.
    d. break down protein, carbohydrates, acids, and foreign substances that may enter the cell.

34. (013) The part of the cell which houses the functions for cell expansion, growth, and replication carried out is known as the
    a. plasma membrane.
    b. dendrites.
    c. cytoplasm.
    d. nucleus.

35. (013) The types of cells that are *most* affected by exposure to ionizing radiation are those that
    a. reproduce slowly.
    b. reproduce rapidly.
    c. are tightly packed together.
    d. are loosely packed together.

36. (014) Which type of tissue is tightly packed together and serves as an interface tissue?
    a. Epithelial.
    b. Connective.
    c. Nervous.
    d. Muscle.

37. (014) Which type of tissue is highly cellular and well supplied with blood vessels?
    a. Epithelial.
    b. Connective.
    c. Nervous.
    d. Muscle.

38. (014) Which type of tissue is responsible for coordinating and controlling many body activities?
    a. Muscle.
    b. Nervous.
    c. Connective.
    d. Epithelial.

39. (015) Considered the innermost layer of the eye, the membrane upon which images are received is known as the
    a. ciliary body.
    b. choroid.
    c. retina.
    d. iris.

40. (015) Ultraviolet radiation can create a photochemical reaction in the very outside layer of the eye, killing the cells there. Which *best* describes a potential effect of overexposure?
    a. Sunburned eyeballs.
    b. Collapsed sclera.
    c. Burst retina.
    d. Cataracts.

41. (015) The Eustachian tube is critical to the functioning of the ear because it
    a. promotes drainage.
    b. serves as a receptor for hearing.
    c. conducts sound to the auditory nerve.
    d. provides a means of equalizing pressure.

42. (015) The organ of Corti is critical to the functioning of the ear because it
    a. promotes drainage.
    b. serves as a receptor for hearing.
    c. conducts sound to the auditory nerve.
    d. provides a means of equalizing pressure.

43. (015) Nearly every known variety of germs are prevented from passing through the skin's surface due to the
    a. nerve endings in the dermis.
    b. hornlike protein material called keratin.
    c. overlapping arrangement of epidermal cells.
    d. secretion of sebum by the sebaceous glands.

44. (015) When the skin gets cold, heat is conserved when the body
    a. constricts capillaries to reduce the amount of blood at the skin's surface.
    b. dilates capillaries to let warm blood near the skin's surface.
    c. secretes perspiration to insulate the skin.
    d. secretes sebum to conserve heat.

45. (016) The main function of bones within the human body is to provide
    a. a framework that supports and protects the soft organs of the body.
    b. adjustments which contribute to joint stability.
    c. and maintain homeostasis.
    d. movement and support.

46. (016) The function of the red marrow of the bones is to form
    a. red blood cells only.
    b. blood platelets and synovial fluid only.
    c. red blood cells and white blood cells only.
    d. red and white blood cells and blood platelets.

47. (016) The *most* radiation-sensitive cells in the body are in the bone marrow; as a result, when they are exposed to intense irradiation,
    a. normal replacement of circulating blood cells is impaired.
    b. neuroglia cells can no longer conduct nerve impulses.
    c. nerve cells are destroyed and cannot be replaced.
    d. synovial fluid production is decreased.

48. (017) The muscular system is comprised of specialized cells called muscle fibers with the chief function of
    a. support.
    b. connectivity.
    c. joint stability.
    d. contractibility.

49. (017) Smooth muscle
    a. contracts slowly and rhythmically.
    b. contracts strong and rhythmically.
    c. is dependent upon neighboring muscle fibers.
    d. acts independently of neighboring muscle fibers.

50. (018) What two major body systems work together to allow the body to regulate and maintain homeostasis?
    a. Lymphatic and respiratory.
    b. Endocrine and lymphatic.
    c. Nervous and endocrine.
    d. Muscular and nervous.

51. (018) Within the nervous system, highly specialized nerve cells that function by conducting nerve impulses are known as
    a. neuroglia.
    b. dendrites.
    c. neurons.
    d. axial.

52. (018) What is the *main* function of the central nervous system?
    a. Controls the visceral motor nerve fibers.
    b. Serves as the major signal receptor *and* integration site.
    c. Transmits impulses from peripheral organs to the central nervous system.
    d. Transmits impulses from the central nervous system out to the peripheral organs.

53. (018) While central nervous system stimulants excite acetylcholine production, cholinesterase appropriately neutralizes this effect; however, a nerve agent stimulant that inhibits cholinesterase is known as
    a. benzene.
    b. acetone.
    c. ethylene glycol.
    d. organophosphate.

54. (019) What two major body systems work together in the regulation of body activities?
    a. Lymphatic and respiratory.
    b. Endocrine and lymphatic.
    c. Nervous and endocrine.
    d. Muscular and nervous.

55. (019) Which is considered the master gland because of the effect it has on other glands?
    a. Hypothalamus.
    b. Pituitary.
    c. Thyroid.
    d. Adrenal.

56. (019) The alpha cells in the pancreatic islets secrete the hormone glucagon in response to a
    a. high concentration of glucose in the blood.
    b. high concentration of insulin in the blood.
    c. low concentration of glucose in the blood.
    d. low concentration of insulin in the blood.

57. (020) If the heart is the organ that keeps the blood moving through the vessels, what is the transport medium?
    a. Veins.
    b. Blood.
    c. Arteries.
    d. Capillaries.

58. (020) The *primary* function of capillaries within the cardiovascular system is to
    a. increase the osmotic pressure.
    b. inhibit the return of fluid into the capillaries.
    c. regulate the blood flow into the tissue capillaries.
    d. facilitate the exchange of materials between the blood and tissue cells.

59. (020) Because the walls of veins are thinner and less rigid than arteries, veins can
    a. hold less blood.
    b. hold more blood.
    c. pump blood faster.
    d. pump blood slower.

60. (021) When fluid is prevented from returning to the capillaries and accumulates in the tissue spaces, what is the result?
    a. Dermatitis.
    b. Silicosis.
    c. Angina.
    d. Edema.

61. (021) What is the *primary* function of mature lymphocytes within the lymphatic system?
    a. Transmission of nerve impulses.
    b. Defense against disease.
    c. Hormone production.
    d. Homeostasis.

62. (021) Which condition *best* illustrates an exaggerated immune response?
    a. Hearing loss.
    b. Cervical strain.
    c. Hypersensitivity.
    d. Carpal Tunnel Syndrome.

63. (022) What two systems work together to supply oxygen and remove waste products from the body?
    a. Circulatory and respiratory systems.
    b. Respiratory and lymphatic systems.
    c. Lymphatic and endocrine systems.
    d. Endocrine and nervous systems.

64. (022) What body system is considered the major entry mode for toxic substances?
    a. Reproductive.
    b. Respiratory.
    c. Lymphatic.
    d. Endocrine.

65. (023) Within the digestive system food is broken down until the molecules are small enough to be absorbed and waste products are
    a. absorbed.
    b. eliminated.
    c. maintained.
    d. converted to energy.

66. (024) One of the functions of the urinary system is to
    a. maintain normal potential of hydrogen (pH) levels within the blood.
    b. break down proteins, fats and starches.
    c. metabolize toxic substances.
    d. increase insulin production.

67. (024) If toxic substances such as heavy metals or halogenated hydrocarbons are not filtered out of the body and become concentrated, damage can be caused to the
    a. lungs.
    b. liver.
    c. kidneys.
    d. ovaries.

68. (025) What is a possible effect on the reproductive systems of overexposure to ionizing radiation?
    a. Bone loss.
    b. Lymphoma.
    c. Hypersensitivity.
    d. Genetic mutations.

Please read the unit menu for unit 4 and continue ➔

Unit 4. Toxicology

PHILIPPUS Theophrastus Aureolus Bombastus von Hohenheim (fig. 4–1), also known as (a.k.a.) Paracelsus, a physician-alchemist and the son of a physician, formulated many revolutionary views that remain an integral part of the structure of toxicology today. Paracelsus, who lived during the 16th century, was the first to explain the dose-response relationship of toxic substances.

All substances are poisons; there is none which is not a poison. The right dose differentiates a poison from a remedy.

– Paracelsus (1493-1541)

Figure 4–1. Paracelsus by Quentin Massys.

4–1. Introduction to Toxicology

The principles of toxicology are essential for accomplishing risk assessment. Knowledge of substances workers can be exposed to and their effects is essential to your effectiveness in protecting the health and well-being of the workers and community around you.

The human body exists in a delicate balance, constantly being assaulted with foreign substances. Our work environments may contain many of these substances in highly concentrated forms. As a bioenvironmental engineering journeyman, your main efforts are directed toward preventing conditions that may impair the health, comfort, or efficiency of Air Force workers.

AFI 48–145, *Occupational and Environmental Health Program,* is the publication to assist BE in dealing with the identification, assessment, and management of potential health hazards arising in the workplace. The large number of workplaces you must evaluate, their diversity and the variety of exposures workers may face, make this a challenging subject. Toxicology, as it relates to occupational health, involves the study of substances found in the workplace that are potentially harmful to the human system.

026. Basic terminology

Toxicology is an evolving science and so are its terms. In order for you to gain a better understanding of toxicology, it is necessary to provide you with a few basic definitions. Those terms most commonly used are provided in the following paragraphs.

NOTE: Terminology and definitions for materials that cause toxic effects are not always consistently used. For example, toxicant, toxin, and poison are often used interchangeably; however, there are subtle differences.

Toxicology is the study of the adverse effects of chemicals or physical substances on living organisms. A toxicologist is a scientist who determines the harmful effects of substances and the mechanisms responsible for the effects. Toxicants refer to toxic substances, produced by or by-products of, human activities, not biological systems (living organisms). They can be chemical or physical and the effects can be of various types (acute, chronic, etc.). The term toxin generally refers to toxic substances produced by living organisms such as plants, animals, fungi, or bacteria. Most toxins will produce immediate effects. Poisons are toxicants that cause immediate illness or death even when experienced in very small amounts.

A toxic agent is any substance that can produce an adverse physiological effect. It can be a chemical (such as cyanide), physical (such as radiation), or biological agent (such as anthrax). A toxic substance is simply a material, which has toxic properties. It can be a discrete toxic chemical or a mixture of toxic chemicals. For example, lead chromate, asbestos, and gasoline are all toxic substances. Interestingly enough, toxic substances may not always have a constant composition. Take gasoline as an example; its composition will vary with the octane level, the manufacturer, the time of year, and so forth.

Toxic substances can be systemic toxins or organic toxins. A systemic toxicant or toxin is one that affects the entire body or many organs rather than a specific site. For example, potassium cyanide is systemic in that it affects virtually every cell and organ in the body by interfering with the cell's ability to utilize oxygen. Toxicants may also affect only specific tissues or organs while not producing damage to the body as a whole. These specific sites are known as the target organs or target tissues.

- Benzene is a specific organ toxic agent or toxicant because it affects blood-forming tissues.
- Lead is also a specific organ toxicant; however, it has three target organs—central nervous system, kidney, and hematopoietic system.

A toxicant may affect a specific type of tissue, such as connective tissue, that is present in several organs. The toxic site is then referred to as the target tissue.

There are many cells in the body, and they can be classified in several ways. Germ cells are those cells that are involved in the reproductive process and can give rise to a new organism. Male germ cells give rise to sperm and female germ cells develop into ova. Toxicity to germ cells can cause effects on the developing fetus, such as birth defects and abortions. Somatic cells are all body cells except the reproductive germ cells. They have two pairs of chromosomes. Toxicity in somatic cells can result in a variety of toxic effects to the exposed individual, such as dermatitis, cancer, and death.

Additional toxicological terms are included in the following table:

Term	Description
Bioaccumulate	The increased concentration of harmful substances in tissues or organisms higher up the food chain.
Biotransformation	The sum of the processes by which a xenobiotic (foreign compound) is subjected to chemical change by living organisms.
Carcinogen	A material that produces cancer in some form.
Dose	The quantity of a substance contacting the body or being absorbed into the body – amount of exposure to a chemical substance.
Dose-response curve	A graphic representation of the relationship between the dose administered and the effect produced.
Half-life	The length of time required for the quantity of matter or property in question to be reduced by half.
Health Risk	A health risk is an identified health threat and the vulnerability of the population at risk of coming into contact with the health risk.
Health Threat	A health threat is a potential or actual condition that can cause short or long-term injury, illness, or death to personnel. A health threat can be occupational or environmental in origin; internal or external to the installation; or continuous, intermittent, or transient, and includes enemy capability and intent.
Mutagen	A material that produces mutagenesis – an undesirable effect, or mutation, which is a change in the character of a gene that is perpetuated in subsequent divisions of the cell in which it occurs. For instance, if the mutation occurs in a germ cell then the effect is *passed on* to the next generation. But if a mutation occurs in a non-germ cell then other effects can occur, such as a cancerous tumor.
Pollutant	A substance present in greater than natural concentration as a result of human activity and having a net detrimental effect on its environment.
Response	The effect on the body or organ.
Risk	Probability a substance will cause harm under specific conditions during use.
Synergism	An interaction between two chemicals in which one chemical enhances the toxic effects of the other.
Teratogen	A material that causes birth defects.
Threshold	The point on a dose-response curve above which effects occur and below which no effects occur.
Toxigenic	An organism producing toxins or poisons.

027. Dose-response relationships

Paracelsus was the first person to explain the dose-response relationship of toxic substances. The dose-response relationship shows the correlation between the amount of exposure to a substance or toxic chemical and the resulting effect on the body. The amount of a chemical dose delivered to an organ is critical in defining its toxicity.

The terms toxicity and hazard, often used interchangeably, have important differences. For example, toxicity defines what a specific substance is capable of as far as producing unwanted effects. It is actually a characteristic of the substance in question used to compare it to other substances. On the other hand, a hazard defines the degree of effects that an agent can produce under various circumstances.

028. Factors that influence biological response to dosage

The toxicity of a substance is described by the dose (amount) of the substance and the response produced by that dose in a specific biological system (organ). For example, let us say that a certain dose of a chemical caused the death (the response produced) on one-half of a group of test mice. A different chemical administered under the same conditions to an identical group of test mice caused the entire group to die. Therefore, you would likely say that the second chemical could be considered more toxic to the mice than the first chemical.

NOTE: An identical group of mice was used for the second experiment. Therefore, it is necessary to use the same type of biological system to compare toxicities directly.

In many instances, the effects may be reversed for other animals – laboratory rats may suffer greater toxic effects from the first chemical. Such tests are used to get an idea of how toxic these chemicals may be to humans; however, caution must be used in making comparisons.

Human response to these chemicals could be different from the observed test animals. However, important information can be obtained on what caused the death of the animals; that is, what organs were affected and might similar organs be affected in humans. This further specifies the biological system responding to the dose.

The intensity, or the degree of hazard, depends on quite a bit more than simply how much of the substance was administered. Just as identical groups of test mice were used, the second chemical was administered under the same conditions. The chemical's rate of entry, the tolerance or sensitivity exhibited, the age, exposure route, and weight of the organisms all play a vital role.

Rate of entry

The rate of entry, or the time over which the dose was received, is one of the most important considerations affecting the intensity of the toxic action. When someone is exposed to a large dose within a short period of time, it is referred to as an acute exposure. In contrast, chronic exposures are those involving relatively small doses received over a long period of time. Whether you call a dose large or small depends heavily upon the susceptibility of the organism.

