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Light Microscopy

Learning Outcomes

3.1 Light Microscopes Versus Electron Microscopes
   - Describe three differences between the compound light microscope and the electron microscope.
   Prelab Question: Greater magnification enlarges the subject, but what is another equally important attribute of a microscope? Explain.

3.2 Stereomicroscope (Binocular Dissecting Microscope)
   - Identify the parts of and tell how to focus the stereomicroscope.
   Prelab Question: If you wanted to examine the external features of a fly, you might decide to use a stereomicroscope. Why?

3.3 Use of the Compound Light Microscope
   - Name and give the function of the basic parts of the compound light microscope.
   - List the steps for bringing an object into focus with the compound light microscope.
   - Describe how the image is inverted by the compound light microscope.
   - Calculate the total magnification and the diameter of field of view for both low- and high-power lens systems.
   - Explain how a slide of colored threads provides information on the depth of field.
   Prelab Question: What's the difference between low power and high power when using the compound light microscope?

3.4 Microscopic Observations
   - Name and describe three types of cells studied in this exercise.
   Prelab Question: What is there about live Euglena that makes them difficult to study microscopically?

Application for Daily Living: Microscopic Diagnoses

Introduction

This laboratory introduces you to the features, functions, and use of the stereomicroscope and the compound light microscope. Transmission and scanning electron microscopes are explained, and micrographs produced by using these microscopes are shown throughout these exercises. The stereomicroscope and the scanning electron microscope view the surface and/or the three-dimensional structure of an object. The compound light microscope and the transmission electron microscope can view only extremely thin sections of a specimen. If a subject was sectioned lengthwise for viewing, the interior of the projections at the top of the cell, called cilia, would appear in the micrograph (Fig. 3.1b). A lengthwise cut through any type of specimen is called a longitudinal section (ls). On the other hand, if the subject was sectioned crosswise below the area of the cilia, you would see other portions of the interior of the subject (Fig. 3.1c). A crosswise cut through any type of specimen is called a cross section (cs).

Figure 3.1 Longitudinal and cross sections.
   a. Transparent view of a cell. b. A longitudinal section would show the cilia at the top of the cell. c. A cross section shows only the interior where the cut is made.
3.1 Light Microscopes Versus Electron Microscopes

Biological objects can be small, so we often use a microscope to view them. Many types of instruments, ranging from the hand lens to the electron microscope, are effective magnifying devices. A short description of two types of light microscopes and two types of electron microscopes follows.

**Light Microscopes**

Light microscopes use visible light rays magnified and focused by means of lenses. The **stereomicroscope** (binocular dissecting microscope) is designed to study entire objects in three dimensions at low magnification. The **compound light microscope** is used for examining small or thinly sliced sections of objects under higher magnification than that of the stereomicroscope. The term **compound** refers to the use of two sets of lenses: the ocular lenses located near the eyes and the objective lenses located near the object. Illumination is from below, and visible light passes through clear portions but does not pass through opaque portions. To improve contrast, the microscopist uses stains or dyes that bind to cellular structures and absorb light. Figure 3.2a is a **photomicrograph**, a photograph of an image produced by a compound light microscope.

**Figure 3.2 Comparative micrographs.**

Micrographs of a lymphocyte, a type of white blood cell. a. A photomicrograph (light micrograph) shows less detail than a (b) transmission electron micrograph (TEM). c. A scanning electron micrograph (SEM) shows the cell surface in three dimensions.

a. Photomicrograph (LM) of a lymphocyte 2150x

b. Transmission electron micrograph (TEM) of a lymphocyte 2150x

c. Scanning electron micrograph (SEM) of a lymphocyte 5000x
Electron Microscopes

Electron microscopes use a beam of electrons magnified and focused on a photographic plate by means of electromagnets. The transmission electron microscope is analogous to the compound light microscope. For electron microscopy, the object is ultra-thinly sliced and treated with heavy metal salts to provide contrast. Figure 3.2a is a micrograph produced by this type of microscope. The scanning electron microscope is analogous to the dissecting light microscope. It gives an image of the surface and dimensions of an object, as is apparent from the scanning electron micrograph in Figure 3.2c.

The micrographs in Figure 3.2 demonstrate that much smaller objects can be viewed with electron microscopes than with compound light microscopes. The difference between these two types of microscopes, however, is not simply a matter of magnification; it is also the electron microscope’s ability to show detail. The electron microscope has greater resolving power. Resolution is the minimum distance between two objects at which they can still be seen, or resolved, as two separate objects. The use of high-energy electrons rather than light gives electron microscopes a much greater resolving power because two objects much closer together can still be distinguished as separate points. Table 3.1 lists several other differences between the compound light microscope and the transmission electron microscope.

<table>
<thead>
<tr>
<th>Compound Light Microscope</th>
<th>Transmission Electron Microscope</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Glass lenses</td>
<td>1. Electromagnetic lenses</td>
</tr>
<tr>
<td>2. Illumination by visible light</td>
<td>2. Illumination due to a beam of electrons</td>
</tr>
<tr>
<td>3. Resolution (\geq 200 \text{ nm})</td>
<td>3. Resolution (\geq 0.1 \text{ nm})</td>
</tr>
<tr>
<td>4. Magnifies to 2,000x</td>
<td>4. Magnifies to 1,000,000x</td>
</tr>
<tr>
<td>5. Costs up to tens of thousands of dollars</td>
<td>5. Costs up to hundreds of thousands of dollars</td>
</tr>
</tbody>
</table>

3.2 Stereomicroscope (Binocular Dissecting Microscope)

The stereomicroscope (binocular dissecting microscope) allows you to view objects in three dimensions at low magnifications. It is used to study entire small organisms, any object requiring lower magnification, and opaque objects that can be viewed only by reflected light. It is also called a stereomicroscope because it produces a three-dimensional image.

Identifying the Parts

After your instructor has explained how to carry a microscope, obtain a stereomicroscope and a separate illuminator, if necessary, from the storage area. Place it securely on the table. Plug in the power cord, and turn on the illuminator. There is a wide variety of stereomicroscope styles, and your instructor will discuss the specific style(s) available to you. Regardless of style, the following features should be present:

1. **Binocular head**: Holds two eyepiece lenses that move to accommodate the various distances between different individuals’ eyes.

2. **Eyepiece lenses**: The two lenses located on the binocular head. What is the magnification of your eyepieces? ________ Some models have one independent focusing eyepiece with a knurled knob to allow independent adjustment of each eye. The nonadjustable eyepiece is called the fixed eyepiece.
3. **Focusing knob**: A large black or gray knob located on the arm; used for changing the focus of both eyepieces together.

4. **Magnification changing knob**: A knob, often built into the binocular head, used to simultaneously change magnification in both eyepieces. This may be a zoom mechanism or a rotating lens mechanism of different powers that clicks into place.

5. **Illuminator**: Used to illuminate an object from above; may be built into the microscope or separate.

Locate each of these parts on your stereomicroscope, and label them on Figure 3.3.

---

**Focusing the Stereomicroscope**

1. Place a plastomount, that contains small organisms, in the center of the stage.
2. Adjust the distance between the eyepieces on the binocular head so that they comfortably fit the distance between your eyes. Using both eyes, you should be able to see an organism in the plastomount as one three-dimensional image.

---

**Figure 3.3 Stereomicroscope.**
Label this microscope with the help of the text material.
3. Use the focusing knob to bring an organism in the plastomount into focus.

4. Does your microscope have an independent focusing eyepiece? If so, use the focusing knob to bring an organism in the plastomount in the fixed eyepiece into focus, while keeping the eye at the independent focusing eyepiece closed. Then adjust the independent focusing eyepiece so that the image is clear, while keeping the other eye closed. Is the image inverted?

5. Turn the magnification changing knob, and determine the type of mechanism on your microscope. A zoom mechanism allows continuous viewing while changing the magnification. A rotating lens mechanism blocks the view of the object as the new lenses are rotated. Be sure to click each lens firmly into place. If you do not, the field will be only partially visible. Which of these mechanisms is on your microscope?

6. Set the magnification changing knob on the lowest magnification. Choose an organism from the plastomount and sketch it in the following circle as though this represents your entire field of view:

7. Rotate the magnification changing knob to the highest magnification. Draw another circle within the one provided to indicate the reduction of the field of view.

8. Experiment with various objects at various magnifications until you are comfortable with using the binocular dissecting microscope.