Tolerance and sensitivity

Many organisms show a marked natural tolerance to substances that would cause severe adverse reactions in other organisms. A good example of this is the ability of guinea pigs to withstand amounts of the insecticide parathion, which proved lethal to rabbits. The dose would be considered large to the rabbit but relatively small to the guinea pig.

In addition to this natural tolerance, animals often demonstrate an acquired tolerance. Repeated exposures to small amounts of some chemicals have caused animals and humans to adapt; that is, show less response to the same dosage as time goes on. It takes more and more of the chemical to produce the original response. This is especially true in the case of cockroaches that in some areas have acquired a tolerance to certain types of pesticides. These insects are said to be resistant to the pesticides. In humans, this can be illustrated by drug abuse in which more and more of the substance is needed to attain the same effects.

Some chemicals can cause the opposite effect. Small amounts over a period of time can result in increased reactions. When an organism displays more adverse effects to the same dosage of a chemical, it has become sensitized. This has happened repeatedly in industrial areas. Many workers using cleaning substances find that after using the chemicals for a while with no problems, they begin to notice that even brief exposures to small amounts are causing what seems to be unreasonable itching, burning, or redness of the skin. Another worker doing the same task may never experience any ill effects. As with tolerance, the sensitivity of the organ or animal can be natural. For example, bone marrow is far more sensitive than the gastrointestinal (GI) tract to some substances. Individual responses to any environmental stress can vary widely and are often puzzling.

Age

The very young and the very old are typically affected much more acutely than those in between. This is due mainly to protective systems that are either undeveloped (the young) or breaking down (the old). There is also a greater susceptibility to disease among these age groups, further adding to the effects they may suffer. This is one reason why exposure standards are much lower for the community as a whole than they are for occupational workers.

Exposure route

The method by which a substance enters the body has a great deal to do with the organs affected and the severity. For example, inhaling a substance gets it into the body quickly and concentrates on its target organ very effectively. The same material spilled on the skin may simply affect only the skin layers, may be slowly absorbed into the body to seek out its target organ. Depending upon the substance, absorption may occur slowly or rapidly.

Weight

The amount of the substance compared to the weight of the organ or organism is another factor in determining whether the dose is small or large and what response it is likely to produce. The unit of measure most often used in this concept is milligrams of substance per kilogram (mg/kg) of body weight. This is used to accurately compare doses and effects of substances on different organisms. Ten milligrams of a toxic chemical may kill a rabbit but have little effect on a large dog. No comparison can be made except to say that it takes more to kill a dog. On the other hand, if body weight is taken into account, you may find that the rabbit more easily tolerates the equivalent dose in mg/kg.

Quantifying dose

The amount of exposure, or dosage, is one of the most important topics toxicologists consider. This is important because for each chemical, a certain dose produces specific biological effects in the individual organism. Any biological effect caused by the exposure is called the response. With few exceptions, the greater the dose, the greater the response. The relationship of dose to response may be illustrated by a dose-response curve (fig. 4–2).

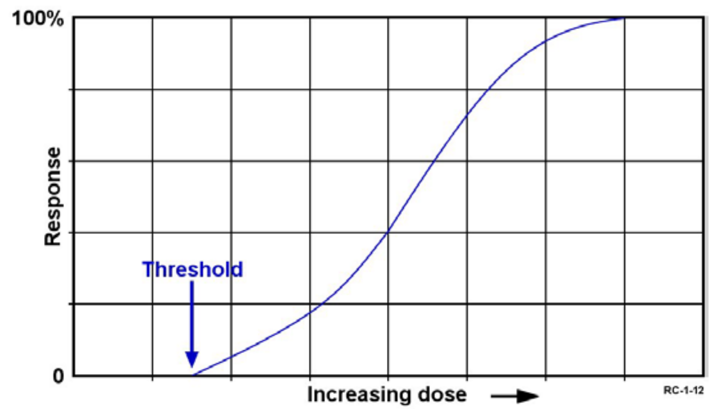


Figure 4–2. Dose-response relationship.

An important aspect of dose-response relationships is the concept of threshold. For most types of toxic responses, there is a dose called a threshold, below which there are no adverse effects from exposure to the chemical. The human body has defenses against many toxic substances. Cells in human organs, especially in the liver, break down chemicals into nontoxic substances that can be eliminated from the body in urine and feces.

The identification of the threshold beyond which the human body cannot remain healthy depends on the type of response that is measured and can vary depending upon the individuals being tested. Thresholds based on acute responses, such as disease or death, are more easily determined. However, while thresholds for chemicals that cause cancer or other chronic responses are harder to determine.

When a threshold is difficult to determine, toxicologists look at the slope of the dose-response curve to give them information about the toxicity of a chemical. A sharp increase in the slope of the curve can suggest increasingly higher risks of toxic responses as the dose increases, as illustrated by line A in figure 4–3. A relatively flat slope suggests that the effect of an increase in dose is minimal (line B).

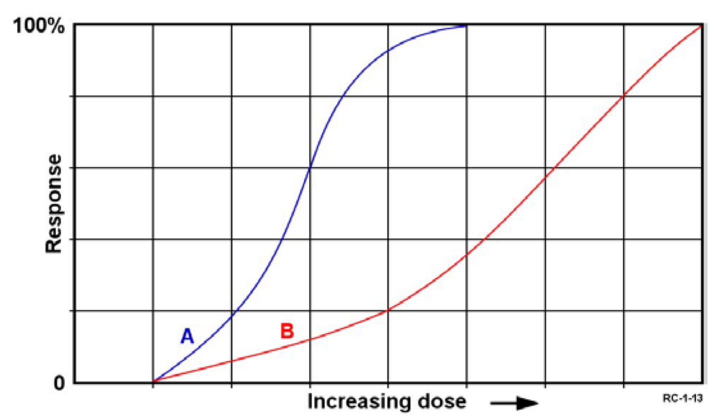


Figure 4–3. Dose-response comparison.

Toxicological studies have shown many times that levels thought to be safe in the past turned out to have severe effects on the body. In toxicity testing, a range is found at the lower end at which all animals survive. This establishes the highest dose that the animals can safely withstand. At the upper end of the range, the dose is found at which all the animals die. From this range, toxicologists can then go on to find how much of the substance will kill; for example, ten percent of the test animals. After it is discovered what doses will kill certain percentages up to 100 percent, a dose-response curve can be graphed.

The point on this curve that shows a 50 percent death rate is of particular note. It is used as the standard for comparing the toxicity of various chemicals and is known as lethal dose (LD) to fifty percent of the test animals, or LD_{50}. The LD is determined from the exposure to the substance by any route other than inhalation. When using this concept, the test organism, route of exposure, and duration of exposure must be specified. The following are examples of lethal doses:

- LD_0 = indicates a dose that does not produce any deaths (rarely to never used).
- LD_{50} = indicates a dose that kills half of a group of test animals.
- LD_{100} = indicates a dose that kills all of the test animals.

Sometimes we are more interested in the effects caused by a chemical vapor. In this case, the concentration of the chemical in the air that the animals are inhaling becomes important. It may be difficult to assess how much of the material an animal actually gets into its body; however, it is relatively simple to keep it exposed to a constant concentration. The lethal concentration (LC) is used for airborne materials. The following are examples of lethal concentrations:

- LC_0 = indicates a concentration that does not produce any deaths.
- LC_{50} = indicates a concentration that kills half of the exposed animals.
- LC_{100} = indicates a concentration that kills all of the exposed animals.

The unit of measure used in this concept is parts per million (ppm) of air containing a substance (toxin). This unit, most often used to indicate exposure by inhalation, may also be used for vapor concentrations, which may be absorbed through the skin or eyes. Like the lethal dose concept, the test organisms, exposure route, and duration of exposure must be specified.

Margin of safety

The slope of the dose-response curve shows the margin of safety that exists between the doses causing low death rates and those causing high death rates. If the curve is steep, the percentage of deaths rises sharply with small increases in the dose and the margin of safety is slight. Such a substance goes quickly from safe to dangerous without the gradual change one might prefer. In comparing the dose-response curves for two different chemicals (fig. 4–4), you can get an idea of which chemical is more dangerous by observing the steepness of each curve. For example, Chemical A causes a high percentage of death (75 percent) with a low increase in dose (6 mg/kg). In contrast, Chemical B, given under the same conditions, does not produce 75 percent deaths until a dosage of 12 mg/kg is given. Therefore, Chemical B has the greater margin of safety. Information such as this can be of great value in recommending the substitution of a substance used in the workplace with one that is safer. It can also help you decide what worker protection should be used.

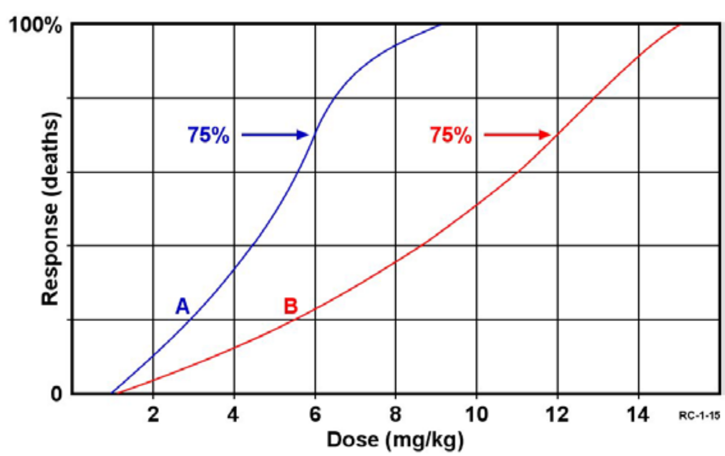


Figure 4–4. Comparing dose-response curves.

All substances can be hazardous if given the proper conditions. Industrial operations require the use of a multitude of potentially hazardous chemicals, though many are not considered highly toxic. One of our major concerns is to ensure that these chemicals are used in ways that prevent hazardous conditions.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

026. Basic terminology

1. Match the term listed in column B with the appropriate definition listed in column A. Each term in column B may be used only once.

Column A	*Column B*
____ (1) The quantity of a substance contacting the body or being absorbed into the body.	a. Toxicants.
____ (2) A material that causes birth defects.	b. Poisons.
____ (3) Toxicants that cause immediate illness or death when experienced even in very small amounts.	c. Toxic agent.
____ (4) An interaction between two chemicals in which one chemical enhances the toxic effects of the other.	d. Carcinogen.
____ (5) A material that produces cancer in some form.	e. Dose.
____ (6) Toxic substances produced by, or are by-products, of human activities.	f. Mutagen.
____ (7) A material that produces a change in the character of the gene and is then passed on to the next generation.	g. Response.
____ (8) A substance that can produce an adverse physiological effect.	h. Teratogen.
____ (9) The point on a dose-response curve above which effects occur and below which no effects occur.	i. Threshold.
____ (10) The effect on the body or organ.	j. Synergism.

027. Dose-response relationships

1. What does the dose-response relationship demonstrate?

2. What is critical when defining a chemical's toxicity?

3. Define toxicity.

4. Define hazard.

028. Factors that influence biological response to dosage

1. What is one of the most important considerations affecting the intensity of toxic action?

2. What type of response occurs when an organism displays more adverse effects or increased reaction over time to the same chemical dosage?

3. What does the method by which a substance enters the body tell us?

4. Chemical A produces an 80 percent death rate at a dose of 4 mg/kg. In contrast, Chemical B produces an 80 percent death rate at a dose of 8 mg/kg. Which chemical has the greater margin of safety?

4–2. Exposure Routes

The response to a given dose of a toxic substance can vary considerably, depending not only on how it enters the body, but also on the method by which the body tries to counteract or rid itself of the substance. Some chemicals reach their targets unaltered to produce toxic effects, while the body may convert others to relatively harmless substances. In still other instances, a chemical may undergo a change while in the body which makes it more dangerous than it was in its original form.

029. Effects exposure routes have on responses to toxic substances

The route of exposure was mentioned as one of the primary factors influencing the degree of toxic action produced by a substance. It plays a vital role in how fast and large a concentration can build up in a target or critical organ. There are four major ways a substance enters the body: inhalation, cutaneous absorption, ingestion, and injection.

Inhalation

Our biggest concern are those substances which can be easily inhaled and impair health or comfort of workers. There are an enormous number of chemical vapors that can be inhaled in the workplace, and this entry route allows doses into the body quickly. The seriousness of such exposures explains the need for the amount of time we spend on air sampling. Further, determining the concentrations of potentially hazardous vapors or fumes workers breathe is one of our primary duties.

To get an idea of why inhalation is such an important entry mode, consider what happens to a contaminant in the respiratory system. For example, the upper respiratory tract, composed of the nose, throat, trachea, and major bronchial tubes, is the area of first contact for inhaled substances. Portions of many types of toxic substances are trapped here, which can be good or bad depending on the toxic substance. Nasal hairs, for example, help to filter out the larger particles that would otherwise reach the lower portions of the respiratory tract. The twisting, moist mucous membranes absorb considerable amounts of very water-soluble gases (such as ammonia and sulfur dioxide), in addition to catching particulates getting past the nasal hairs. The trachea and bronchial tubes are lined with cilia—tiny hair-like outgrowths that beat rhythmically to force mucous up toward the larynx. Contaminants that have been trapped by the mucous membranes are carried up this mucociliary escalator and eventually coughed out or swallowed, reducing the hazard from this exposure.

While these are considered protective mechanisms, the fact that they attack contaminants can result in adverse effects; for example, acid mists can cause considerable tissue damage at these sites. Even small amounts of some toxicants can be so irritating that a reflexive partial or complete closure of the bronchioles can occur. While this restricts the further intake of the chemical, it also impedes oxygen from getting to the alveoli. When most contaminants contact the lungs and ultimately the alveoli, serious problems begin.

A fact difficult to grasp is that the total alveolar surface of an adult lung is about 70 square meters. This large surface, together with the capillary network surface of about 140 square meters, makes possible the rapid absorption into the bloodstream of many substances from the air in the alveoli. Any gas or vapor can be absorbed into the blood if enough of it is inhaled. Once in the bloodstream, it is free to concentrate in its organ of choice quickly.

Solid particles entering the lung behave differently than gases and vapors in most aspects. Particles of certain sizes, called respirable particulates, are our main concern. Those that are too large do not make it very far into the lung; however, significant portions of those that are quite small are exhaled. Perfectly round particles of the right size would be ideal for finding their way to the alveoli; however, what we usually find are irregularly shaped dusts and elongated fibers. These characteristics can also prevent them from getting deep into the lungs. When the size and shape enables entry into the alveoli, a particulate can pass into the blood and on to the organs that have a special affinity or attraction for the toxic substance. Highly soluble materials such as chromates pass through easily while insoluble mineral dusts such as certain types of asbestos remain mostly trapped in the lung. Some water-soluble particles, though small to begin with, absorb so much moisture in the lungs that they swell to larger sizes and never reach the deeper parts of the lung.

A particle's size and shape have a great deal to do with how it might enter the body. The term respirable refers to particulates that get past the protective mechanisms and are retained in the lung; for example, particles smaller than 10 micrometers in diameter can penetrate to the deeper areas. In the turbulent, twisting region of the nose, trachea and bronchi, larger particles are stopped by the nasal hairs and by impacting on the mucous membranes. For most dusts, almost one-half of the totals that are trapped in the lung will be in the range 0.5 to 5.0 micrometers. Only a very small percentage will fall between 5 and 10 micrometers. The other one-half retained in the lung will be smaller than 0.5 micrometers. The lower size of the respirable range is less well-defined.

Notice the reference to diameter in the preceding paragraph, suggesting that we are speaking of spherical objects. In practice, this is rarely the case. What we see are aerosols that may be anything from roughly spherical to needle-like fibers or flat platelets such as found with mica. Oddly, shaped dusts have to be compared with spherical objects in order to talk about their sizes. A typical method is the projected area diameter. For an example of an elongated particle, the projected area diameter is taken as the diameter of a circle, which has the same area as the particle. This can be visualized by superimposing a circle over a particle of the same total area to come up with the effective diameter of the particle. Density also affects the way we look at size. Denser particles behave differently in the air and in the lungs. The effective size tends to become smaller, enabling it to be deposited in the lungs more efficiently.

Just as size and shape vary, the differences in toxic potential are vast. There is a range from so-called inert, or nuisance dusts, up to those causing intense irritation or serious damage to vital organs. We have seen examples of the more serious effects, but nuisance dusts need more explanation. These do not cause toxic effects at the concentrations normally found in work areas.

Cutaneous absorption

Cutaneous absorption is absorption via dermal contact. Contact with the skin is the second most frequent route of chemical exposure. Many materials are absorbed through the skin quickly and cause systemic poisoning. The main routes of entry for chemicals through the skin are the hair follicles, sebaceous glands, sweat glands, and cuts or abrasions of the outer layers of the skin. The follicles and the glands are abundantly supplied with blood vessels, which facilitate the absorption of many chemicals.

While not typically the most serious, absorption via dermal contact is the most commonly encountered cause of occupational disease. A common result of dermal contact is localized irritation. We constantly have workers complaining of itching or burning due to contact with various solvents and detergents.

When a substance contacts the skin, the following four actions are possible:

1. The skin with its associated film of lipids (oils) and sweat may act as an effective barrier against penetration, injury, or other disturbances.
2. The substance can react with the skin surface and cause primary irritation (dermatitis).
3. The substance can penetrate the skin and join with tissue protein to sensitize the skin.
4. The substance can penetrate the skin, enter the bloodstream, and act as a potential systemic poison.

The thickness and elasticity of the skin together with its lipid film protect the underlying muscles, nerves, and blood vessels from many water-soluble chemicals. The skin also resists mild acids, microorganisms, ultraviolet radiation, physical injury, and helps prevent water loss. It is when the defenses provided by the skin break down that damage occurs. Detergents, solvents, alkaline materials, and warm water cut through the protective oils and penetrate the outer surface.

The human skin exhibits great differences in absorption at different parts of the body. Using the forearm as a reference, the back of the hand and the skin of the abdomen have twice the potential for absorption while sites containing large numbers of hair follicles such as the scalp and forehead have four times the potential. The armpit has a four- to seven-fold increase, while the skin of the scrotum allows almost total absorption. We typically think of liquids as being the major hazard for this type of exposure. Vapors and gases may not be present in large enough concentrations for cutaneous absorption to be much of a problem. Normally these would be taken in through the respiratory tract first. However, keep in mind that there are exceptions to everything; the skin readily absorbs some gaseous substances.

Solid materials often do not possess the properties needed to get through the skin’s defenses unless either the material or the skin is altered in some way. For example, a sodium hydroxide pellet on dry skin may not produce an effect. If that same pellet is placed on a sweaty palm, it will mix with the sweat, increasing the pH of the skin, and a burning sensation will be felt in a very short period of time. Ordinary table salt placed on the palm will not have much effect unless it comes in contact with an area of freshly abraded or cut skin. Quite a few chemicals used in industrial areas are capable of penetrating the skin and producing irritation if the exposure is long enough.

A skin sensitizer may or may not cause irritation on first contact. After such a chemical has invaded and combined with tissues, it penetrates the skin and joins with tissue protein to render the skin very susceptible, or sensitive, to further contact. The next exposure may cause intense itching and burning. When someone has been sensitized to a substance, he or she may not be able to work around the substance at all. Even minute exposures may be intolerable. With most people, however, the effects are not so severe and simple measures to prevent contact, such as rubber gloves and aprons, can enable them to continue to work with the chemical. Diethylenetriamine (DETA), a solvent used in dyes and resins, and certain materials used in photography, such as catechol, are examples of sensitizers.

Phenol illustrates the type of chemicals that pass very quickly through the skin and enter the bloodstream in amounts large enough to produce toxic effects in other organs. Some chemicals are absorbed with no apparent effect on the skin but exert harmful actions on their target organs like those we saw with absorption from the lungs. Others can damage the skin severely before going into the bloodstream. A combination of absorbed chemicals can be very dangerous.

Absorption mainly concerns the entry of a chemical through the skin, but eye exposures are sometimes included since we are talking about absorption by intact portions of the body. Quite often, exposure through the eyes can cause much more severe and rapid effects than experienced with the skin route.

Ingestion

Some people may relate oral exposure as the primary route of exposure to toxic chemicals. However, this route is not normally much of a problem with occupational workers since they are typically familiar with the substances they use and would not knowingly put such things in their mouths. The smell, taste, or feel of the chemical also limits exposure by ingestion. Contact occurs by eating, drinking, and smoking with chemically contaminated hands or in chemically contaminated workplaces. As an example, laboratory workers should wear gloves and wash their hands immediately after the use of any chemical substance and before leaving the lab to prevent entry of chemicals into their mouth. Further, food and drinks should not be stored or consumed in the lab area.

Ingestion of inhaled particles can also occur. The larger particles that cannot get into the alveoli and are carried up the mucociliary escalator are swallowed and later absorbed through the gastrointestinal tract. The toxicity of some ingested substances is reduced more effectively than with other routes of entry due to a neutralizing effect from the high acidity (pH 1 to 3) in the stomach, the alkaline medium of pancreatic juices in the small intestine, and the action of pancreatic enzymes on toxicants. Additionally, food and liquid can mix with a toxic material in the stomach to provide dilution and frequently interact with one another to form less soluble chemicals. Non-lipid soluble toxicants cannot be absorbed and are eventually excreted without causing serious adverse health effects. Lastly, humans can induce vomiting unlike other organisms, which will reduce or eliminate the chance of toxic substances causing adverse health effects.

Injection

Injection of a substance directly into the body is the rarest form of entry for occupational exposures. The only way it happens is when an object contaminated with some toxic substance breaks the skin. This route of entry is particularly effective in allowing less soluble chemicals, which could not otherwise be absorbed into the body. Injection is used mainly in toxicity testing because it is a fast method of getting known quantities of chemicals into test animals. This method of estimating industrial exposure effects bypasses most of the body defenses that are designed to prevent or slow the entry of particular toxic chemicals.

Detoxification

Detoxification is a more complicated bodily function that greatly reduces the effects of toxic substances in the body. As toxic materials are absorbed into the bloodstream, they are either stored in tissues or altered as less toxic substances. The most common tissues that store toxic agents are fat (organic compounds), bone (lead strontium), liver and kidney (cadmium, zinc, and lead), and plasma (dieldrin). The blood is constantly trying to rid the body of foreign materials by depositing them into the liver where detoxification occurs. The liver converts lipid-soluble compounds into more easily absorbed compounds that can be excreted. The kidneys also play a part by filtering out waste products in the blood. These waste products are then eliminated in the urine. The actions of these two organs in cleansing the blood attribute to their common mention as critical target organs for many toxic chemicals.

030. Physiological effects of toxic materials

Some toxic effects of chemicals are reversible, while others are not. If a chemical produces pathological injury to a tissue, the ability of that tissue to regenerate largely determines whether the effect is reversible or irreversible. For example, for a tissue such as liver, which has a high ability to regenerate, most injuries are reversible, whereas injury to the CNS is largely irreversible. This is due to the inability of the CNS's differentiated cells to divide and be replaced. Once carcinogenic and teratogenic effects of chemicals occur, they are typically considered irreversible.

One of the first questions that may come to a person's mind when confronted with a toxic substance is "What could this do to me?" In discussing the influence of entry routes on the degree of toxic response, we touched lightly on what those responses were. In this section, we will examine the specific effects of materials on the body in more detail. As we proceed, keep in mind the potential for accompanying vague effects such as decreases in alertness, motivation, and efficiency. Although these symptoms can compound the problems associated with occupational exposures, supervisors and assessors often discount them.

Irritants

Irritation is the first action produced by numerous chemicals upon contact with the body. Irritants cause inflammation of the skin or mucous membranes of the respiratory tract. Further, any substance that irritates the mucous membranes also affects the eyes; however, the irritation is more severe even at lower concentrations. Many typical irritants are corrosive chemicals such as acids and bases; therefore, it is essential to distinguish between corrosion and inflammation. For example, corrosion is the destruction of tissue due to contact with high concentrations of a material, while inflammation is marked by capillary dilatation, which is the reaction of living tissue to much lower concentrations.

As we discussed in entry routes, highly soluble chemicals mainly affect the upper respiratory tract while those of less solubility go farther to affect lungs and beyond. Exceptions to this concept are certain insoluble chemicals, such as ethyl ether, which are readily absorbed from the alveoli. For this reason, they do not accumulate in the lungs and cause adverse health effects. However, sufficient amounts build up in the upper respiratory passages and produce irritation. Another exception is a material of low solubility like bromobenzyl cyanide, which attacks the eyes, skin, and upper respiratory tract. Because of its low solubility, you would normally expect such a chemical to affect the lungs or be absorbed from the alveoli, but it does not.

Irritants can also interfere with breathing by causing a reflex constriction of the respiratory passages resulting in coughing and choking. In some cases, there may be a decreased compliance (elastic behavior) of the lungs. One group of chemicals, which includes acetic acid and formaldehyde, causes a combination of increased breathing resistance due to constriction, some reduction in compliance, and with high enough concentrations, decreased breathing rate. Another group typified by ozone increases the breathing rate while decreasing compliance.

Long-term lung problems may result from a severe single exposure to an irritant or, more often, from chronic exposures to low concentrations. Animal experiments have provided evidence that long-term exposures to irritants can stimulate more mucous secretion and create a condition similar to chronic bronchitis. This information has led to the interest in studying the effects on populations living in areas with significant air pollution.

The fact that some substances only result in irritation while others produce serious problems in other parts of the body after their initial inflammation conveniently divides them into two classes. These include primary and secondary irritants.

Primary irritants

Either primary irritants exert little or no system toxic action, or their irritant properties are much more important than any systemic toxicity. Acids and riot control chemicals are typical of this class.

Secondary irritants

The results of secondary irritants may be severe; however, this effect is typically far less significant than system effects following absorption. A good example of a secondary irritant is cyanogen chloride.

Asphyxiants

Asphyxiants are classified by their ability to prevent oxygen from reaching body tissues, which eventually results in suffocation. An irritant can cause asphyxiation by producing severe pulmonary edema or constriction of the bronchioles. From this point of view, such materials can be called asphyxiants; however, since this is primarily an irritant action, they are not typically included in the asphyxiant category. Classified on the basis that they do not damage the lung, the two types of asphyxiants include simple and chemical.

Simple asphyxiants

This group is composed of gases that have no toxic effect of their own but displace oxygen when present in high enough concentrations. They dilute the normal amount of oxygen in the air so that tissues do not receive enough oxygen to meet their needs. Examples are nitrogen, carbon dioxide, hydrogen, and acetylene. Some members of this class also present major fire and explosion hazards.

Chemical asphyxiants

In contrast to simple asphyxiants, chemical asphyxiants do not dilute oxygen; however, through their chemical properties, they reduce the body's capacity to use the oxygen it receives. Since these materials are chemically active in the body, it takes much less concentration to cause damage. Carbon monoxide and hydrogen cyanide are good examples of this type.

Carbon monoxide

Carbon monoxide interferes with the normal transfer of oxygen to the tissues. Hemoglobin, the oxygen-carrying component of the blood, picks up carbon monoxide much more readily than it does oxygen; therefore, the body tissues suffocate.

Hydrogen cyanide

Hydrogen cyanide does not interfere with oxygen transport but combines with certain enzymes in the tissues. The enzymes become unable to aid cells take in the oxygen from the body. As before, the tissues suffocate.

Anesthetics

Substances in this category depress the CNS and are often called CNS depressants. This depression, or narcosis, causes a person to become dizzy, sleepy, or unconscious, and may even lead to death when concentrations and exposure times are great enough. These are effects that would be expected from narcotics, which is another term you will hear applied to this group. Aside from the dangers of the substance itself, a worker under the influence of an anesthetic chemical may not pay proper attention to the job, and may not even care about safe work practices. Imagine the possible consequence of suffering from narcosis while working over a large solvent tank or with a cutting machine.

A major factor that distinguishes anesthetic chemicals from other categories is their tendency to produce unconsciousness without seriously harming other organs. Ethyl ether is one of the best examples of an anesthetic because of its high margin of safety. It will put someone to sleep at relatively low concentrations but does not become dangerous until high levels are inhaled. Other members of this group include some alcohols, ketones, and many related hydrocarbons commonly found in industrial areas. Although primarily classified as an anesthetic, most of these chemicals can cause a number of systemic effects when exposures are great enough. For example, long-term glue sniffing and inhaling paint vapors from spray cans have resulted in liver damage to many people.

Systemic poisons

To qualify as a systemic poison, a substance must damage certain specific organs or organ systems of the body. The most familiar systemic effects at this point of our study are those exerted on the organs of the abdomen and thorax. The liver, kidneys, stomach, and intestines should immediately come to mind as primary organs in this region. Carbon tetrachloride and nitrosamines are an example of systemic poisons that severely damage the liver, giving them the name hepatotoxic substances. Uranium exerts its effects on the kidneys; therefore, it is considered a nephrotoxic substance. Many of the solvents mentioned as causing narcosis will also attack these organs.

Nerve poisons – neurotoxic substances – make up another group of systemic poisons. These chemicals produce their major toxic actions on the nervous system in various ways. Organic phosphorus insecticides inhibit a type of enzyme in the body that causes the nerves to produce excessive, erratic stimulation of the muscles. Mercury and lead are heavy metal examples of chemicals, which damage nerves as well as other organs. Carbon disulfide is another chemical that mainly affects the nervous system producing fatigue, loss of appetite, headaches, and nervousness.

Some chemicals produce their effects by attacking the blood and blood-forming organs, the hematopoietic system. These are separate and distinct actions compared to chemical asphyxiation. In this case, there is some type of damage to the blood or blood-forming organs as opposed to interference with the bloods normal function. Benzene fits into this class due to its damage to the hematopoietic cells of the bone marrow causing leukemia. A somewhat different action results in the case of arsine. Severe exposure to arsine results in the destruction of red blood cells causing anemia.

A variety of miscellaneous metals and inorganic materials are important systemic poisons. A few of the more familiar types are beryllium, cadmium, fluorides, and arsenic.

Other chemicals

The effects produced by some chemicals may not fit as neatly into the categories already discussed. One of the most important groups is the lung-damaging chemicals; chemicals of this group damage the pulmonary tissue but not by immediate irritant action. Two well-known materials that produce typical lung tissue damage are silica and asbestos. Asbestos in particular has been the subject of intense interest as a cancer-causing chemical. There is even suspicion that there may be effects from low-level exposures to people who are not asbestos workers. Other dusts, such as coal dust, can produce tissue changes in the lungs. While the term dusty lung is commonly used, the proper term is pneumoconiosis.

A few other terms mentioned in toxicology and occupational and environmental health include carcinogen, mutagen, and teratogen.