9. When you are finished, return your stereomicroscope and illuminator to their correct storage areas.

**Conclusions: Microscopy**

- Which two of the three types of microscopes studied (compound light microscope, transmission electron microscope, stereomicroscope) view the surface of an object?

- Which two types of microscopes view objects that have been sliced and treated to improve contrast?

- Of the three microscopes, which one resolves the greater amount of detail?

### 3.3 Use of the Compound Light Microscope

As mentioned, the name **compound light microscope** indicates that it uses two sets of lenses and light to view an object. The two sets of lenses are the ocular lenses located near the eyes and the objective lenses located near the object. Illumination is from below, and the light passes through clear portions but does not pass through opaque portions. This microscope is used to examine small or thinly sliced sections of objects under higher magnification than would be possible with the stereomicroscope.
Identifying the Parts

Obtain a compound light microscope from the storage area, and place it securely on the table. Identify the following parts on your microscope, and label them in Figure 3.4.

1. Eyepieces (ocular lenses): What is the magnifying power of the ocular lenses on your microscope? 

2. Body tube: Holds nosepiece at one end and eyepiece at the other end; conducts light rays.

3. Arm: Supports upper parts and provides carrying handle.

4. Nosepiece: Revolving device that holds objectives.

5. Objectives (objective lenses):
   a. Scanning power objective: This is the shortest of the objective lenses and is used to scan the whole slide. The magnification is stamped on the housing of the lens. It is a number followed by a multiplication sign (×). What is the magnifying power of the scanning lens on your microscope?

Figure 3.4 Compound light microscope.
Compound light microscope with binocular head and mechanical stage. Label this microscope with the help of the text.
b. **Low-power objective**: This lens is longer than the scanning lens and is used to view objects in greater detail. What is the magnifying power of the low-power objective lens on your microscope?

c. **High-power objective**: If your microscope has three objective lenses, this lens will be the longest. It is used to view an object in even greater detail. What is the magnifying power of the high-power objective lens on your microscope?

d. **Oil immersion objective** (on microscopes with four objective lenses): Holds a 95X (to 100X) lens and is used in conjunction with immersion oil to view objects with the greatest magnification. Does your microscope have an oil immersion objective?

If this lens is available, your instructor will discuss its use when the lens is needed.

6. **Coarse-adjustment knob**: Knob used to bring object into approximate focus; used only with low-power objective.

7. **Fine-adjustment knob**: Knob used to bring object into final focus.

8. **Condenser**: Lens system below the stage used to focus the beam of light on the object being viewed.

9. **Diaphragm or diaphragm control lever**: Controls amount of light used to view the object.

10. **Light source**: An attached lamp that directs a beam of light up through the object.

11. **Base**: The flat surface of the microscope that rests on the table.

12. **Stage**: Holds and supports microscope slides.

13. **Stage clips**: Hold slides in place on the stage.

14. **Mechanical stage** (optional): A movable stage that aids in the accurate positioning of the slide.

Does your microscope have a mechanical stage?

15. **Mechanical stage control knobs** (optional): Two knobs usually located below the stage. One knob controls forward/reverse movement, and the other controls right/left movement.

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**Rules for Microscope Use**

1. Figure 3.5 shows the proper way to carry the microscope.

2. The lowest power objective (scanning or low) should be in position both at the beginning and at the end of microscope use.

3. Use only lens paper for cleaning lenses.

4. Do not tilt the microscope as the eyepieces could fall out, or wet mounts could be ruined.

5. Keep the stage clean and dry to prevent rust and corrosion.

6. Do not remove parts of the microscope.

7. Keep the microscope dust-free by covering it after use.


9. Do not use coarse focus when viewing a specimen with the high-power objective.
Focusing the Microscope—Lowest Power

1. Turn the nosepiece so that the lowest-power lens is in straight alignment over the stage.
2. Always begin focusing with the lowest-power objective lens (4× [scanning] or 10× [low power]).
3. With the coarse-adjustment knob, lower the stage (or raise the objectives) until it stops.
4. Place a slide of the letter e on the stage, and stabilize it with the clips. (If your microscope has a mechanical stage, pinch the spring of the slide arms on the stage, and insert the slide.) Center the e as best you can on the stage or use the two control knobs located below the stage (if your microscope has a mechanical stage) to center the e.
5. Again, be sure that the lowest-power objective is in place. Then, as you look from the side, decrease the distance between the stage and the tip of the objective lens until the lens comes to an automatic stop or is no closer than 3 mm above the slide.
6. While looking into the eyepiece, rotate the diaphragm (or diaphragm control lever) to give the maximum amount of light.
7. Using the coarse-adjustment knob, slowly increase the distance between the stage and the objective lens until the object—in this case, the letter e—comes into view, or focus.
8. Once the object is seen, you may need to adjust the amount of light. To increase or decrease the contrast, slightly rotate the diaphragm.
9. Use the fine-adjustment knob to sharpen the focus if necessary.
10. Practice having both eyes open when looking through the eyepiece, as this greatly reduces eyestrain.

Inversion

Inversion refers to a microscopic image that is upside down and reversed.

Observation: Inversion

1. Draw the letter e as it appears on the slide (with the unaided eye, not looking through the eyepiece).
2. Draw the letter e as it appears when you look through the eyepiece.
3. What differences do you notice?
4. Move the slide to the right. Which way does the image appear to move? Explain.

Focusing the Microscope—Higher Powers

Compound light microscopes are parfocal—one once the object is in focus with the lowest power, it should also be almost in focus with the higher power.

1. Bring the object into focus under the lowest power by following the instructions in the previous section.
2. Make sure that the letter e is centered in the field of the lowest objective.
3. Move to the next higher objective (low power [10×] or high power [40×]) by turning the nosepiece until you hear it click into place. Do not change the focus; parfocal microscope objectives will not hit normal slides when changing the focus if the lowest objective is initially in focus. (If you are on low power [10×], proceed to high power [40×] before going on to step 4.)
4. If any adjustment is needed, use only the fine-adjustment knob. (Note: Always use only the fine-adjustment knob and not the coarse-adjustment knob with high power.)
5. On a drawing of the letter e, draw a circle around the portion of the letter that you are now seeing with high-power magnification.
6. When you have finished your observations of this slide (or any slide), rotate the nosepiece until the lowest-power objective clicks into place, lower the stage, and then remove the slide.
Total Magnification

Total magnification is calculated by multiplying the magnification of the ocular lens (eyepiece) by the magnification of the objective lens.

Observation: Total Magnification

Calculate total magnification figures for your microscope, and record your findings in Table 3.2.

<table>
<thead>
<tr>
<th>Objective</th>
<th>Ocular Lens</th>
<th>Objective Lens</th>
<th>Total Magnification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scanning power (if present)</td>
<td>×</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td>Low power</td>
<td>×</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td>High power</td>
<td>×</td>
<td>×</td>
<td>×</td>
</tr>
</tbody>
</table>

Field of View

A microscope’s field of view is the circle visible through the lenses. The diameter of field is the length of the field from one edge to the other. Like any other measurement in science, the diameter of the field is measured using metric units. The metric system has tremendous advantages because all conversions are in units of ten. Table 3.3 provides the metric units for length. The basic unit of length is the meter (m), and Table 3.3 tells you how the other units of length relate to the meter. You would use a meter to measure your car or this classroom. Examine a meterstick on display. It is divided into centimeters (cm) and millimeters (mm). Look at 1 mm, and imagine dividing up that amount of space into 1,000 micrometers (μm). A meter is much too large a unit for microscopy. The units appropriate for microscopic use are highlighted in Table 3.3. They are

1.0 millimeter (mm) = 1,000 micrometers (μm) = 1,000,000 nanometers (nm)

For light microscopy, the most useful unit of these is μm, and you will be asked to convert millimeters into micrometers by multiplying by 1,000 in the exercises that follow.