Carcinogen

A carcinogen is a material that produces cancer in some form and the word for this action is carcinogenesis. Many substances have been found to be carcinogens or suspected carcinogens. The difference is that a suspected carcinogen produces cancer in some laboratory animals but has not been proven to do so in humans. Benzene and asbestos are known to produce cancers in people. Benzene causes leukemia, which is a form of cancer of the blood; asbestos causes mesothelioma, lung cancer, ovarian cancer, and cancer of the voice box.

Mutagen

Substances that produce mutagenesis cause an undesirable effect or mutation that occurs in the descendants of the person exposed. Changes in chromosomes may occur when enough of a mutagen is present even though the body may not be hurt by it.

Teratogens

Teratogens cause malformations of the fetus, usually without harming the mother. The word actually means monster agent and women, especially in their first trimester of pregnancy, exposed to such substances may produce children with birth defects. The effects from this group of substances are one of the major reasons for so much concern about protecting pregnant workers.

You have probably noticed that there are overlapping effects for most substances. Indeed, quite a few will fall into more than one category. Many irritate upon first contact and then go on to produce narcotic effects, systemic effects, or sometimes both. However, the most important action is the key to their classification.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

029. Effects exposure routes have on responses to toxic substances

1. Why is inhalation the most common cause of serious effects in occupational exposures?

2. How do most solid materials get through the skin?

3. What effect does a sensitizer have on the skin?

4. Name at least two reasons why ingestion ordinarily results in lesser toxic effects than other entry routes.

030. Physiological effects of toxic materials

1. Match the mode of action in column B with the appropriate effect in column A. Each mode of action in column B may be used only once.

Column A	*Column B*
____ (1) Produces malformations in the fetus usually without harming the mother.	a. Irritant.
____ (2) Tendency to produce unconsciousness without seriously harming other organs.	b. Simple asphyxiant.
____ (3) Dilutes the normal amount of oxygen in the air so that tissues do not receive adequate oxygen.	c. Chemical asphyxiant.
____ (4) Produces undesirable effects in the descendants of the person exposed.	d. Anesthetic.
____ (5) Interferes with breathing by causing a reflex constriction of the respiratory passages.	e. Systemic poison.
____ (6) Produces cancer.	f. Carcinogen.
____ (7) Reduces the body's capacity to use oxygen.	g. Mutagen.
____ (8) Damages the blood or blood-forming organs.	h. Teratogen.

2. What is the difference between corrosion of the skin and inflammation of the skin?

3. How are asphyxiants classified?

4. What is the difference between simple asphyxiants and chemical asphyxiants?

5. What is pneumoconiosis?

4–3. Classification of Toxic Materials/Substances

General classifications of toxic materials depend on their type of characteristics. For example, toxic substances can be classified in terms of their physical state, their chemical stability or reactivity, general chemical structure, or poisoning potential. In this section, you will become familiar with factors that distinguish the various forms of toxic substances.

031. Factors that distinguish the forms of toxic agents

The effects of substances on the body – covered in the previous section – can be considered a classification by physiological effect. If we are interested in what form a chemical may be in to help us determine how it might get into the body most easily, we can use the physical classification. No single classification is applicable to the entire spectrum of toxic materials.

A typical way to group substances according to their physical form is whether they are solids, liquids, or gases. This is simple enough until we get to a discussion of airborne contaminants, our primary interest in this area. For airborne substances, we need to be more specific about our descriptions. This is where factors of temperature and size play a big role. You will often hear of airborne substances separated simply into two main classes: gaseous materials (gases and vapors) and aerosols. For our purposes, we will break aerosols down into different forms of liquids and solids.

Gases and vapors

In occupational and environmental health, a gas refers to a substance that is naturally in the gaseous state at normal room temperature and pressure (25°C and 29.92 in Hg). Note that there is a slight difference in temperature from the chemistry definition of standard temperature and pressure. A chemical with a boiling point near or below 25°C can be considered a gas. Typical true gases that workers may be exposed to are ammonia, found in some copying processes; carbon monoxide, which can be present around any combustion engine; and chlorine, used in water treatment operations.

A vapor is the gaseous form of material that is a liquid or solid at normal room temperature and pressure. Some types of vapors you should expect to deal with include methylene chloride, toluene, and methyl ethyl ketone. Methylene chloride can be found in printing processes and spray painting. Toluene may be found in a variety of industrial materials, including paints and strippers. Methyl ethyl ketone is a solvent cleaner.

Gases and vapors are grouped together because their behaviors are so similar. Both will expand or contract with changes in temperature and pressure. Both spread out or diffuse rapidly to fill a room, enabling quicker exposure to the chemical. Gaseous forms are also the easiest to get into the body and can cause rapid toxic actions.

Liquid aerosols

This group is comprised of mists and fogs, the difference being primarily the size. A mist broadly refers to very small droplets generated from the liquid state by spraying or splashing. You find mists in operations such as insecticide spraying and spray painting, usually combined with the vapor form. This can make some chemicals quite dangerous to the skin as well as the respiratory tract. You may find some substances such as sulfuric acid and phosphoric acid, which present their hazard as a mist.

A fog is composed of still smaller droplets, again generated from the liquid state. In this case, the liquid changes to a vapor by increasing the temperature and the vapor condenses to very small droplets of fog. A fogger, which throws out rolling clouds of insecticide for mosquito control, is an excellent example of generating.

Solid aerosols

Smokes, fumes, and dusts are solid aerosols, distinguished from one another by their make-up and method of generation rather than their size. Particulate sizes are generally dependent on the first two factors. Incomplete combustion of substances containing carbon produce smokes, particles generated when certain combustible oils, fuels, and solvents burn. In other words, smokes are not normal industrial contaminants. They are more an indication that something is not operating properly or there has been some accident.

Fumes are produced somewhat like fogs except they come from metals. Enough heat applied to a metal, such as iron, causes it to melt followed by evaporation to the gaseous state. Fumes are formed when the vapor condenses to a tiny solid particle suspended in the air. There is typically a combining with oxygen during this process, which results in contaminants such as iron oxide fumes or zinc oxide fumes. We automatically think of welding when speaking of fumes; however, whenever high enough temperatures are applied to metal, this aerosol is generated. You hear people talk in everyday language about fumes when referring to things like carbon monoxide, which is a vapor gas. While a dictionary might support this common usage, in our practice, we must remember the difference in vapors and fumes.

Dusts contain the greatest variety of materials, sizes, shapes, and toxic effects of all the solid aerosols. Virtually all solid materials can become airborne dusts. Dusts get into the air through actions such as crushing, sawing, sanding, grinding, and polishing of solids.

As previously mentioned, a particle's size and shape have a great deal to do with how it might get into the body. The term respirable refers to particulates that get past the protective mechanisms to remain in the lung. Density also affects the way we look at sizes. Denser particles behave differently in the air and in the lungs. The effective size tends to become smaller, enabling it to be deposited in the lungs more efficiently.

Like most attempts at grouping things into concrete categories, there is overlap. One of the best-known examples is smog, the combination of smoke and fog. There are also instances when a particle absorbs a chemical vapor; the chemical vapor may not only affect the particle's size but also the particle's effect on the body. It may even change the chemical makeup of the contaminant, making it more or less hazardous.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

031. Factors that distinguish the forms of toxic agents

1. What is the difference between a gas and a vapor?

2. What is the difference between a mist and a fog?

3. State the two factors that distinguish smokes, fumes, and dusts from each other.

4. What determines the efficiency of dust penetration into the lungs?

Answers to Self-Test Questions

026

1. (1) e.
   (2) h.
   (3) b.
   (4) j.
   (5) d.
   (6) a.
   (7) f.
   (8) c.
   (9) i.
   (10) g.

027

1. The correlation between the amount of exposure to a substance or toxic chemical and the resulting effect on the body.
2. The amount of a chemical dose delivered.
3. What a specific substance is capable of as far as producing unwanted effects.
4. The degree of effects that an agent can produce.

028

1. Rate of entry.
2. It has become sensitized.
3. The potential organs that will be affected and how severe the action will be.
4. Chemical B.

029

1. There are an enormous number of vapors that can be inhaled in the workplace; this entry route quickly allows doses into the body.
2. Either the material or skin is altered in some way.
3. It penetrates the skin and joins with tissue protein to render the skin very susceptible to future exposures.
4. (1) High acidity in stomach, alkaline medium, and enzymes of the pancreas have a neutralizing effect,
   (2) Poor absorption into the bloodstream detoxification in the liver, and filtering by the kidneys.

030

1. (1) h.
   (2) d.
   (3) b.
   (4) g.
   (5) a.
   (6) f.
   (7) c.
   (8) e.
2. Corrosion is the destruction of tissue while inflammation is the reaction of living tissue.
3. By their ability to prevent oxygen from reaching body tissues.
4. Simple asphyxiants dilute the normal amount of oxygen in the air so tissues do not receive enough oxygen to meet their needs while chemical asphyxiants reduce the body’s capacity to use oxygen.
5. Changes in the lungs referred to as dusty.

031

1. A gas refers to a substance that is naturally in the gaseous state at normal room temperature and pressure; on the other hand, a vapor is the gaseous form of a material that is a liquid or solid at normal room temperature and pressure.
2. A mist broadly refers to very small droplets generated from the liquid state by spraying or splashing; however, a fog is composed of still smaller droplets.
3. Make-up and method of generation.
4. Size, shape, and density.

Complete the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field-Scoring Answer Sheet.

Do not return your answer sheet to the Air Force Career Development Academy (AFCDA).

69. (026) A material that produces a mutation is known as a mutagen; if the mutation occurs in a germ cell, then the effect
    a. is passed on to the next generation.
    b. is not passed on to the next generation.
    c. to the exposed individual results in cancer.
    d. to the exposed individual results in dermatitis.

70. (026) What term describes the probability a substance will cause harm under specific conditions during use?
    a. Threshold.
    b. Half-life.
    c. Target.
    d. Risk.

71. (027) The dose-response relationship illustrates the correlation between the
    a. tolerance and sensitivity.
    b. exposure route and response.
    c. rate of entry and individual differences.
    d. amount of exposure and the resulting effect.

72. (027) The amount of a chemical dose delivered to an organ is *critical* in defining its
    a. toxicity.
    b. resistance.
    c. sensitivity.
    d. exposure route.

73. (028) Inhaling high levels of carbon monoxide in a short period of time would be classified as
    a. a chronic exposure.
    b. an acute exposure.
    c. a chronic effect.
    d. an acute effect.

74. (028) If an organism displays more adverse effects to the same dosage of a chemical over time, then the organism has become
    a. sensitized.
    b. resistant.
    c. tolerant.
    d. chronic.

75. (028) Toxicity testing on a uniform group of rats results in 40 percent deaths when they receive a 10 milligrams of substance per kilogram (mg/kg) oral dose of a substance. The 10 mg/kg is called the
    a. LC_{40}.
    b. LD_{40}.
    c. LC_{10}.
    d. LD_{10}.

76. (029) If you are assessing a shop where workers are exposed to potentially hazardous vapors, then which hazard would you be most concerned with identifying?
    a. Absorption.
    b. Inhalation.
    c. Ingestion.
    d. Injection.

77. (029) If you are assessing a shop were your main concern is the entry of chemicals through the skin, which hazard are you *mainly* concerned with identifying?
    a. Absorption.
    b. Inhalation.
    c. Ingestion.
    d. Injection.

78. (029) Toxic substances that are ingested are generally less harmful than when exposure occurs through other routes due to the
    a. alkaline medium of pancreatic juices in the small intestines.
    b. selective mode of the intestines that limits absorption.
    c. long length of the gastrointestinal tract.
    d. low acidity in the stomach.

79. (030) How does the action of a primary irritant differ from that of a secondary irritant?
    a. Primary irritants exert little or no system toxic action.
    b. Secondary irritants exert little or no system toxic action.
    c. Primary irritants dilute the normal amount of oxygen in air.
    d. Secondary irritants dilute the normal amount of oxygen in air.

80. (030) Which statement *best* describes the effects of a chemical asphyxiant on the body?
    a. Inflammation of mucous membranes of the respiratory tract.
    b. Destruction of tissue due to contact with material.
    c. Reduction of the body's capacity to use oxygen.
    d. Depression of the central nervous system.

81. (030) Which example *best* describes a chemical that would be classified as a central nervous system depressant?
    a. Uranium.
    b. Hydrogen.
    c. Acetylene.
    d. Ethyl ether.

82. (030) Which example *best* describes a material capable of producing lung tissue damage?
    a. Hydrogen cyanide.
    b. Carbon disulfide.
    c. Asbestos.
    d. Mercury.

83. (031) A chemical with a boiling point near or below 25 degrees Celsius (°C) can be considered a
    a. gas.
    b. fog.
    c. mist.
    d. vapor.

84. (031) What is the *primary* difference between mists and fogs?
    a. Method of generation.
    b. Make-up.
    c. Shape.
    d. Size.

85. (031) Which example *best* describes how fumes are formed?
    a. Incomplete combustion of substances containing carbon.
    b. Vapor condenses to a tiny solid particle suspended in air.
    c. Incomplete combustion of substances containing oxygen.
    d. Liquid condenses to a tiny solid particle suspended in air.

86. (031) Of the solid aerosols, which group has the *greatest* variety of materials, sizes, shapes, and toxic effects?
    a. Smokes.
    b. Fumes.
    c. Dusts.
    d. Fogs.

Please read the unit menu for unit 5 and continue ➔

Student Notes

Unit 5. Ecology and Environmental Toxicology

MANY DIFFERENT CHEMICALS are regarded as pollutants, ranging from simple inorganic ions to complex organic molecules. In this unit, we will discuss the biosphere and the role ecological life forms have within the biosphere. We will also discuss the fate and transport of pollutants in the living environments, along with their effects upon living organisms.

This we know... the earth does not belong to man, man belongs to earth.
All things are connected, like the blood, which connects one family. Whatever
befalls the earth befalls the children of the earth. Man did not weave the web of life -
he is merely a strand in it. Whatever he does to the web, he does to himself.
- Chief Seattle, 1854

5–1. The Biosphere and Ecological Life Forms

The purpose of this unit, the word biosphere describes our living world (fig. 5–1). It is the part of our Earth in which the land (lithosphere), air (atmosphere), and water (hydrosphere) come together to help sustain life. The biosphere continually maintains an even distribution of materials and energy, each used for food and fuel. All of this energy comes from the Sun, and it activates the different processes that occur throughout the biosphere. The energy, transferred from one type to another, is never destroyed. The solar energy used to grow a tree will become food energy for animals that eat the vegetation, which will in turn provide minerals and seed to the earth by way of their wastes, starting the growth cycle of the tree. This tree could provide shelter for birds, or become coal used to make steel, or be logged and then processed into paper. Therefore, the Sun's energy is the basis for survival in the biosphere. Let us look at the components of the biosphere and their function for the survival of the Earth.

Figure 5–1. Earth from Space (Courtesy of NASA).

032. Elements of the biosphere

Earth is the only planet in the universe known to have life. A thin blanket of gases, which we call the atmosphere, surrounds the Earth. The atmosphere is a moving source of life for every creature on

Earth. While the atmosphere is mainly composed of nitrogen (N_2), it also contains gases such as oxygen (O_2) and carbon dioxide (CO_2) that animals and plants need for survival. The atmosphere has specialized molecules like ozone (O_3) that filter out harmful radiation from space. Without the atmosphere, Earth would be as barren and dead as the Moon. The envelope of gas surrounding the Earth changes from the ground up and is divided into five distinct layers (fig. 5–2).

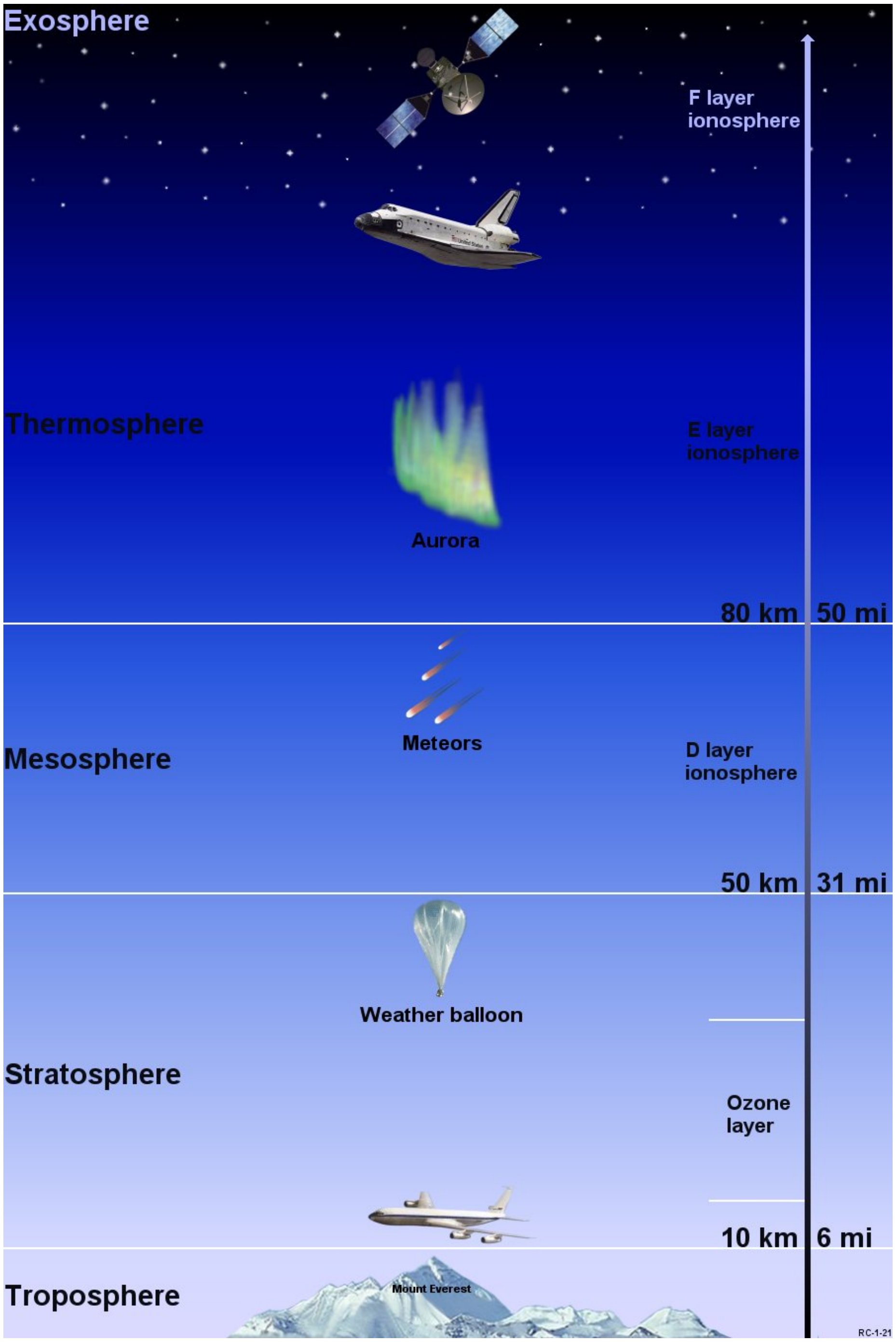


Figure 5–2. Atmospheric layers of the Earth.

Layers of the atmosphere

The troposphere is the lowest layer of the atmosphere, which begins at the Earth's surface and extends up to 4–12 miles (6–20 kilometers) high. This layer in which we live is in constant motion.

For example, the Sun heats the Earth's surface and the air above it, causing warm air to rise. As the warm air rises, air pressure decreases, causing the air to expand and cool. The cool air is denser than the surrounding air, so it sinks and the cycle starts again. This constant cycle of the air causes our weather. The transition boundary between the troposphere and the layer above it is called the tropopause. Both the tropopause and the troposphere are known as the lower atmosphere.

High above the troposphere, approximately 30 miles above the Earth's surface, is a layer of still air called the stratosphere. This layer holds 19 percent of the atmosphere's gases. Temperature increases with height as oxygen molecules, which lead to the formation of ozone, increasingly absorb radiation. The temperature rises from an average of –76°F at the troposphere level to a maximum of about 5°F at the stratopause, due to this absorption of ultraviolet radiation. The increasing temperature also makes it a calm layer with slow movement of the gases.

Above the stratosphere is the mesosphere, extending from the stratopause to about 53 miles (85 kilometers) above the Earth. The gases, including the oxygen molecules, continue to become thinner and thinner with height. As such, the effect of the warming by ultraviolet radiation also becomes less and less—leading to a decrease in temperature with height. On average, temperature decreases from about 5°F to as low as –184°F at the mesopause. The regions of the stratosphere and the mesosphere, along with the stratopause and mesopause, are called the middle atmosphere.

Things start to get hot in the next layer of the atmosphere, the thermosphere, which extends from the mesopause to 430 miles (690 kilometers) above the earth. This layer is known as the upper atmosphere. The gases of the thermosphere are increasingly thinner than in the mesosphere. As such, only the higher energy ultraviolet and x-ray radiation from the Sun are absorbed. Due to this absorption, the temperature increases with height and can reach as high as 3,600°F near the top of this layer.

The exosphere is the final layer that extends from the thermopause (the transition boundary that separates the exosphere from the thermosphere below) to 6,200 miles (10,000 kilometers) above the Earth. In this layer, atoms and molecules escape into space and satellites orbit the Earth.

Life in the troposphere

Let us look at the atmosphere within in the troposphere, the layer we call home. Nitrogen makes up 78 percent of the atmosphere, while oxygen makes up 21 percent. The remaining 1 percent consists of argon and small amounts of other gases. The atmosphere also contains water vapor, carbon dioxide, water droplets, dust particles, and small amounts of many other chemicals released by volcanoes, fires, living things, and human activities. Held to the Earth by gravity, air is constantly moving around us. As the Sun heats the Earth, the warmer air rises, replaced by cool air. This air circulation mixes the components of the air and sustains life. Nitrogen, in its gaseous form, is the major component of air and is essential to all living things. The soil absorbs it, and the plant roots consume it. The plants turn it into proteins, and then make it available to animals and other organisms through the food chain, which we will discuss in detail later in this unit.

All living organisms also constantly need oxygen. Although it is free flowing throughout the atmosphere (most abundant at sea level), there is a lack of oxygen at high altitudes and in the subsurface layers of the Earth. That is why mammals cannot live permanently at altitudes higher than about 3 miles above sea level. There is a small amount of carbon dioxide in the air, and if this minute amount of essential gas were not there, all life would come to a stop. Plants consume carbon dioxide through photosynthesis. When animals respire and dead organic matter decomposes, carbon dioxide is released back into the air. It is also an important factor in regulating global temperature, because it absorbs infrared heat radiated by the Earth's surface, preventing a temperature increase. Water vapor, which comes from evaporation that has taken place over moist land or bodies of water, helps to determine the temperature distribution over the world, and is the source of our fresh water.

As you have just learned, constant mixing of atmospheric elements is vital to the life of organisms on earth—providing nutrients, making respiration possible, determining weather conditions, and supplying fresh water. The atmosphere also works together with the other components of the biosphere to make Earth a viable place to live. Let us look at how the hydrosphere functions as the main force in life on Earth.

Hydrosphere

The hydrosphere is approximately 71 percent of the Earth's surface covered by water, either in liquid or frozen forms, and most of it in the oceans. The Earth is the only planet in our solar system with abundant liquid water on its surface. Water has chemical and physical properties, unmatched by any other substance, and it is essential for life on Earth. The hydrologic cycle (water cycle), the basis of the hydrosphere, makes it possible for living organisms to have the water essential for life (fig. 5–3). Water starts its course through the hydrologic cycle when the Sun shines on moist lands and bodies of water, causing evaporation. The water vapor rises and forms clouds, carried by winds over the land and are precipitated as rain or snow. The hydrologic cycle is a continuous process.

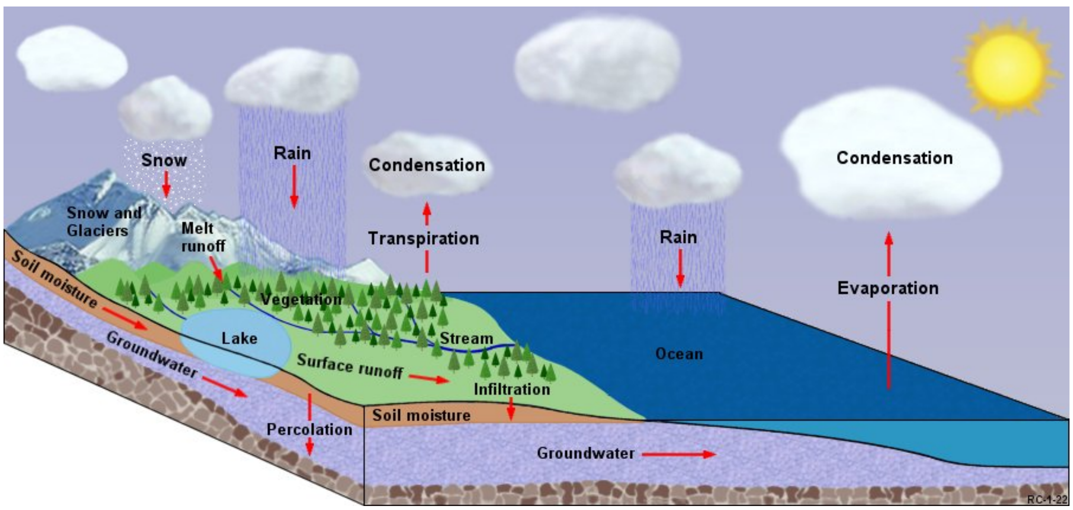


Figure 5–3. Hydrologic cycle.

Unfortunately, fresh water is distributed unevenly across the Earth. Some areas get little or no water, while others get far too much. Circulation of water in the hydrosphere results in the climate differences in different regions of the world. Most precipitation is in the form of rain droplets. Snow, the most common form of atmospheric water at high altitudes, makes up a small part of the total precipitation. Natural irrigation is a major benefit from the winter's snow-covered mountain caps; they provide an abundant flow of water for vegetation in some farm regions.

Most of the water returns to the air through evaporation from lakes, streams, soil moisture, melting snow, or oceans. Soil moisture, however, is subject to another form of water retrieval called transpiration. In this process, plants take up moisture through their roots and discharge it to the atmosphere through their leaves. There is no direct method for measuring evaporation or transpiration, but about two-thirds of all precipitation returns to the atmosphere by these methods. The remaining one-third returns to the ocean through runoff, rivers, streams, and from ground water. Since earliest history, humans have also used rivers and streams as sources of potable water, places to discard wastes, and for transporting goods.

Lithosphere

The crust and upper mantle of Earth from the surface to about 60 miles down make up the lithosphere, the final component of the biosphere. The thin crust results from natural chemicals, called minerals, composed of different combinations of elements. Oxygen is the most abundant chemical element in rocks in the Earth's crust—making up about 47 percent of the weight of all rock. The Earth has two kinds of crust. The dry land of the continents is composed mostly of granite and other light silicate minerals, while the ocean floors are composed mostly of a dark, dense volcanic rock called basalt.

From everyday experiences of observing farmland or mountains in rural areas, walking through shopping malls, or riding expressways in cities, one may think that the Earth's surface is very rigid. It would appear so, when you think of the multi-story buildings or ice-capped mountains standing for years without collapsing. However, the Earth yields to changing weights on its surface. It is not at rest as it may appear; rather, it is slowly adapting at a constant pace to the elements introduced by nature and society. Under water, the surface is mostly rock and its derivatives. On land, most of the rock breaks down because of weathering and mixes with organic matter to form soil. In either environment, the Earth's surface provides shelter and nourishment to its inhabitants.

The point to remember is that the atmosphere, hydrosphere, and lithosphere all work together to provide living organisms the essentials for survival. Plants use carbon dioxide from the atmosphere and water from the hydrologic cycle for photosynthesis, and release oxygen and waste. Animals need oxygen to respire, and release carbon dioxide and water as waste. Much of the oxygen needed by animals comes from plants, and much of the carbon dioxide needed by plants comes from animals. Water for both of them comes from the hydrosphere. Shelter for animals and soil for plants come from the lithosphere. Air, water, and land are interrelated elements necessary for life on Earth.

033. Ecological life forms

The biosphere is broken down into subunits called ecosystems. An ecosystem may be defined as a grouping of various species of plants, animals, and microbes interacting with each other and with their environment. The environment includes temperature, precipitation, amount of moisture, and all other chemical and physical factors to which organisms are exposed. Ecosystems are not isolated from one another; instead, one ecosystem blends into the next through a transitional region (an ecotone) common to the two adjacent systems. The biosphere is structured into a hierarchy of ecological life forms. Despite the diversity of each ecosystem, they each have the following three basic categories of organisms that interact together in the same way: producers, consumers, and detritus feeders and decomposers.

All living organisms in an ecosystem need energy from the Sun in order to survive and is accomplished through food distribution. Green plants are the only living organisms able to produce food from the Sun's energy. Therefore, energy transfers first through an ecosystem by green plants, which make up the first link in the food chain.

Each time eating takes place in the food chain, only a small amount of the Sun's energy passes along to the next consumer. With each consumer receiving less energy, the number of links in a chain is typically limited to four or five. Surely, you can remember your parent(s) insisting that you eat all the vegetables on your dinner plate because; they are good for you! In actuality, eating vegetables and other plants is more energy efficient than eating any other food group. When we eat plants, there are only two links in the food chain—the produce and the primary consumer.

The idea of the food chain functioning so that one organism is dependent on a few lesser organisms in a progressive chain may be misleadingly simple. When we consider the function of the food chain, we must combine feeding relationships with energy flow in the ecosystem. Areas of concern include the amount of energy available at each level; whether this food energy can be adequately replaced; and determining the influence of nutrition on a species. These are just a few items that indicate the food chain is a complex natural structure requiring a delicate balance to continue to support top consumers like you and me.

Ecological life forms

Before going any further, let us take a moment to look at the types of ecological life forms and their metabolic processes. Autotrophic organisms are the first major breakdown of ecological life. These self-nourishing organisms manufacture their own food entirely from inorganic substances so they are not dependent on other organisms for food. Based on their source of energy, autotrophs can metabolize through either photosynthesis or chemosynthesis. Photosynthesis (the process of food and new cell mass production using light as the energy source), is represented by green plants and some bacteria. Autotrophic organisms that perform chemosynthesis (chemotrophs), mostly bacteria that live in the dark, produce food and new cell mass with energy from the oxidation of certain inorganic substances.

Heterotrophic organisms use already formed organic compounds (plants, animals, or particulate organic matter) as a basis for nutrition, so they depend on autotrophic organisms, either directly or indirectly. All animals and most bacteria are heterotrophs, classified by their type of respiration, as in the following:

1. Aerobic—with oxygen.
2. Anaerobic—without oxygen.
3. Facultative—with or without oxygen.

We can further categorize heterotrophs as phagotrophs, which are mostly animals that consume living organisms, or saprotrophs, mainly bacteria and fungi that feed on dead organic matter (detritus).