<table>
<thead>
<tr>
<th>Unit</th>
<th>Symbol</th>
<th>Value (m)</th>
<th>Value (cm)</th>
<th>Value (mm)</th>
<th>Value (μm)</th>
<th>Value (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meter</td>
<td>m</td>
<td>1.0 m</td>
<td>100 cm</td>
<td>1,000 mm</td>
<td>1,000,000 μm</td>
<td>1,000,000,000 nm</td>
</tr>
<tr>
<td>Centimeter</td>
<td>cm</td>
<td>0.01 m</td>
<td>1.0 cm</td>
<td>10 mm</td>
<td>10,000 μm</td>
<td>10,000,000 nm</td>
</tr>
<tr>
<td>Millimeter</td>
<td>mm</td>
<td>0.001 m</td>
<td>0.1 cm</td>
<td>1.0 mm</td>
<td>1,000 μm</td>
<td>1,000,000 nm</td>
</tr>
<tr>
<td>Micrometer</td>
<td>μm</td>
<td>0.000001 m</td>
<td>0.001 cm</td>
<td>0.001 mm</td>
<td>1.0 μm</td>
<td>1,000 nm</td>
</tr>
<tr>
<td>Nanometer</td>
<td>nm</td>
<td>0.000000001 m</td>
<td>0.000001 cm</td>
<td>0.000001 mm</td>
<td>0.001 μm</td>
<td>1.0 nm</td>
</tr>
</tbody>
</table>
**Observation: Field of View**

**Low-Power (10×) Diameter of Field**

1. Place a clear, plastic metric ruler across the stage so that the edge of the ruler is visible as a horizontal line along the diameter of the low-power (not scanning) field. Be sure that you are looking at the millimeter side of the ruler.

2. Estimate the number of millimeters, to tenths, that you see along the field: ___________ mm.
   (Hint: Start with one of the millimeter markers at the edge of the field.) Convert the number to micrometers: ___________ μm. This is the **low-power diameter of field (lpd)** for your microscope in micrometers.

**High-Power (40×) Diameter of Field**

1. To compute the **high-power diameter of field (hpd)**, substitute these data into the formula given:
   a. \[ \text{lpd} = \text{low-power diameter of field (in micrometers)} \quad = \quad \text{___________} \quad \mu m \]
   b. \[ \text{lpm} = \text{low-power total magnification (from Table 3.2)} \quad = \quad \text{___________} \times \]
   c. \[ \text{hpm} = \text{high-power total magnification (from Table 3.2)} \quad = \quad \text{___________} \times \]

\[ \text{hpd} = \text{lpd} \times \frac{\text{lpm}}{\text{hpm}} \]

\[ \text{hpd} = ( \mu m) \times \left( \frac{\text{___________}}{\text{___________}} \right) = \text{___________} \mu m \]

**Conclusion: Total Magnification and Field of View**

- What unit of metric measurement is most useful for light microscopy? ________________________________

  Use the micrometer row in Table 3.3 to convert 1 μm to millimeters. 1 μm = ____________ mm

  Use the meter row to convert 1 m to μm. 1 m = __________ μm

- Does low power or high power have a larger field of view (allowing you to see more of the object)?
  ________________________________

- Does low power or high power have a smaller field but magnifies to a greater extent? ________________________________

- To locate small objects on a slide, first find them under ___________________________; then place them in the center of the field before rotating to ___________________________.

**Depth of Field**

When viewing an object on a slide under high power, the **depth of field** (Fig. 3.6) is the area—from top to bottom—that comes into focus while slowly focusing up with the microscope's fine-adjustment knob.

**Observation: Depth of Field**

1. Obtain a prepared slide with three or four colored threads mounted together, or prepare a wet-mount slide with three or four crossing threads or hairs of different colors. (Directions for preparing a wet mount are given in Section 3.4.)

2. With low power, find a point where the threads or hairs cross. Slowly focus up and down. Notice that when one thread or hair is in focus, the others seem blurred. Determine the order of the threads or hairs, and
complete Table 3.4. Remember, as the stage moves upward (or the objectives more downward), objects on top come into focus first.

<table>
<thead>
<tr>
<th>Depth</th>
<th>Thread (or Hair) Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top</td>
<td></td>
</tr>
<tr>
<td>Middle</td>
<td></td>
</tr>
<tr>
<td>Bottom</td>
<td></td>
</tr>
</tbody>
</table>

3. Switch to high power, and notice that the depth of field is more shallow with high power than with low power. Constant use of the fine-adjustment knob when viewing a slide with high power will give you an idea of the specimen's three-dimensional form. For example, viewing a number of sections allows reconstruction of the three-dimensional structure, as demonstrated in Figure 3.6.

Figure 3.6  Depth of field.
A demonstration of how focusing at depths 1, 2, and 3 would produce three different images (views) that could be used to reconstruct the original three-dimensional structure of the object.

3.4 Microscopic Observations
In this part of the laboratory session, you will have an opportunity to first examine a prepared slide and then two slides you will prepare yourself.

Human Blood Cells
Human blood contains red blood cells that transport oxygen about the body and white blood cells that fight infection. You will have no difficulty finding the red blood cells on the slide because they are numerous (see Fig. 3.2(a)).
Observation: Human Blood Cells

1. Obtain a prepared slide of human blood, and mount it on the microscope stage. Use the method you learned previously to bring the red blood cells into focus. Practice observing different parts of the slide and switching to high power. Can you find a white blood cell? White blood cells are generally much larger than red blood cells.

2. Red blood cells are small, only 7–8 μm in diameter, and their small size can account for why there are so many in the blood. Blood is a liquid tissue, and this gives us an opportunity to refer to the liquid measurement in science. The metric system is uniform. Table 3.3 can be used to describe the units of liquid measurement, as long as you appropriately change the terms.

<table>
<thead>
<tr>
<th>Instead of these terms:</th>
<th>Use:</th>
</tr>
</thead>
<tbody>
<tr>
<td>meter (m)</td>
<td>liter (l)</td>
</tr>
<tr>
<td>centimeter (cm)</td>
<td>centiliter (cl)</td>
</tr>
<tr>
<td>millimeter (mm)</td>
<td>milliliter (ml)</td>
</tr>
<tr>
<td>micrometer (μm)</td>
<td>microliter (μl)</td>
</tr>
</tbody>
</table>

Instead of these terms: Use:

There are generally 4–6 million red blood cells in a microliter (μl). To appreciate this quantity, observe the micropipette on display. If so advised by your instructor, use the micropipette to measure a μl and disperse this quantity into a beaker.

Wet Mounts

When a specimen is prepared for observation, the object should always be viewed as a wet mount. A wet mount is prepared by placing a drop of liquid on a slide or, if the material is dry, by placing it directly on the slide and adding a drop of water or stain. The mount is then covered with a coverslip, as illustrated in Figure 3.7. Dry the bottom of your slide before placing it on the stage.

![Figure 3.7 Preparation of a wet mount.](image-url)

a. Add drop of suspension or dry object and solution.

b. Lower coverslip slowly.
Human Epithelial Cells

Epithelial cells cover the body’s surface and line its cavities.

**Observation: Human Epithelial Cells**

1. Obtain a prepared slide, or make your own as follows:
   a. Obtain a prepackaged flat toothpick (or sanitize one with alcohol or alcohol swabs).
   b. Gently scrape the inside of your cheek with the toothpick, and place the scrapings on a clean, dry slide. Discard used toothpicks in the biohazard waste container provided.
   c. Add a drop of very weak methylene blue or iodine solution, and cover with a coverslip.
2. Observe under the microscope.
3. Locate the nucleus (the central, round body), the cytoplasm (interior), and the plasma membrane (outer cell boundary). *Label Figure 3.8.*
4. Your epithelial slides are biohazardous, so they must be disposed of as indicated by your instructor.

---

**Euglena**

Examination of *Euglena* (a unicellular organism with a flagellum to facilitate movement) will test your ability to observe objects with the microscope, to use depth of field, and to control illumination to heighten contrast.

**Observation: Euglena**

1. Make a wet mount of *Euglena* by using a drop of a *Euglena* culture and adding a drop of Protosol (methyl cellulose solution) onto a slide. The Protosol slows the organism’s swimming.
2. Mix thoroughly with a toothpick, and add a coverslip.
3. Scan the slide for *Euglena*: Start at the upper left-hand corner, and move the slide forward and back as you work across the slide from left to right. The *Euglena* may be at the edge of the slide because they show an aversion to Protosol. *Use Figure 3.9 to help identify Euglena.*
4. Experiment by using scanning, low-power, and high-power objective lenses; by focusing up and down with the fine-adjustment knob; and by adjusting the light so that it is not too bright.
5. Compare your *Euglena* specimens with Figure 3.9. Can you distinguish between the anterior and posterior ends? (The anterior end has a red eye spot.) Does *Euglena* move forward or backward? Does *Euglena* have internal structures? *Figure 3.9 Euglena.*

*Euglena* is a unicellular, flagellated organism.
Microscopic Diagnoses

Microscopic examination of discharges, tissues, and the blood plays an important part of a physical exam. For example, your doctor may order a differential blood cell count when he or she believes it will help diagnose your illness. Or, he or she may microscopically examine a discharge if you may have a particular bacterial sexually transmitted disease (STD).