Types of food chains

We have learned that all self-sufficient ecosystems have producers and consumers, which make up the food chain. There are two types of food chains (fig. 5–4). The grazing food chain begins the autotrophic-phagotrophic succession, and the detritus food chain begins the detritus-saprotrophic succession.

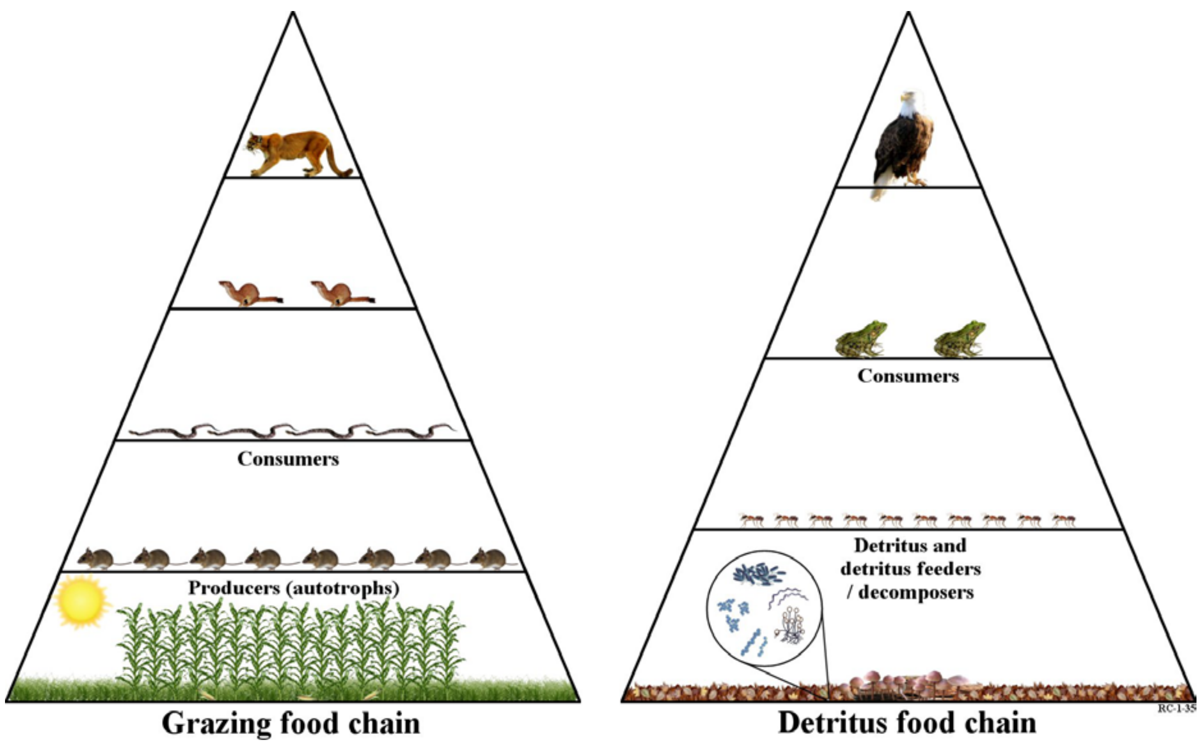


Figure 5–4. Food chains.

Although both grazing and detritus routes make up the complete food cycle with similar results, there are marked differences in early succession (first and second trophic levels). For example, consumption of living organisms and dead organic matter is not likely to occur in the same area or time. There is also a difference in the size and metabolism of phagotrophic animals (which are larger aerobic animals) and the saprotrophic bacteria and fungi (which are small, sometimes anaerobic, and typically immobile). Food getting also differs; the phagotrophs actively seek or gather their food, while the saprotrophs usually imbed within the decomposition process. Another interesting fact is that the detritus food chain actually consumes the animal waste from the grazers.

As food chains mature, food consumption is quite similar. In a detritus food chain of the marine environment, there may be small fish that feed on detritus consumers, which are then eaten by larger fish. In turn, these may become the hunted prey for human consumption. In a grasslands food chain, there may be rodents who eat the vegetation and small carnivores, like foxes, who eat the rodents. Although species may be different, carnivores are always present at upper trophic levels. In either chain, these animals catch and kill the organisms to be consumed, and are larger, quicker, or stronger than their prey.

Whether a community receives energy through the grazing or detritus food chain mainly depends on the impact of the grazing consumer. The rate of removal of living plant material is the primary factor; also important is the amount of energy in the food assimilated through digestion or photosynthesis. The resulting dead plants and animal wastes become the producers for the food chain. A good example of this occurs in most forests, where numerous vegetation dies before consumption, and where dead animals and animal wastes remain in the open. Thus, in most forests the majority of food transfers via the detritus food chain.

Influence of nutrients on living organisms

Food transfer between trophic levels is definitely the controlling factor in building an ecosystem, but the food's nutritional value is the controlling factor for growth and production of living organisms. Plants and animals must have certain nutrients in proper amounts throughout their life history, from conception through development and reproduction, and eventually to death. Nutritional needs may vary in different stages of life.

Nutrition

The principal elements that are essential for plant life are carbon, oxygen, hydrogen, nitrogen, sulfur, and phosphorus. Nitrogen and phosphorus are usually scarce in land and water environments. Nitrogen makes up 78 percent of the atmosphere and is readily dissolved in natural waters; therefore, it would seem that plants would have an abundant supply. However, green plants get their nitrogen from nitrogen compounds instead of gas, and these compounds are not plentiful. Other elements needed in trace quantities include iron, manganese, copper, zinc, molybdenum, and boron. The amounts of these trace elements are very critical; too much of them can seriously harm or even kill the plants. On the other hand, plants are quite flexible if there is a lack of nutrients. They can substitute one nutrient by absorbing more of another. Although the minimum amount is required over time sustain life, this flexibility lets them produce some growth temporarily under inadequate conditions.

The nutrients animals need are proteins, carbohydrates, fats, salts, and additional substances like vitamins. In contrast to vegetation, the lack or absence of essential nutrients is critical for animals. It may cause limited growth and reproduction, serious deficiency diseases, or even death. Animals must get certain elements and vitamins in trace quantities, either directly from the plants that manufacture them or in some other way. Humans have compensated for the lack or absence of these nutrients in food supplies by providing supplemental nutrients in water sources, fertilizers, and common food stuffs, not only for ourselves but domestic and urban animals and plants as well.

Decomposition

Since the food of all heterotrophic forms depends on green plants, their nutrition is clearly of basic importance. The required plant nutrients that are likely to run short; phosphorus and nitrogen compounds come mostly from decomposing dead organisms. In decomposition, certain types of fungi change dead organic matter and animal wastes into inorganic materials. This inorganic material is nutrition for the plants, but its consumable only in certain forms. For example, phosphorus must be transformed into phosphate and nitrogen into nitrate. Decomposition also produces food for the detritus-feeding animals and modifies the Earth's surface by producing nutrient-rich soil. With essential elements for plant life made available through decomposition, death is an important part of production; in other words, death expands the food chain, returning nutrients to their point of origin.

You now have an understanding of the basic principles of ecology—the interactions between organisms, and organisms and their environments. Based on what you have learned, what do you think might happen when pollution enters this equation?

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

032. Elements of the biosphere

1. Describe the cycle of air within the troposphere.

2. Describe the process by which ozone is formed.

3. Describe the hydrologic cycle.

4. Cite the two types of crust that make up the lithosphere and give a description of each.

5. Why is the Earth's surface important?

033. Ecological life forms

1. List the two ways in which autotrophic organisms metabolize.

2. Define photosynthesis.

3. How do heterotrophic organisms satisfy their nutritional needs?

4. Cite the two types of food chains.

5. What similarity can be found at the upper trophic levels of either chain?

5–2. Toxic Substances in the Environment

The problem with pollution is not new; it has been recognized since ancient times. A 4,000 year-old Egyptian manuscript relates the proceedings of a conference on pollution of the Nile River. The Roman statesman Seneca (in 61 anno Domini [A.D.]) stated that the polluted air of Rome had an adverse effect on his morale and disposition. In recent decades, names like Chernobyl and the Exxon Valdez have come to symbolize a growing anxiety over pollutants (toxic substances) in our environment. The study of toxic substances in the environment essentially involves several disciplines.

- Environmental chemistry**—**Focuses on the presence and fate of chemicals in the environment and on their transport between air, soil, and water.
- Environmental toxicology**—**Focuses on the effects of chemicals in the environment on organisms.
- Ecology**—**Focuses on interactions between organisms, and organisms and their environments (whether or not humans are present).

Despite differences in the backgrounds and focuses of the three, the subjects are impossible to separate. An understanding of the transport, transformation, and persistence of chemicals in the air, soil, and water is a necessary part of understanding the effects of toxic substances in the environment.

034. Chemicals in the environment and their transport

The use of chemicals greatly improves our quality of life; however, improper use and disposal can interfere with human health and the natural order of ecosystems. Although most people do not make a distinction between contamination and pollution, it is beneficial to make one in the context of environmental fate and transport. It is common practice to reserve the word contamination for the introduction or presence of a foreign substance in the environment without suggestion of any adverse effect. In contrast, pollution refers to the potential or actual damage or harm caused by the presence of a foreign substance in the environment. Therefore, we could say that contamination characterizes the source, pollution relates to the receptor, and the exposure pathway includes all the elements that link a contaminant source to a receptor population.

Exposure pathway

An exposure pathway consists of the following five elements:

1. Source —The origin of environmental contamination.
2. Environmental fate and transport—Once released into the environment, contaminants move through and across different media, with some degrading altogether.
3. Exposure point—The specific location where individuals might be exposed to a contaminated medium.
4. Exposure route—The means by which the contaminant actually enters or contacts the body such as ingestion, inhalation, or dermal contact.
5. Receptor population—Individuals that may come or may have been exposed to contaminants.

Figure 5–5 illustrate these five elements. While complete avoidance of contamination is our ultimate objective, contaminant release to the environment will continue, whether by deliberate or accidental means. Therefore, an understanding of what happens to the contaminants once released is essential. This includes an understanding of both chemical transport, referring to the processes that move chemicals through the environment, and chemical fate, referring to the eventual disposition—either destruction or long-term storage.

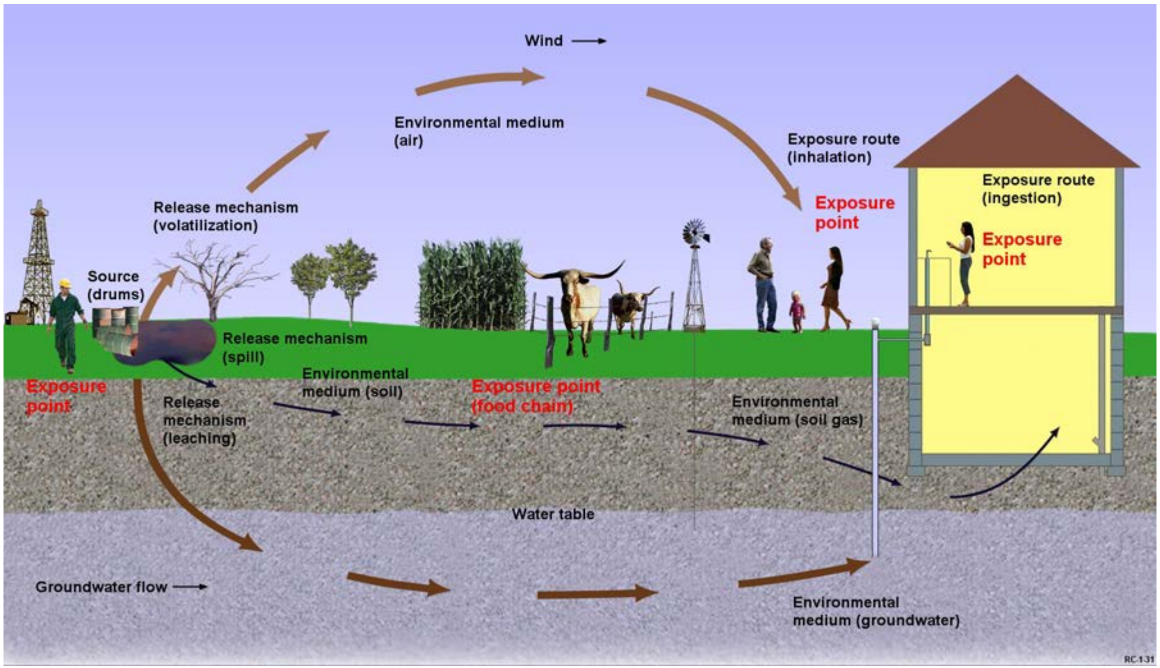


Figure 5–5. Exposure pathway representation.

Environmental fate and transport

Environmental fate and transport is the link between the release of a chemical from a source and its contact with a receptor at the exposure point. It involves obtaining the distribution of chemical concentrations at the source and following it to the receptor, taking into account all of the physical and chemical changes that a chemical can undergo.

Evaluating the fate and transport of contaminants within environmental media (air, soil, or water) is the step in the exposure pathway evaluation that will assist you in determining how likely it is that contaminants have moved or will move beyond the source area and how likely it is that contamination and exposure could occur.

The following information provides some of the factors that you might consider when you are evaluating fate and transport of environmental contaminants. This information is for guidance on issues you might consider on some sites. There is no implication that you will treat each site in the same manner; as a health risk assessor, you will often be required to use your judgment when evaluating this element of the exposure pathway.

When evaluating fate and transport, you will use a variety of information, such as the following:

- Possible transport processes that may carry a substance away from its source.
- Physical, chemical, and biological factors that influence the persistence and movement of a substance within and across environmental media.
- Site-specific environmental conditions such as climate and topography that determine how contaminants move through the environment at a given site.

Fate and transport processes

When assessing a site, you will need an overall appreciation of the main fate and transport release processes, intermediate transfer mechanisms, and transport pathways that might influence the ultimate fate of site-related contamination. Typically, transport and fate mechanisms may be simplified into the following four basic categories:

1. Emission—The actual release or discharge of the material from a source.
2. Advection/Convection**—**The normal migration or movement of the contaminant through a medium.
3. Dispersion—Spreading of contaminants in a liquid, gas, or solid phase due to impingement of the contaminant by that phase material.
4. Attenuation—The retardation, degradation, or adsorption of a contaminant.

Examples for emission, advection, dispersion, and attenuation for soil and surface water are shown in the following table to follow along with inter-media transfers that could occur.

Transport Category	Medium: Soil	Medium: Surface Water
Emission	Mass of contaminant loading per day (e.g., spill/release from drum, pipe, or truck).	Pipe discharges or spills. Surface runoff and soil loss. Deposition from air. Groundwater discharges.
Advection	Infiltration. Soil gas migration. Soil creep. Erosion via wind or water.	Stream flow. Lake currents and turnovers.
Dispersion	Impingement with soil particles.	Mixing zone in watercourse or water body.
Attenuation	Adsorption. Biodegradation. Hydrolysis. Oxidation/reduction. Photolysis. Volatilization.	Sedimentation and the others listed for soil.
Inter-media transfer	Migration of gases or particles to air. Migration to groundwater. Migration to surface water, sediments, and aquatic biota. Biologic uptake to plants and animals.	Sediment adsorption. Bioaccumulation. Gas migration to air. Recharge into groundwater.

The following questions are helpful considerations for understanding how fate and transport mechanisms might influence the likelihood of exposures.

How fast are contaminants moving?

For example, groundwater flow rates can determine when a groundwater contamination plume may have reached down gradient private wells or may migrate to other down gradient wells in the future.

How fast are contaminants dispersing along the flow path?

For example, air models can estimate how ambient air concentrations of pollutants are expected to decrease with downwind distance from a particular emissions source. The rate of this decrease ultimately will depend on the type of source, its release parameters, and other factors.

Where are contaminants moving in a particular medium?

For example, when evaluating a site with contaminated groundwater, you should consider the likelihood that contaminants might migrate crossways (perhaps to drinking water supply wells) or up and down (into different aquifers that may or may not be used for drinking water supply).

To what extent might natural attenuation be occurring?

Natural attenuation refers to any natural process known to degrade or dissipate environmental contamination. As a site-specific example, for chemicals found at elevated concentrations in soil, you might decide that migration to exposure points is improbable for those chemicals with both a high predisposition for adsorbing to soil and with a relatively short half-life for biologic degradation.

Are contaminants entering the food chain?

For example, though the source of contamination at a facility might be limited to its wastewater discharge of polychlorinated biphenyls (PCB) to surface water, these contaminants can biomagnify. In turn, this results in relatively high concentrations in fish at the highest level of the food chain.

Physical and chemical-specific factors

Within the next several paragraphs, we will briefly describe physical and chemical properties that can influence a contaminant's fate in the environment. An awareness of these properties will permit you to understand a contaminant's behavior in the environment and can help, when necessary, to focus the assessment on transport mechanisms of potential significance. The following paragraphs review some commonly cited physical and chemical properties that might help you with evaluating your exposure pathways.

Water solubility

This refers to the maximum concentration of a chemical that dissolves in a given amount of pure water. Environmental conditions, such as temperature and pH, can influence a chemical's solubility, which, in turn, also affects a contaminant's volatilization from water. Solubility provides an important indication of a contaminant's ability to migrate in the environment. For example, highly soluble compounds will tend to move with groundwater, while insoluble compounds do not.

Density of liquid

This refers to a liquid's mass per volume. For liquids that are insoluble in water, liquid density plays a critical role. For example, in groundwater, liquids with a higher density than water may penetrate and preferentially settle to the base of an aquifer, while less dense liquids will float.

Vapor pressure

This is a measure of the volatility of a chemical in its pure state. Therefore, the vapor pressure can essentially determine how rapidly contaminants will evaporate from surface soils or water bodies into the air. Contaminants with higher vapor pressures will evaporate more readily.

Henry's Law Constant

This is a measure of the tendency for a chemical to pass from an aqueous (watery) solution to the vapor phase. It is a function of molecular weight, solubility, and vapor pressure. Thus, a high Henry's Law Constant corresponds to a greater tendency for a chemical to volatilize to air.

Transformation and degradation rates

These take into account physical, chemical and biologic changes in a contaminant over time. Chemical transformation is influenced by hydrolysis, oxidation, photolysis, and biodegradation. Biodegradation is the breakdown of organic compounds by microorganisms – a significant environmental process in soil. Media-specific half life provides a comparative measure of how persistent a substance might be in a particular environmental medium.

Knowledge of the factors discussed in the preceding paragraphs will assist you in understanding the chemical's behavior in the environment and will help to focus the assessment on transport mechanisms of the greatest significance.

Site-specific factors

Many climatic and physical factors can affect—speed up, slow down, or even stop—how contaminants transport through the environment and in the end affect whether human exposures may occur. Attaining this information can help you determine whether and how quickly contaminants are likely to reach points of possible exposure. For example, precipitation, topography, hydrology, hydrogeology, and soil type indicate how quickly water-soluble contaminants will enter groundwater, while temperature and other factors affect whether and how quickly contaminants will volatilize into the air.

Climatic

Factors associated to climate can be important when trying to understand the probability of contaminant movement in a particular setting. You can see some commonly cited climatic factors in the following table:

Climatic Factors	Description
Annual precipitation and evaporation rates	These are helpful in determining the amount of surface-water runoff, groundwater recharge rates, and soil moisture content influencing contaminant migration in a particular setting. The topography of the land and flow patterns of local surface water will influence the materialization of these properties. Additionally, precipitation promotes the removal of particulates and soluble vapors from the atmosphere.
Temperature conditions	Temperature conditions influence the volatilization of contaminants – chemicals are more likely to evaporate in warmer environments. Additionally, ground temperature can affect the movement of contaminants as frozen ground cover can increase runoff and hinder groundwater recharge. Furthermore, frozen soils can increase the lateral spread of soil gas.
Wind speed and direction	Wind speed and direction influence the dispersion and volatilization of airborne contaminants. Knowing the prevailing wind patterns for a site can help give a qualitative understanding of where "downwind" locations are. This provides increased ability to evaluate potential air exposures.
Seasonal conditions	Seasonal conditions can be a major factor affecting rates of contaminant migration where precipitation temperatures vary greatly.

Geologic and hydrogeologic

Geologic and hydrogeologic conditions will influence the rate and direction contaminants in soil and groundwater might move. They will ultimately determine if and how contaminants might encounter people—the receptor. These conditions should be considered when deciding whether available sampling data is sufficient to characterize exposure points. Some key conditions are provided in the following table:

Key Conditions	Description
Groundwater hydrology and geologic composition	These influence the direction and extent of contaminant transport in groundwater.
Physical characteristics of aquifers	Those below or near a site, especially the porosity and permeability of their geologic materials, will greatly influence the vertical and lateral movement of groundwater and contaminants.
Depth to groundwater (the depth of the water table)	This can be important during your assessment. For example, this depth is a key consideration when evaluating whether volatile contaminants from groundwater might evaporate and migrate into indoor air.

Key Conditions	Description
Soil characteristics	Those such as configuration, composition, porosity, permeability, and cation exchange capacity of the soil ultimately influence the rate of percolation, groundwater recharge, contaminant release, and transport.
Ground cover and vegetative characteristics	These at the site influence rates of soil erosion, percolation, and evaporation.
Topography	This influences the direction and rate of surface water runoff, the rate of soil erosion, and the potential for flooding.
Man-made objects	Things such as sewers, culverts, and drainage channels, can vary the movement of contaminants.

Now that you have a grasp of environmental fate and transport, it is time to link the exposure potential with health effects.

035. Toxic substances in the environment

Humans modify ecosystems to have a constant supply of the materials we need for survival and want for comfort. With increasing population comes the demand to alter natural resources into environments suitable to our cultural and behavioral desires. As our demands develop, so does the demand for various energy forms, the use of which produces waste that, in turn, becomes pollution. In our use of manmade electrical, thermal, chemical, or nuclear energy to build cities, harvest land, or extract minerals and petroleum from the Earth, we produce excess materials that we do not know or care how to use. What is the result? We dump this waste back into the biosphere, placing a new demand on nature to maintain a balance and prevent disorder in its ecosystems. Nature becomes polluted when it cannot rid itself of this waste.

Health effects of air pollution

When air pollution affects various parts of an ecosystem, the result will most likely affect the human population. The effect may lead to costly building repairs or higher prices for food (economical); it may be the awful stench from a nearby dump or the inability to see the horizon (social). Whatever direct or indirect, social or economic problems air pollution may cause for humans, none is more important than the health effects.

All forms of air pollution (gases, particulates, or liquid droplets) can damage human health. You must consider two types of health effects from air pollution, which are pulmonary and systemic. Pulmonary injury occurs when inhalation of a chemical injures the lungs themselves. However, the lungs also provide a portal to the bloodstream. Since blood picks up oxygen in the lungs and carries it to every cell in the organism, an agent present in the lungs may affect any organ.

To be toxic to an organ, an agent must reach the organ. The access of a chemical to the lungs depends first on its state. Gases readily penetrate the lungs, as do vapors. For liquid droplets and for particulates, penetration depends on size. Particulates and droplets best reach the lungs when they are less than 5.0 micrometers (μm) in diameter; larger particles tend to be trapped by the cilia lining of the respiratory tract. Once in the lung, an agent's toxicity depends on its reactivity and on physical parameters. A chemical may stay in the lung, damaging cells that it contacts. In such pulmonary toxicity, the lungs are the target organ for the toxicant. For most chemicals that affect primarily the lungs, exposure by inhalation is the major route of entry.

Whatever they do to the lungs, most gases are absorbed into the bloodstream from the alveoli, and so enter the body. Particulates are either inert, in which case they may stay in the alveoli, or they dissolve and cross into lung tissue or into the bloodstream. Both lead and asbestos are examples of airborne particulates that cause major health effects. Recently, evidence has been found that exposure to particulates is more harmful than previously thought, especially for children, the elderly, and those with pre-existing respiratory problems.

Air pollution can affect our health in many ways with both short-term and long-term effects. Examples of short-term effects include irritation to the eyes, nose and throat, and upper respiratory infections such as bronchitis and pneumonia. Short-term air pollution can also aggravate the medical conditions of individuals with asthma and emphysema. Other symptoms can include headaches, nausea, and allergic reactions. Long-term health effects can include chronic respiratory disease, lung cancer, heart disease, and even damage to the brain, nerves, liver and kidneys. Continual exposure to air pollution affects the lungs of growing children and may aggravate or complicate medical conditions in the elderly.

Regardless of the pollutant and resulting damage, there are certain variables to consider when evaluating those effects. The first variable is the level of the pollutant to which a receptor is exposed and the duration of that exposure. Susceptibility and sensitivity of the receptor are also considerations, as are the meteorological conditions. Finally, we must consider that the interactions of two or more pollutants may cause greater harm—the synergistic effect.

Health effects of water pollution

Water can be contaminated by airborne pollutants carried in rain, by soil-deposited pollutants washed into rivers, lakes, and/or groundwater, and by direct discharge into bodies of water. Natural pollutants—whether bacterial or chemical—have always been released into the air, soil, and water and have always found their way into water. Pollutants seriously affect the ecosystems of these waters and make them unsuitable for human use.

Polluted water is dangerous to human health. Human infectious diseases are among the most serious effects of water pollution, especially in developing countries, where sanitation may be inadequate or non-existent. Waterborne diseases occur when parasites or other disease-causing microorganisms are transmitted via contaminated water. These include typhoid, intestinal parasites, and most of the intestinal and diarrhea diseases caused by bacteria, parasites, and viruses. Developed countries are not immune to the problem of infectious waterborne diseases. For example, in 1993 high cryptosporidium (a protozoan parasite that causes gastrointestinal illness) levels in Milwaukee’s drinking water supply sickened more than 400,000 residents.

Contamination of recreational water is also a problem. Every year, there are thousands of closings at beaches, splash parks, and other recreational water parks. In 2005, after numerous reports by patrons of gastrointestinal upset, a water park in upstate New York was found to have two water storage tanks infected with cryptosporidium.

Over the years, many types of harmful chemicals such as pesticides from agriculture and heavy metals like lead and mercury from industrial processes have found their way into our waterways, and they continue to do so today. The use of pesticides requires strict controls. They can enter waterways through direct discharge, drift from spray areas, and runoff from treated areas. Golf courses are sometimes major problems for this type of contamination. In terms of general health effects, pesticides can affect and damage the nervous system, cause liver damage, damage DNA and cause a variety of cancers, cause reproductive and endocrine damage, and cause other acutely toxic or chronic effects.

There are synthetic organic chemicals in nearly every Air Force industrial process. They are in adhesives, degreasers, paints, and fuel additives. Some well-known types are phenols, ketones, trichloroethylene, methylene chloride, and PCBs. PCBs, for instance, are classified as probable human carcinogens. Tests on laboratory animals show that PCB exposure can cause cancers, tumors, birth defects, reproductive failures, as well as liver, eye and gastric tract disorders. As PCBs are stable compounds, they do not degrade rapidly, and are passed up the aquatic food chain in increasing levels in a phenomenon known as bioaccumulation. The major source of PCB exposure for the general public is contaminated fish consumption.

The following health effects on humans have been related to exposure to water polluted by chemicals:

1. Cancer.
2. Hormonal problems that can disrupt reproductive and developmental processes.
3. Damage to the nervous system.
4. Liver and kidney damage.
5. Damage to the DNA.

Health effects of soil pollution

Soil pollution occurs when substances, mostly chemicals, are out of place or are present at concentrations higher than normal, which can cause adverse effects on humans and other organisms. The substances generally become physically or chemically attached to soil particles or trapped in the small spaces between soil particles. These substances can adversely affect the health of humans when they ingest, inhale, touch contaminated soil, or when they eat plants or animals that have themselves been affected by soil pollution. The most common chemicals involved in causing soil pollution are petroleum hydrocarbons, heavy metals, pesticides, and solvents.

Health effects will be different, depending on what kind of pollutant is in the soil. The following soil pollution effects on humans have been reported:

1. Headaches, nausea, fatigue, eye irritation and skin rash.
2. Lead in soil is especially hazardous for young children, causing developmental damage to the brain.
3. Mercury can increase the risk of kidney damage.
4. Neuromuscular blockage as well as depression of the central nervous system.
5. Cancers, including leukemia.

Soil pollution can lead to water pollution if toxic substances leach into groundwater, or if the contaminated runoff reaches streams, lakes, or oceans.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

034. Chemicals in the environment and their transport

1. Match the term listed in column B with appropriate definition listed in column A.

Column A	*Column B*
____ (1) Means by which the contaminant actually enters or contacts the body.	a. Source.
____ (2) Contaminants moving through and across different media.	b. Environmental Transport and Fate.
____ (3) Individuals that encounter contaminants.	c. Exposure point.
____ (4) Origin of environmental contamination.	d. Exposure route.
____ (5) Location where individuals might encounter contaminated medium.	e. Receptor population.

2. What are the five elements that characterize exposure pathways?

3. During your exposure pathway evaluation, what information could evaluating the fate and transport of a contaminant within an environmental media provide?

4. Cite the four categories of transport and fate mechanisms and provide a description of each.

5. Match the term listed in column B with appropriate description listed in column A.

Column A

____ (1) Influences the direction and extent of contaminant transport in groundwater.

____ (2) Indicator of a contaminant's ability to migrate in the environment.

____ (3) Influences the direction and rate of surface water runoff and potential for flooding.

____ (4) Indicator of how quickly a contaminant will evaporate from surface soils or water into the air.

____ (5) Influences the dispersion and volatilization of airborne contaminants.

____ (6) Influence the rate of percolation, groundwater recharge, contaminant release, and transport.

____ (7) Influences the volatilization of contaminants.

____ (8) Influences the vertical and lateral movement of groundwater and contaminants.

Column B

a. Water solubility.
b. Vapor pressure.
c. Temperature conditions.
d. Wind speed.
e. Geologic composition.
f. Physical characteristics of aquifers.
g. Soil characteristics.
h. Topography.

035. Toxic substances in the environment

1. What two types of health effects can occur when air pollutants enter the lungs?

2. Why are inhaled particles or droplets with a diameter greater than 5 µm not likely to reach the lungs?

3. What health effects have been related to exposure to water pollutants?

4. How can soil pollution lead to water pollution?

Answers to Self-Test Questions

032

1. The troposphere is in constant motion. The Sun heats the Earth's surface and the air above it, causing warm air to rise. As the warm air rises, air pressure decreases, causing the air to expand and cool. The cool air is denser than the surrounding air, so it sinks and the cycle starts again. It is this constant cycle of the air that causes our weather.
2. Temperature increases with height as radiation is increasingly absorbed by oxygen molecules, leading to the formation of ozone.