The Pap test, which women have during a routine gynecological exam, is a low-cost, easy microscopic examination of cells taken from the cervix located at the entrance to the womb. Pap tests look for abnormal cells in the lining of the cervix to determine if they are precancerous or cancerous. The more abnormal the appearance of the cells, the greater the concern (Fig. 3.10).

To do a Pap test, a physician merely takes a sample of cells from the cervix, which is then microscopically examined for signs of abnormality. Pap tests are credited with preventing over 90% of deaths from cervical cancer.

![Image of cell samples](image)

a. Cells are normal. 250x
b. Cells are precancerous. 250x
c. Cells are cancerous. 250x

Figure 3.10 Pap test.
A Pap test is a microscopic examination of cells from the cervix at the entrance to the womb. a. The cells are normal and cancer is not present. b. The cells are precancerous. c. The cells are abnormal and cancer is present.
Laboratory Review 3

1. Of the three types of microscopes studied, which one best shows the surface of an object?

2. The resolving power of a light microscope is lower than that of an __________ microscope.

3. What does compound refer to in the designation compound light microscope?

4. Which type of microscope would you use to view a Euglena swimming in pond water?

5. What are the ocular lenses?

6. Which objective always should be in place when beginning to use the microscope and also when putting it away?

7. A total magnification of 100× requires the use of the 10× ocular lens with which of the objective lenses?

8. Which part of a microscope controls the amount of light?

9. What word is used to indicate that if the object is in focus at low power it will also be in focus at high power?

10. If the thread layers are red, brown, green, from top to bottom, which layer will come into focus first if you are using the microscope properly? *?

11. What adjustment knob is used with high power?

12. If Euglena are swimming to the left, which way should you move your slide to keep them in view?

13. What is the final item placed on a wet mount before viewing with a light microscope?

14. What type of object do you study with a stereomicroscope?

Thought Questions

15. Why is a stereomicroscope also called a binocular dissecting microscope?

16. What is the advantage of focusing on different levels of an object?
4 Chemical Composition of Cells

Learning Outcomes

4.1 Carbohydrates
- Identify the test for the presence of starch and the test for the presence of sugars.
- Explain how monosaccharides, such as glucose, relate to disaccharides and polysaccharides.
Prelab Question: Why is it a good idea to avoid foods high in sugars?

4.2 Proteins
- Cite examples of typical structural and functional proteins, and describe their respective functions.
- Relate the manner in which amino acids join to form a polypeptide (protein).
- Identify the test for the presence of protein, and tell how to conduct the test.
Prelab Question: When testing a food for protein, what test might you use and how would you do the test?

4.3 Lipids
- State the structural composition of a common lipid, such as fat, and explain the difference between a naturally occurring saturated/unsaturated fat and a trans fat.
- Describe a simple test for the detection of fat.
Prelab Question: Why is butter solid at room temperature, while an oil is a liquid even when placed in the refrigerator?

4.4 Testing Foods and Unknowns
- Explain a procedure for testing the same food for all three components—carbohydrates, proteins, and fats.
Prelab Question: Explain why it would not be possible to use one test tube when testing a food for proteins, carbohydrates, and lipids all at once.

Application for Daily Living: Nutrition Labels

Introduction
The U.S. Food and Drug Administration is charged with the task of ensuring that our foods are safe and wholesome. Investigators and inspectors visit more than 15,000 facilities a year, overseeing that food products are not contaminated and are labeled truthfully. About 3,000 products a year are found to be unfit for consumers and are withdrawn from the marketplace, so the task of testing foods is a necessary one.

Food products contain three major components: proteins, carbohydrates, and lipids. Today you will learn how to test a food for the presence of these components. You will also learn how proteins, carbohydrates, and lipids are constructed and, therefore, why they give a positive result with particular reagents. A positive result indicates that a component is present, and a negative result indicates that a component is not present.
What is a Control?

The experiments in today’s laboratory have both a positive control and a negative control. The positive control goes through all the steps of the experiment and does contain the substance being tested. Therefore, positive results are expected. The negative control goes through all the steps of the experiment except it does not contain the substance being tested. Therefore, negative results are expected.

For example, if a test tube contains glucose (the substance being tested) and Benedict’s reagent (blue) is added, a red color develops upon heating. This test tube is the positive control; it tests positive for glucose. If a test tube does not contain glucose and Benedict’s reagent is added, Benedict’s is expected to remain blue. This test tube is the negative control; it tests negative for glucose.

What benefit is a positive control? Positive controls give you a standard by which to tell if the substance being tested is present (or acting properly) in an unknown sample. Negative controls ensure that the experiment is giving reliable results; after all, if a negative control should happen to give a positive result, then the entire experiment may be faulty and cannot be relied on.

4.1 Carbohydrates

Carbohydrates include starch, glycogen, and sugars. Starch and sugar are major components of baked goods, such as breads, cakes, and cookies. Flour contains starch, but starch does not taste sweet. The disaccharide, called sucrose, which does taste sweet, is often added to baked goods. Although we enjoy the sweet taste of sucrose, research has shown it is detrimental to our health. Researchers at the Harvard School of Public Health found that subjects who consumed sugar-sweetened sodas more than once per day for eight years exhibited an 80% increased risk of the illness diabetes mellitus. Also, they gained 17 pounds on the average, showing the link between sugar consumption and obesity. Obese individuals tend to suffer from cardiovascular disease more than those of normal weight.

Starch and Glycogen

When you digest your food, the starch component from plants is broken down to maltose and then maltose is digested to glucose, the sugar found in your blood (Fig. 4.1).

![Diagram showing the conversion of maltose to glucose]

Figure 4.1 Maltose, a disaccharide.

During a digestion reaction, the components of water are added, and the bond is broken. During a synthesis reaction, a bond forms between the two glucose molecules, the components of water are removed, and maltose results.

Your body stores excess glucose as glycogen, often called animal starch, in the liver. Both glycogen and starch are long chains of glucose molecules; therefore, they are polysaccharides (Fig. 4.2).
**Figure 4.2 Glycogen and starch.**
Glycogen is a polysaccharide composed of many glucose units as is starch. a. Photomicrograph of glycogen granules in liver cells. b. Structure of glycogen. Glycogen is a very branched molecule, while starch is not branched.

**Test for Starch**

Many foods contain starch. The test for starch is to add an iodine solution. If the substance contains starch, the color shifts from brown to a deep purple to black, as noted in Table 4.1. This positive result is explained thus: Iodine molecules lodge in the coiled structure of starch. This causes a change in the way that iodine molecules are able to reflect light and the color we observe.

**Experimental Procedure: Test for Starch**

In this procedure, you will be running a test for starch much as an employee of the Food and Drug Administration would do. Starch, as you know, is present in a number of different baked goods.

Before running the tests, answer these questions.

1. Choose which of these substances would be in a test tube if you detected starch: starch, albumin, water, iodine.

2. Which substances listed would you include in a negative-control test tube?

3. Why?

3. Why might you run another test using albumin in a test tube instead of a food expected to contain starch?

**The Procedure**

1. Label five clean test tubes (1 to 5).
2. Using the designated graduated transfer pipets, add 1 ml of the experimental solutions listed in Table 4.2 to the test tubes according to their numbers.
3. Then add five drops of iodine solution to the tubes at the same time.
4. Note the final color changes and record your observations in Table 4.2.
<table>
<thead>
<tr>
<th>Tube</th>
<th>Contents</th>
<th>Color</th>
<th>Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Starch suspension</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Water</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Potato juice</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Albumin solution</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Conclusions: Test for Starch**

- From your test results, draw conclusions about whether starch is present in each tube. Write these conclusions in Table 4.2. Explain your data and conclusions.

- Based on your results, is iodine a valid test for starch?

  Explain why.

**Experimental Procedure: Microscopic Study of Potato**

1. With a sharp razor blade, carefully slice a very thin piece of potato. Place it on a microscope slide, add a drop of water and a coverslip, and observe under low power with your compound light microscope. Compare your slide with the photomicrograph of starch granules (Fig. 4.3). Find the cell wall (large, geometric compartments) and the starch grains (numerous clear, oval-shaped objects).

2. Without removing the coverslip, place two drops of iodine solution onto the microscope slide so that the iodine touches the coverslip. Draw the iodine under the coverslip by placing a small piece of paper towel in contact with the water on the opposite side of the coverslip.

3. Microscopically examine the potato again on the side closest to where the iodine solution was applied.

   What is the color of the small oval bodies?

   What is the chemical composition of these oval bodies?

   ![Figure 4.3 Starch. Photomicrograph of starch granules in potato cells.](image)
**Test for Sugars**

Monosaccharides and some disaccharides will react with Benedict’s reagent after being heated in a boiling water bath. The color change can range from green to red, and increasing concentrations of sugar will give a continuum of colored products (Table 4.3). This experiment tests for the presence (or absence) of varying amounts of sugars in a variety of materials and chemicals.

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Chemical Category</th>
<th>Benedict’s Reagent (After Heating)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>Inorganic</td>
<td>Blue (no change)</td>
</tr>
<tr>
<td>Glucose</td>
<td>Monosaccharide (carbohydrate)</td>
<td>Varies with concentration: very low—green low—yellow moderate—yellow-orange high—orange very high—orange-red</td>
</tr>
<tr>
<td>Maltose</td>
<td>Disaccharide (carbohydrate)</td>
<td>Varies with concentration—see “Glucose”</td>
</tr>
<tr>
<td>Starch</td>
<td>Polysaccharide (carbohydrate)</td>
<td>Blue (no change)</td>
</tr>
</tbody>
</table>

**Experimental Procedure: Test for Sugars**

1. Prepare a boiling water bath and label five clean test tubes (1 to 5).
2. Using the designated graduated transfer pipets, add 1 ml of the experimental solutions listed in Table 4.4 to the test tubes according to their numbers.
3. Then add five drops of Benedict’s reagent to all the tubes at this time.
4. Place all the tubes into the boiling water bath at the same time.
5. When, after a few minutes, you see a change of colors, remove all the tubes from the water bath and record your observations in Table 4.4.
6. Save your tubes for comparison purposes when you do Section 4.4.

**Benedict’s reagent** Benedict’s reagent is highly corrosive. Exercise care in using this chemical. If any should spill on your skin, wash the area with mild soap and water. Follow your instructor’s directions for disposal of this chemical.
### Table 4.4 Benedict’s Reagent Test

<table>
<thead>
<tr>
<th>Tube</th>
<th>Contents</th>
<th>Color (After Heating)</th>
<th>Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Glucose solution</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Water</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Onion juice</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Starch suspension</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Conclusions: Test for Sugar**

- From your test results, conclude whether sugar is present and enter your conclusions in Table 4.4. Explain your data and conclusions.

- Based on your results, is Benedict’s reagent a valid test for sugar? Explain.

---

### 4.2 Proteins

Proteins have numerous functions in cells. Some are present for functional reasons, and others provide structural integrity.

- **Antibodies** are functional proteins that combine with disease-causing pathogens as part of the body’s immune response.
- **Transport proteins** combine with and move substances from place to place. Hemoglobin packed inside red blood cells transports oxygen throughout the body. Albumin is another protein in our blood that performs several important roles including fatty acid transport.
- **Regulatory proteins** control cellular metabolism in some way. For example, the hormone insulin regulates the amount of glucose in blood so that cells have a ready supply of energy.
- **Enzymatic proteins** speed chemical reactions. A reaction that could take days or weeks to complete can happen within an instant if the correct enzyme is present. Amylase is an enzyme that speeds the breakdown of starch in the mouth and small intestine.
- **Structural proteins** include keratin, found in hair, and myosin, found in muscle.

### Amino Acids and Peptides

Proteins are long chains of amino acids joined together. About 20 different common amino acids are found in cells. All amino acids have an acidic group (—COOH) and an amino group (H₂N—), each linked to a central carbon by a separate covalent bond. Amino acids differ by the **R group** (rest of molecule) attached to the central carbon atom. The **R** groups have varying compositions, sizes, shapes, and chemical activities.
A chain of two or more amino acids is called a peptide, and the bond between the two amino acids is called a peptide bond (Fig. 4.4). A polypeptide is a long chain of amino acids. A protein can be comprised of one or more polypeptides. When you digest your food, the protein component is broken down to amino acids, and then your body uses these amino acids to synthesize peptides and your proteins.

Figure 4.4 Peptide bond.
Peptide bond formation between amino acids creates a dipeptide. In a polypeptide, many amino acids are held together by multiple peptide bonds. During a digestion reaction, water is added, and the peptide bond is broken. The synthesis reaction involves the removal of one water molecule.

Test for Proteins

Biuret reagent (blue color) contains a strong solution of sodium or potassium hydroxide (NaOH or KOH) and a small amount of dilute copper sulfate (CuSO₄) solution. The reagent changes color in the presence of proteins or peptides because the peptide bonds of the protein or peptide chemically combine with the copper ions in Biuret reagent. In this reaction, two positive results are possible as described in Table 4.5. The copper ions react with amino groups, deforming polypeptide chains and causing a resultant change in color.

⚠️ Biuret reagent. Biuret reagent is highly corrosive. Exercise care in using this chemical. If any should spill on your skin, wash the area with mild soap and water. Follow your instructor's directions for its disposal.

| Table 4.5. Positive Test for Protein and Peptides |
|---------------------------------|----------------|
| Protein                        | Peptides       |
| Biuret reagent (blue)          | Purple         |
|                                 | Pinkish-purple |

If a positive result occurs and protein is present, what color will appear after using the Biuret test?

If a negative result occurs and protein is not present, what color will remain after using the Biuret test?
**Experimental Procedure: Test for Proteins**

In this procedure you will be running a test for protein, much as an employee of the Food and Drug Administration would do. Egg white is composed of the protein called *albumin*. Therefore, albumin can be present in a number of different foods.

Before running the tests, answer these questions.

1. Which of these substances would be in the test tube if you detected protein? albumin, starch, water, Biuret reagent.

2. Which substances listed would you include in a negative-control test tube?
   Why?

3. Why might you run another test using starch in the test tube instead of the food expected to contain protein?
   If the results were negative, would it suggest that Biuret reagent is specific for protein?

**The Procedure**

1. Label three clean test tubes (1 to 3).
2. Using the designated graduated transfer pipets, add 1 ml of the experimental solutions listed in Table 4.6 to the test tubes according to their numbers.
3. Then add five drops of Biuret reagent to the tubes, with swirling to mix.
4. The reaction is almost immediate. Record your observations in Table 4.6.

**Table 4.6 Biuret Test**

<table>
<thead>
<tr>
<th>Tube</th>
<th>Contents</th>
<th>Final Color</th>
<th>Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Protein</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Distilled water</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Starch suspension</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Conclusions: Test for Proteins**

- From your test results, did you conclude that protein is present in any of the three test solutions? Enter your conclusions in Table 4.6. Explain your data and conclusions.

- Based on your results, is Biuret reagent a valid test for protein?
  Explain why.
4.3 Lipids

A number of different molecules, including fats and oils, are grouped together as lipids because they are insoluble in water. Fats and oils differ by their fatty acid content. A fatty acid consists of a long hydrocarbon chain and ends in an acid group (Fig. 4.5). The hydrocarbon chain can have bonds that differ like this:

\[
\begin{align*}
\text{Saturated} & \quad \text{Unsaturated} & \quad \text{Trans fats} \\
\text{(butter)} & \quad \text{(oils)} & \quad \text{(hydrogenated oils)}
\end{align*}
\]

A saturated fatty acid has no double bonds between the carbon atoms, while an unsaturated fatty acid does have double bonds between certain of the carbon atoms. Saturated fatty acids are found in a solid fat, such as butter, whereas unsaturated fatty acids are found in liquid oils. They are liquid because the double bond creates a kink that prevents close packing of hydrocarbon chains. Saturated fats, but not unsaturated oils, encourage the development of plaque in the arteries of the body, leading to cardiovascular disease. Even more harmful than naturally occurring saturated fats are the so-called trans fats, found in vegetable oils that have been partially hydrogenated to make them more solid. Partial hydrogenation does not saturate all bonds. Instead, some hydrogen atoms end up on different sides of the chain. Processed and fast foods are apt to contain trans fats.

**Fats and Oils**

When you digest your food, fats and oils are broken down to one molecule of glycerol and three fatty acids (Fig. 4.5). Later, your body rejoins these molecules to form fat, which is a long-term energy source.

**Figure 4.5** A fat.

During a digestion reaction, water is added, and the bonds are broken. A fat molecule forms when glycerol joins with three fatty acids as three water molecules are removed during a synthesis reaction.
Test for Fats and Oils

Fats and oils do not evaporate from brown paper; instead, they leave an oily spot.