3. It is the basis of the hydrosphere and is a continuous process that makes it possible for living organisms to have the water essential for life.
4. (1) Dry land of the continents is composed mostly of granite and other light silicate minerals.
   (2) Ocean floors are composed mostly of a dark, dense volcanic rock called basalt.
5. It provides shelter and nourishment to its inhabitants.

033

1. Based on their source of energy, autotrophs can metabolize through either photosynthesis or chemosynthesis.
2. Photosynthesis is the process of food and new cell mass production using light as the energy source.
3. They use already formed organic compounds (plants, animals, or particulate organic matter) as a basis for nutrition, so they depend on autotrophic organisms, either directly or indirectly.
4. (1) Grazing.
   (2) Detritus.
5. In either chain, animals catch and kill the organisms to be consumed and are larger, quicker, or stronger than their prey.

034

1. (1) d.
   (2) b.
   (3) e.
   (4) a.
   (5) c.
2. (1) Source.
   (2) Environmental fate and transport.
   (3) Exposure point.
   (4) Exposure route.
   (5) Receptor population.
3. Determine how likely it is that contaminants have moved or will move beyond the source area and how likely it is that contamination and exposure could occur.
4. (1) Emission – Refers to the actual release or discharge of the material from a source.
   (2) Advection/convection – The normal migration or movement of the contaminant through a medium.
   (3) Dispersion – Describes spreading of contaminants in a liquid, gas, or solid phase due to impingement of the contaminant by the phase material.
   (4) Attenuation – The retardation, degradation, or adsorption of a contaminant.
5. (1) e.
   (2) a.
   (3) h.
   (4) b.
   (5) d.
   (6) g.
   (7) c.
   (8) f.

035

1. Pulmonary and systemic.
2. Larger particles tend to be trapped by the cilia lining of the respiratory tract.
3. (1) Cancer.
   (2) Hormonal problems that can disrupt reproductive and developmental processes.

(3) Damage to the nervous system.

(3) Liver and kidney damage.

(4) Damage to the DNA.

4. Toxic substances leach into groundwater, or if the contaminated runoff reaches streams, lakes, or oceans.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field-Scoring Answer Sheet.

Do not return your answer sheet to the Air Force Career Development Academy (AFCDA).

87. (032) What effect does carbon dioxide in the atmosphere have on regulating global temperature?
    a. Promotes water evaporation, preventing temperature decrease.
    b. Inhibits water evaporation, preventing temperature increase.
    c. Radiates infrared heat, preventing temperature decrease.
    d. Absorbs infrared heat, preventing temperature increase.

88. (032) Water starts it course through the hydrologic cycle when the Sun shines on moist lands and bodies of water, causing
    a. condensation.
    b. transpiration.
    c. evaporation.
    d. migration.

89. (032) The Earth's crust is comprised of natural chemicals called minerals, each of which are composed of different elements; within the rocks of the crust, the *most* abundant element is
    a. oxygen.
    b. nitrogen.
    c. hydrogen.
    d. carbon dioxide.

90. (033) Which statement *best* describes an autotrophic organism?
    a. Classified by their type of respiration.
    b. May be further categorized as phagotrophs or saprotrophs.
    c. Employ already formed organic compounds as a basis for food.
    d. Self-nourishing organisms manufacture their own food entirely.

91. (033) What is the controlling factor for growth and production of living organisms?
    a. Nitrogen compounds.
    b. Nutritional value of food.
    c. Impact of the grazing consumer.
    d. Food transfer between trophic levels.

92. (033) Decomposition provides nutrition for plants and modifies the Earth's surface by
    a. producing nutrient-rich soil.
    b. preventing deficiency diseases.
    c. limiting growth and reproduction.
    d. changing wastes into organic materials.

93. (034) What step in the exposure pathway links the release of a chemical from a source and its contact with a receptor at the exposure point?
    a. Source.
    b. Exposure point.
    c. Exposure route.
    d. Environmental fate and transport.

94. (034) When assessing a site, what transport and fate mechanism addresses the *normal* migration or movement of a contaminant through a medium?
   a. Emission.
   b. Dispersion.
   c. Attenuation.
   d. Advection/Convection.

95. (034) Which *best* illustrates an example of the fate and transport mechanism attenuation?
   a. Biodegradation.
   b. Soil gas migration.
   c. Erosion via wind or water.
   d. Impingement with soil particles.

96. (034) The vapor pressure of a contaminant can essentially determine how
   a. rapidly the contaminant is moving.
   b. fast the contaminant will bioaccumulate.
   c. rapidly the contaminant will evaporate into the air.
   d. fast the contaminant is dispersing along the flow path.

97. (034) What two factors influence the direction and extent of contaminant transport in groundwater?
   a. Depth to groundwater and ground cover.
   b. Soil characteristics and man-made objects.
   c. Physical characteristics of aquifers and depth.
   d. Groundwater hydrology and geologic composition.

98. (035) The access of a chemical to the lungs depends foremost on its physical state; for particulates, penetration depends on
   a. size.
   b. shape.
   c. reactivity.
   d. temperature.

99. (035) Which example *best* illustrates a short-term effect of air pollution?
   a. Gastrointestinal upset.
   b. Nervous system damage.
   c. Chronic respiratory disease.
   d. Irritation to eyes, nose, and throat.

Student Notes

Glossary

Terms

acid (Arrhenius definition)—Any substance that releases hydrogen ions (H+) when dissolved in water.

anion—Any ion carrying a negative charge.

aqueous solution—Solution in which a gas, solid, or liquid is dissolved in water.

atom—Smallest ‘piece’ of an element that can exist and still exhibit the properties of that element, including the ability to react with other atoms.

atomic mass unit—Unit used to express the relative masses of atoms on the atomic mass scale; one atomic mass unit is equal to exactly one twelfth the mass of a carbon-12 atom.

Avogadro’s number—Number of atoms in exactly 12 grams of carbon-12 (approximately 6.02 x 1023); it is equivalent to 1 mole of a substance.

base (Arrhenius definition)—Any substance that releases hydroxide ions (OH-) when dissolved in water.

binary compounds—Compounds containing two different elements.

Boyle’s law—Principle that, at constant temperature, the volume of a fixed mass of a given gas is inversely proportional to the pressure; thus, if the pressure is doubled, the volume will be halved.

buffer solution—Solution that contains substantial amounts of both a weak acid and its conjugate base and so resists changes in its potential of hydrogen (pH).

cation—Any ion carrying a positive charge.

Charles’s law—Principle that, at constant pressure, the volume of a fixed mass of a given gas is directly proportional to the temperature in kelvins; thus if the Kelvin temperature doubles, so does the volume.

chemical bonds—Attractive forces that hold atoms together.

compound—Any pure substance that can be broken down by chemical means into two or more different simpler substances.

concentration—Measure of how much solute is contained in a given amount of solvent or solution.

covalent bond—Type of chemical bond formed by the sharing of electrons between two atoms.

element—Any pure substance that cannot be broken down by chemical means into two or more different simpler substances; its atoms all have the same atomic number.

Gay-Lussac’s law—Principle that, at constant volume, the pressure of a fixed mass of a given gas is directly proportional to the temperature in kelvins. Thus, if the Kelvin temperature doubles, so will the pressure.

group—One of 18 vertical columns in the periodic table.

ionic bond—The force of attraction between ions of opposite charge which holds them together in an ionic compound. These ions of opposite charge are formed by the transfer of electrons from one atom to another.

isomer—Any compound that has the same molecular formula but a different structural formula. Each isomer has physical and chemical properties different from those of any other isomer of the same molecular formula.

Law of Conservation of Energy—Principle that energy can be neither created nor destroyed, although it may be transformed from one form to another.

Law of Conservation of Mass—Principle that mass is neither created nor destroyed and that the total mass of the substances involved in a physical or chemical change remains constant.

Law of Definite Proportion—Principle that a given pure compound always contains the same elements in exactly the same proportions by mass. Simply stated, if you were to take a sample of a pure compound it will always contain the same elements combined in the same proportion by mass.

liquid—One of the three states of matter; it is characterized by (1) limited expansion; (2) lack of characteristic shape; (3) maintenance of volume; (4) slight compressibility; (5) high density; and (6) diffusion in other liquids – typically slowly.

mass—Quantity of matter in particular body.

matter—Any substance that has mass and occupies space.

mixture—Heterogeneous matter composed of two or more pure substances, each of which retains its identity and specific properties.

Molality (m)—Measure of the concentration of a solution expressed as the number of moles of solute per kilogram of solvent; it is calculated as the moles of solute divided by the kilograms of solvent.

Molarity (M)—Measure of the concentration of a solution expressed as the number of moles of solute per liter of solution; it is calculated as the moles of solute divided by the liters of solution.

molar mass—Mass in grams of 1 mole of any substance, element or compound.

Mole (mol)—Amount of a substance containing the same number of atoms, formula units, molecules, or ions as there are atoms in exactly 12 grams of carbon-12 (approximately 6.023 x 1023).

molecule—Smallest particle of a pure substance that can exist and undergo chemical changes.

normality—Measure of the concentration of a solution expressed as the number of equivalents of solute per liter of solution; it is calculated as the equivalents of solute divided by the liters of solution.

percent by mass—Measure of the concentration of a solution expressed as the parts by mass of solute per 100 parts by mass of solution; it is calculated as the mass of solute divided by the mass of solution, with the result multiplied by 100.

period—One of the seven horizontal rows in the periodic table.

solid—One of the three states of matter; it is characterized by (1) lack of expansion; (2) definite shape; (3) constant volume; (4) lack of compressibility; (5) high density; and (6) severely limited mixability.

solute—Substance dissolved in a solution; it is usually present in less quantity than the solvent.

solution—Homogeneous mixture involving two or more pure substances; its composition can be varied within certain limits.

solvent—Dissolving substance in a solution; it is usually present in greater quantity than the solute.

standard temperature and pressure —Temperature of 0 C and atmospheric pressure of 760 millimeters (mm) of mercury (760 torr) or 1 atmosphere.

valence electrons—Electrons occupying the highest principal energy level in an atom.

volume—Cubic space taken up by matter.

weight—Measure of the gravitational force of attraction between the body's mass and the mass of the planet or satellite on which it is weighed.

Abbreviations and Acronyms

°	degree
µm	micrometer
1N	one normal
A. D.	anno Domini
a.k.a.	also known as
A1	Directorate of Manpower and Personnel at the Air Staff level
AB	air base
ADVON	advanced echelon
AE	aeromedical evacuation
AEF	air expeditionary force
AF	Air Force
AFB	Air Force base
AFI	Air Force instruction
AFIA	Air Force Inspection Agency
AFMAN	Air Force manual
AFMOA	Air Force Medical Operations Agency
AFMS	Air Force Medical Service
AFMSA	Air Force Medical Support Agency
AFMSA/SG3PB	Air Force Medical Support Agency Bioenvironmental Engineering Office
AFPD	Air Force policy directive
AFRAT	Air Force Radiological Assessment Team
AFSG	Air Force Surgeon General
AMC	Aerospace Medicine Council/Air Mobility Command
AMDS	aerospace medicine squadron
AMP	aerospace medicine program
AMU	atomic mass unit
AOME	Aerospace and Operational Medicine Enterprise
AOR	area of responsibility
A-staff	Air Staff
atm	atmosphere
BE	bioenvironmental engineering
BEC	base environmental coordinator
C	Celsius
C	carbon
C_2H_2	acetylene
C_2H_4	ethylene
C_2H_5	ethyl radical
C_2H_6	ethane

C_3H_8	propane
$C_3H_8O_3$	glycerol
C_4H_{10}	butane
C_5H_{12}	pentane
C_6H_6	benzene
$Ca(OH)_2$	calcium hydroxide
CBRN	chemical, biological, radiological, nuclear
CE	civil engineer
CEF	civil engineering fire department
CEMP	comprehensive emergency management plan
CEX	civil engineering emergency management
CF_4	carbon tetrafluoride
CFM	career field manager
CH_4	methane
cm	centimeter
cm Hg	centimeters of mercury
CNS	central nervous system
CO_2	carbon dioxide
CO_3	carbonate radical
CSAF	Chief of Staff of the Air Force
CSPT	confined space program team
DDT	dichlorodiphenyltrichloroethane
DETA	diethylenetriamine
DNA	deoxyribonucleic acid
DOD	Department of Defense
EPA	Environmental Protection Agency
eq	equivalent
ESOHC	Environment, Safety and Occupational Health Council
F	Fahrenheit
ft^3	cubic feet
GI	gastrointestinal
G-staff	Army's General Staff
H	hydrogen
H^+	hydrogen ion
H_2O	water
H_3PO_4	phosphoric acid
HAZMAT	hazardous material
HCl	hydrogren chloride
Hg	mercury
HOH	water

HRA	health risk assessment
IHMP	Installation Hazardous Material Management Program
in Hg	inches of mercury
J-staff	Joint Staff
K	Kelvin
l	liter
LASIK	laser-assisted in situ keratomileusis
LC	lethal concentration
LD	lethal dose
M	molality
M	mass number of an atom
m	molarity
m^3	cubic meters
MAJCOM	major command
MAJCOM/BE	major command bioenvironmental engineering
mbar	millibar
MEK	methyl ethyl ketone
MFM	major command functional manager
mg/kg	milligrams of substance per kilogram
MGRL	medical global reach laydown
MIBK	methyl isobutyl ketone
ml	milliliter
mm Hg	millimeters of mercury
MNBC	medical nuclear, biological, and chemical
mol	mole
MOPP	mission-oriented protective posture
MTF	medical treatment facility
N	normality
N_2	nitrogen
NaCl	sodium chloride
NaF	sodium fluoride
NaOH	sodium hydroxide
NBC	nuclear, biological, and chemical
NCOIC	noncommissioned officer in charge
NRC	Nuclear Regulatory Commission
NSN	national stock number
N-staff	Navy’s Deputy Chiefs of Naval Operations
O_2	oxygen
O_3	ozone
OB/GYN	obstetrics and gynecology

OEH	occupational and environmental health
OEHSA	occupational and environmental health site assessment
OEHWG	Occupational and Environmental Health Working Group
OH^-	hydroxide ion
OPLAN	operation plan
OSHA	Occupational Safety and Health Administration
p or p+	proton
Pa	Pascal
PAM	preventive and aerospace medicine
PCB	polychlorinated biphenyls
PH	public health
pH	potential of hydrogen
PPE	personal protective equipment
ppm	parts per million
psi	pounds per square inch
RAC	risk assessment code
RAD/NUC	radiation/nuclear
RCAT	Rad/Nuc Crisis Advon Team
RDAT	Rad/Nuc Dosimetry Augmentation Team
RDT	Rad/Nuc Dosimetry Team
RIC	Radioisotope Committee
RLAT	Rad/Nuc Laboratory Augmentation Team
RLT	Rad/Nuc Laboratory Team
RM	risk management
RNA	ribonucleic acid
RSAT	Rad/Nuc Surveillance Augmentation Team
RSO	radiation safety officer
RST	Rad/Nuc Surveillance Team
SE	wing safety office
SECAF	Secretary of the Air Force
SG1	Force Management
SNCO	senior noncommissioned officer
STP	standard temperature and pressure
TIC/TIM	toxic industrial chemical/toxic industrial material
torr	1 millimeter of mercury
US	United States
USAF	United States Air Force
USAFSAM	United States Air Force School of Aerospace Medicine
UTC	unit type code

WVA	water vulnerability assessment
Z	atomic number

Student Notes

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