Experimental Procedure: Test for Fats and Oils

1. Place a small drop of water on a square of brown paper. Describe the immediate effect. *

2. Place a small drop of vegetable oil on a square of brown paper. Describe the immediate effect.

3. Wait at least 15 minutes for the paper to dry. Evaluate which substance penetrates the paper and which is subject to evaporation. Record your observations in Table 4.7.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Observations</th>
<th>Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water spot</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Oil spot</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Emulsification of Lipids

Some molecules are polar, meaning that they have charged groups or atoms, and some are nonpolar, meaning that they have no charged groups or atoms. A water molecule is polar; therefore, water is a good solvent for other polar molecules. When the charged ends of water molecules interact with the charged groups of polar molecules, these polar molecules disperse in water.

Water is not a good solvent for nonpolar molecules, such as fats. A fat has no polar groups to interact with water molecules. An emulsifier, however, can cause a fat to disperse in water. An emulsifier contains molecules with both polar and nonpolar ends. When the nonpolar ends interact with the fat and the polar ends interact with the water molecules, the fat disperses in water, and an emulsion results (Fig. 4.6).

Bile salts (emulsifiers found in bile produced by the liver) are used in the digestive tract. Commercially produced emulsifiers include the wetting agent Tween and detergents. Today milk, such as 1% milk, has been homogenized so that fat droplets do not congregate and rise to the top of the container. Phospholipids are natural emulsifiers that are added to milk.

Figure 4.6 Emulsification.

An emulsifier contains molecules with both a polar and a nonpolar end. The nonpolar ends are attracted to the nonpolar fat, and the polar ends are attracted to the water. This causes droplets of fat molecules to disperse.

*To test an unknown for fats and oils, use this procedure. Instead of water, use the unknown. If fats and oils are present, an oily spot appears.
Experimental Procedure: Emulsification of Lipids

Label three clean test tubes 1 to 3. Using the appropriate graduated transfer pipets add solutions to the test tubes as follows:

**Tube 1**
1. Add 3 ml of water and 1 ml of vegetable oil. Shake.
2. Observe for the initial dispersal of oil, followed by rapid separation into two layers.
   Is vegetable oil soluble in water? ________________________________________________________________________________________
3. Let the tube settle for 5 minutes. Label a microscope slide as 1.
4. Use a dropper to remove a sample of the solution that is just below the layer of oil. Place the drop on the slide, add a coverslip, and examine with the low power of your compound light microscope.
5. Record your observations in Table 4.8.

**Tube 2**
1. Add 2 ml of water, 3 ml of vegetable oil, and 1 ml of the available emulsifier. (Tween or bile salt solution) Shake.
2. Describe how the distribution of oil in tube 2 compares with the distribution in tube 1:
   ______________________________________________________________________________________________________________________
3. Let the tube settle for 5 minutes. Label a microscope slide as 2.
4. Use a different dropper to remove a sample of the solution that is just below the layer of oil. Place the drop on the slide, add a coverslip, and examine with the low power of your compound light microscope.
5. Record your observations of the slides in Table 4.8.

**Tube 3**
1. Add 1 ml of milk and 2 ml of water. Shake well. Label a microscope slide as 3.
2. Use a different dropper to remove a sample of solution. Place a drop on a slide, add a coverslip, and examine with the lower power of your compound light microscope.
3. Record your observations in Table 4.8.

<table>
<thead>
<tr>
<th>Table 4.8: Emulsification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tube</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td></td>
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<tr>
<td></td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

**Conclusion: Emulsification of Lipids**

- From your observations, conclude why the contents of each tube appear as they do under the microscope. Record your conclusions in Table 4.8.
- Explain the correlation between your macroscopic observations (how the tubes look to your unaided eye) and your microscopic observations.
4.4 Testing Foods and Unknowns

It is common for us to associate the term organic with the foods we eat, including carbohydrate foods (Fig. 4.7), lipid foods (Fig. 4.8), and protein foods (Fig. 4.9). Though we may recognize foods as being organic, often we are not aware of what specific types of compounds are found in what we eat. In the following Experimental Procedure, you will use the same tests you used previously to determine the composition of everyday foods (unknowns).

![Carbohydrate foods.](Figure 4.7)  ![Lipid foods.](Figure 4.8)  ![Protein foods.](Figure 4.9)

**Experimental Procedure: Testing Foods and Unknowns**

Your instructor will provide you with several everyday foods including unknowns and your task is to:

1. Develop instructions for a procedure that will allow you to test the foods for carbohydrates (pages 37 and 39), proteins (page 42), and lipids (page 44) using the tests from this laboratory manual.

2. Have your instructor okay your procedure, and then conduct the necessary tests.
3. Record your results as positive or negative in Table 4.9.

**Conclusions: Testing Foods and Unknowns**

- Did any food test positive for only one of the organic compounds? Explain.

- What types of foods would you expect to test positive for more than one of the organic compounds studied in this laboratory?

- What type of carbohydrate might be found in an unknown that tests positive for the iodine test but negative for the Benedict’s test?
Table 4.9  Testing Foods and Unknowns

<table>
<thead>
<tr>
<th>Sample Name</th>
<th>Starch (Iodine)</th>
<th>Sugar (Benedict's)</th>
<th>Protein (Bluret)</th>
<th>Lipid (Brown Paper)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Results:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conclusion:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Results:</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Conclusion:</td>
<td></td>
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</tr>
</tbody>
</table>

Application for Daily Living

**Nutrition Labels**

For good health, the diet should be balanced and should not contain an overabundance of either protein, carbohydrate, or fat. Everyone should become familiar with reading nutrition labels. A portion of one is shown in Figure 4.10.

It is very important to note the serving size and servings per container. For comparison purposes, you need to compare the same serving sizes. The % daily values are based on an intake of 2,000 calories per day. A calorie is an indication of the amount of energy provided, and the number of calories taken in should match the number required per day, unless you wish to gain weight.

Most people are extremely interested in the amount of fat provided by a food. One serving of this food provides 18% of the total fat required for the day. If you find this excessive, you could look for another macaroni and cheese that supplies less total fat and less saturated fat. If you decide that you prefer this product, you might wish to balance it with a food that contains very little fat and one that provides a carbohydrate that contains fiber. This food contains no fiber. Complex carbohydrates containing fiber, such as those found in whole grains, are recommended and not those that contain simply starch.

Making wise decisions about the foods we buy can lead to a longer, healthier life.

**Figure 4.10**  Sample nutrition label for macaroni and cheese.

As of January 2006, foods must include the quantity of trans fat. There is no % Daily Value for trans fats, and they should be avoided. See page 43.
Laboratory Review 4

1. What type of bond joins amino acids to make peptides?
2. What type of protein speeds chemical reactions?
3. What group is different between types of amino acids?
4. If iodine solution turns blue-black, what substance is present?
5. If Benedict's reagent turns red, what substance is present?
6. When you digest food, starch is broken down to what molecule?
7. Is starch a monosaccharide or a polysaccharide?
8. What is the function of fat in humans?
9. What molecules are released when fat undergoes digestion?
10. What type of organic molecule is not soluble in water?
11. Name two organic molecules that are acids.
12. If Biuret reagent turns purple, what substance is present?
13. A student adds iodine solution to egg white and waits for a color change. How long will the student have to wait?
14. To test whether a sample contains glucose, what test should be done?

Thought Questions

15. Why is it necessary to shake a bottle of salad dressing before adding it to a salad?

16. An unknown sample is tested with both Biuret reagent and Benedict's reagent. Both tests result in a blue color. What has been learned? Why are these called negative results?

17. Starch and water are mixed together as ingredients for making gravy. Why doesn't starch automatically react with water to produce monosaccharides?
5

Cell Structure and Function

Learning Outcomes

5.1 Anatomy of a Human Cell
- Using a model or drawing, identify the parts of a human cell and state a function for each part.
  Prelab Question: Why is it beneficial for different parts of the cell to have specific functions?

5.2 Diffusion of Solutes
- Describe the process of diffusion as a physical phenomenon independent of the plasma membrane.
- Predict which solutes can cross the plasma membrane by diffusion and which cannot cross the plasma membrane by diffusion.
  Prelab Question: Why is it beneficial for cellular substances to cross the plasma membrane by diffusion?

5.3 Osmosis: Diffusion of Water Across the Plasma Membrane
- Define osmosis and explain the movement of water across a membrane.
- Define isotonic, hypertonic, and hypotonic solutions and give examples in terms of NaCl concentrations.
- Predict the effect that solutions of different tonicitities have on red blood cells.
  Prelab Question: Why is 0.9% the usual tonicity of intravenous solutions?

5.4 Enzyme Activity
- Explain how enzymes have the ability to speed chemical reactions in cells.
- List some factors that can affect the speed of enzymatic reactions.
  Prelab Question: Why is a warm body temperature advantageous to metabolism?

Application for Daily Living: Dehydration and Water Intoxication

Introduction

We are accustomed to observing the outward appearance of human beings and rarely have an opportunity to become aware that humans are composed of small entities called cells. Though we often think that the heart, liver, or intestines enable the human body to function, it is actually cells that do the work of these organs. In Laboratory 3, you observed human cheek cells (see Figure 3.8) using a compound light microscope. The much more powerful electron microscope led to the discovery that cells are actually very complicated because they contain many organelles that carry out enzymatic functions.

The model of an animal cell available in the laboratory is based on electron micrographs. In today’s laboratory, we review the structure and function of organelles, subcompartments of a cell, before actually observing how its outer surface, the plasma membrane, serves as a selective regulator of what enters and exits cells. We will discover that the passage of water into a cell depends on the difference in concentration of solutes (particles) between the cytoplasm (contents of a cell) and the surrounding medium or solution.

Enzymes are proteins that carry out metabolic reactions within organelles, and we will have an opportunity to marvel at the rapidity of an enzymatic reaction, even at room temperature.
5.1 Anatomy of a Human Cell

Figure 5.1 shows that an animal cell is partitioned into a number of compartments. Just like a house works more efficiently when each room has a specialized function, so does a cell with different compartments for varied functions.

Figure 5.1 Human (animal) cell.

- **Plasma membrane:** outer surface that regulates entrance and exit of molecules
- **Phospholipid**
- **Cytoskeleton:** maintains cell shape and assists movement of cell parts
- **Microtubules:** cylinders of protein molecules present in cytoplasm, centrioles, cilia, and flagella
- **Intermediate filaments:** protein fibers that provide support and strength
- **Actin filaments:** protein fibers that play a role in movement of cell and organelles
- **Centrioles:** short cylinders of microtubules
- **Centrosome:** microtubule-organizing center that contains a pair of centrioles
- **Vesicles:** membrane-bounded sacs that stores and transports substances
- **Lysosomes:** vesicle that digests macromolecules and even cell parts
- **Cytoplasm:** semifluid matrix outside nucleus that contains organelles
- **Nucleus:**
  - **Nuclear envelope:** double membrane with nuclear pores that encloses nucleus
  - **Chromatin:** diffuse threads containing DNA and protein
  - **Nucleolus:** region that produces subunits of ribosomes
- **Endoplasmic Reticulum:**
  - **Rough ER:** studded with ribosomes, processes proteins
  - **Smooth ER:** lacks ribosomes, synthesizes lipid molecules
- **Ribosomes:** particles that carry out protein synthesis
- **Mitochondrion:** organelle that carries out cellular respiration, producing ATP molecules
- **Polyribosome:** string of ribosomes simultaneously synthesizing same protein
- **Golgi apparatus:** processes, packages, and secretes modified cell products
## Learning the Organelles of the Cell

Identify these parts of a cell:

### Composition and Function

<table>
<thead>
<tr>
<th>Number</th>
<th>Description</th>
<th>Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Stack of membranous saccules; functions in processing, packaging, and distribution of molecules</td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>Membranous sacs; storage and transport of substances</td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>Have a double membrane; responsible for cellular respiration and production of ATP molecules</td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>Particles that carry out protein synthesis</td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>Outer surface that regulates entrance and exit of molecules</td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td>Region in nucleus that produces subunits of ribosomes</td>
<td></td>
</tr>
<tr>
<td>7.</td>
<td>Short cylinders, present in centrosomes, of unknown function</td>
<td></td>
</tr>
<tr>
<td>8.</td>
<td>Central body, having diffuse threads of DNA and protein</td>
<td></td>
</tr>
<tr>
<td>9.</td>
<td>Vesicle that digests macromolecules and even cell parts</td>
<td></td>
</tr>
<tr>
<td>10.</td>
<td>Composed of microtubules, actin filaments, and intermediate filaments; responsible for the shape of the cell and movement of its parts</td>
<td></td>
</tr>
<tr>
<td>11.</td>
<td>Membranous saccules and canals having no ribosomes; synthesizes lipid molecules</td>
<td></td>
</tr>
</tbody>
</table>

### Learning That the Organelles Work Together

1. Imagine that this cell produces digestive enzymes that are sent to the digestive tract:
   - a. Which part of the endoplasmic reticulum would produce these enzymes? ____________________
   - b. How would they be transported to another part of the cell? ____________________
   - c. Which organelle would process and package these enzymes for export? ____________________

2. Imagine that this cell produces a sex hormone (a lipid molecule):
   - a. Which part of the endoplasmic reticulum would produce these lipid molecules? ____________________
   - b. How would they be transported to another part of the cell? ____________________
   - c. Which organelle would process and package this hormone for export? ____________________

3. The nucleus produces the subunits of ribosomes.
   - a. Where in the nucleus are the subunits produced? ____________________
   - b. What part of the nuclear envelope allows them to get out of the nucleus? ____________________
   - c. Where do the subunits go and what happens to them? ____________________

4. How a cell breaks down engulfed substances.
   - a. *Label Figure 5.1* where a vesicle is forming in order to take in a substance that will be digested.
   - b. This vesicle will fuse with a ___________ that contains digestive enzymes.
5.2 Diffusion of Solutes

Diffusion is the random movement of molecules from the area of higher concentration to the area of lower concentration until they are equally distributed. A solution contains a molecule called the solute dissolved in a solvent (a liquid, most often water).

Environmental Factors and Diffusion of Molecules

If you spray a deodorant in one corner of the room, it will soon spread to fill the room because diffusion has occurred. (Notice, therefore, that diffusion can occur independently of a plasma membrane.) Environmental factors such as temperature and the resistance of the medium can affect the speed of diffusion. Air offers little resistance to random motion of molecules, followed by a liquid, and then by any type of a solid.

Observation: Environmental Factors and Diffusion

You will calculate the speed of diffusion (1) through a semisolid gel and (2) through a liquid. Hypothesize whether you expect diffusion to occur faster through a semisolid or through a liquid, and give a reason for your hypothesis.

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Diffusion Through a Semisolid

1. Observe a petri dish containing 1.5% gelatin (or agar) to which a crystal of potassium permanganate (KMnO₄) was added previously (time zero) in the center depression.

2. Obtain time zero from your instructor and record time zero and the final time (now) in Table 5.1. Calculate the length of time in hours and minutes; then convert the entire time to hours. _______________ hr

3. Using a ruler placed over the petri dish, measure (in mm) the movement of color from the center of the depression outward in one direction. _______________ mm

4. Calculate the speed of diffusion. _______________ mm/hr (Divide the number of millimeters by the number of hours.)

5. Record all data in Table 5.1.

Diffusion Through a Liquid

1. Add water to a glass petri dish.

2. Place the petri dish over a thin, flat ruler.

3. With tweezers, add a crystal of potassium permanganate (KMnO₄) directly over a millimeter measurement line. Note time zero in Table 5.1.

4. After 10 minutes, note the distance the color has moved (Fig. 5.2). Record the final time, length of time, and distance moved in Table 5.1.

5. Calculate the speed of diffusion by multiplying the length of time and the distance moved by 6. _______________ mm/hr. Record in Table 5.1.

---

Figure 5.2 Process of diffusion.

Diffusion is apparent when dye molecules have equally dispersed.

- b. Dye molecules diffuse.
- c. Dye molecules are evenly distributed.
<table>
<thead>
<tr>
<th>Table 5.1</th>
<th>Speed of Diffusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medium</td>
<td>Time Zero</td>
</tr>
<tr>
<td>Semisolid</td>
<td></td>
</tr>
<tr>
<td>Liquid</td>
<td></td>
</tr>
</tbody>
</table>

**Conclusions: Diffusion**

- Why did the dye molecules move rather than stay where they were originally?
- In which experiment was diffusion the fastest?
- What accounts for the difference in speed?

**The Plasma Membrane and Diffusion of Molecules**

The plasma membrane regulates the passage of molecules into and out of cells. It is said to be **selectively permeable**, because only small, noncharged molecules can diffuse across the plasma membrane without assistance (Fig. 5.3a). Carriers, proteins embedded in plasma membrane, can assist the passage of molecules across a membrane. Each carrier is specific to a particular molecule. During facilitated transport, a carrier (or a channel protein) assists a molecule diffusing across the membrane (Fig. 5.3b). During active transport, a carrier assists a molecule moving the opposite to diffusion: from lower concentration outside the cell to higher concentration inside the cell and energy is required (Fig. 5.3c). In other words, energy is not required when a molecule is diffusing down its concentration gradient and, otherwise, energy is required.

**Figure 5.3** Passage of molecules across a plasma membrane.

- **a.** During diffusion, molecules move from the higher to the lower concentration. **b.** During facilitated transport, carrier proteins transport molecules from the higher to the lower concentration. **c.** During active transport, molecules move from the lower to the higher concentration; a protein carrier and energy are required.
**Experimental Procedure: The Plasma Membrane and Diffusion of Solute**

In this experiment, an artificial membrane is used to simulate the plasma membrane; the artificial membrane is also semipermeable. Only certain molecules can cross the membrane. The artificial membrane contains no carriers to assist the movement of molecules across the membrane.

Notice in Figure 5.4 that at the start of this experiment, glucose (small molecule) and starch (large molecule) will be inside the membranous bag and iodine (small molecule) will be outside the bag. Hypothesize which molecules will cross the membrane and in which direction they will move.

- to inside the bag ____________________________
- to outside the bag ____________________________

![Figure 5.4 Diffusion experiment.](image)

**Diffusion Through a Selectively Permeable Membrane**

At the start of this experiment:

1. Cut a piece of membranous tubing approximately 40 cm (approximately 16 in) long. Soak the tubing in water until it is soft and pliable.
2. Close one end of the tubing with two knots.
3. Fill the bag halfway with glucose solution.
4. Add four full droppers of starch suspension to the bag.
5. Hold the open end while you mix the contents of the bag. Rinse off the outside of the bag with water.
6. Record the color of the bag contents in Table 5.2.
7. Fill a beaker 2/3 full with water.
8. Add droppers of iodine solution (IKI) to the water in the beaker until an amber (tealike) color is apparent.
9. Record the color of the solution in the beaker in Table 5.2.
10. Place the bag in the beaker with the open end hanging over the edge. Secure the open end of the bag to the beaker with a rubber band as shown (Fig. 5.4). Make sure the contents do not spill into the beaker.
After about 5 minutes, at the end of the experiment:

11. You will note a color change. Record the present color of the bag contents and the beaker contents in Table 5.2.

12. Obtain a small test tube. Using a graduated transfer pipet, draw 1 ml from the bottom of the beaker (near the bag) and place it in the test tube. Using a designated transfer pipet, add 3 ml of Benedict’s reagent. Heat in a boiling water bath for 5 to 10 minutes, observe any color change, and record your results as positive or negative in Table 5.2. (Optional use of glucose test strip: Dip glucose test strip into beaker. Compare stick with chart provided by instructor.)

13. Remove the dialysis bag from the beaker. Dispose of it and the used Benedict’s reagent solution in the manner directed by your instructor.

<table>
<thead>
<tr>
<th>Table 5.2: Solute Diffusion Through a Membrane</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>At Start of Experiment</strong></td>
</tr>
<tr>
<td><strong>Contents</strong></td>
</tr>
<tr>
<td>Bag</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Beaker</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

Conclusions: Plasma Membrane and Diffusion of Solutes

- Based on the color change noted in the bag, conclude what molecule diffused across the membrane from the beaker to inside the bag, and record your conclusion in Table 5.2.
- From the results of the Benedict’s test on the beaker contents, conclude what molecule diffused across the membrane from the bag to the beaker, and record your conclusion in Table 5.2.
- Which molecule did not diffuse across the membrane from the bag to the beaker? Explain.

5.3 Osmosis: Diffusion of Water Across the Plasma Membrane

Osmosis is the diffusion of water molecules across a selectively permeable membrane. Like other molecules, water follows its concentration gradient and moves from a region of higher concentration to a region of lower concentration. A new finding has been that water passes through a channel protein called an aquaporin because of its specificity. Therefore, osmosis (the diffusion of water) is a form of facilitated transport.

Tonicity is the relative concentration of solute (e.g., salt molecules) and solvent (water molecules) outside the cell compared to inside the cell. An isotonic solution has the same concentration of solute (and therefore of water) as the cell. When cells are placed in an isotonic solution, there is no net movement of water. A hypertonic solution has a higher solute (therefore, lower water) concentration than the cell. When cells are placed in a hypertonic solution, water moves out of the cell into the solution. A hypotonic solution has a lower solute (therefore, higher water) concentration than the cell. When cells are placed in a hypotonic solution, water moves from the solution into the cell.

The next two Experimental Procedures explore tonicity using potato strips and red blood cells.

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1Percent solutions are grams of solute per 100 ml of solvent. Therefore, a 10% solution is 10 g of sugar with water added to make up 100 ml of solution.
**Experimental Procedure: Tonicity and Potato Strips**

This procedure runs for 1 hour. Prior setup can maximize your time efficiency.

1. Cut two strips of potato, each about 7 cm long and 1 1/2 cm wide.
2. Label two test tubes 1 and 2. Place one potato strip in each tube.
3. Fill tube 1 with water to cover the potato strip.
4. Fill tube 2 with 10% sodium chloride (NaCl) to cover the potato strip. NaCl is table salt.
5. After 1 hour, observe each strip for limpness (water loss) or stiffness (water gain). Which tube has the limp potato strip? __________ Why did water diffuse out of the potato strip? __________
   Which tube has the stiff potato strip? __________ Why did water diffuse into the potato strip? __________

---

**Red Blood Cells (Animal Cells)**

A solution of 0.9% NaCl is isotonic to red blood cells. In such a solution, red blood cells maintain their normal appearance (Fig. 5.5a). A solution greater than 0.9% NaCl is hypertonic to red blood cells. In such a solution, the cells shrink up, a process called **crenation** (Fig. 5.5b). A solution of less than 0.9% NaCl is hypotonic to red blood cells. In such a solution, the cells swell to bursting, a process called **hemolysis** (Fig. 5.5c).

Complete Table 5.3 by following these instructions. In the second column, state whether the solution is isotonic, hypertonic, or hypotonic to red blood cells. In the third column, hypothesize the effect on the shape of the cell after being in this solution. In the fourth column, explain why you hypothesized this outcome. Base your explanation on the movement of water.

<table>
<thead>
<tr>
<th>Concentration (NaCl)</th>
<th>Tonicity</th>
<th>Effect on Cells</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.9%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Higher than 0.9%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower than 0.9%</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

**Figure 5.5  Tonicity and red blood cells.**

- **a. Isotonic solution.** Red blood cell has normal appearance due to no net gain or loss of water.
- **b. Hypertonic solution.** Red blood cell shrivels due to loss of water.
- **c. Hypotonic solution.** Red blood cell fills to bursting due to gain of water.
Experimental Procedure: Tonicity and Red Blood Cells

Three numbered and stoppered test tubes are on display. Each test tube contains NaCl and a few drops of blood.

1. Shake each tube as shown in Figure 5.6a. Then place the tube in front of your lab manual as shown in Figure 5.6b. Determine whether you can see the print on the page and record your decision under Print Visibility in Table 5.4.

2. Dependent on how difficult it is to see the print, which tube is hypotonic (less than 0.9% NaCl), hypertonic (10% NaCl), or isotonic (0.9% NaCl)? Record your deduction under Tonicity in Table 5.4.

3. In the last column of Table 5.4, explain how you arrived at this deduction.

<table>
<thead>
<tr>
<th>Table 5.4 Print Visibility and Tonicity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tube</td>
</tr>
<tr>
<td>--------</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
</tbody>
</table>

Figure 5.6 Proof of hemolysis.
a. Shake the tube as shown here. b. Once the red blood cells burst, you can read print placed behind a tube of diluted blood.
5.4 Enzyme Activity

Enzymes are organic catalysts that speed metabolic reactions, either degradation or synthesis (Fig. 5.7). Each enzyme has a three-dimensional shape that accommodates its substrate(s), the reactant(s) in the enzyme’s reaction. This shape, therefore, determines the specificity of the enzyme and is important to the action of the enzyme. Although the shape of the enzyme and its substrate are compatible, the favored model for enzyme action suggests that the enzyme initially interacts with its substrate, changes shape slightly to improve the interaction, and then proceeds with a more efficient reaction. Certain environmental effects ensure that enzymes can function speedily. A warm temperature, sufficient enzyme and substrate concentrations, and the correct pH (whether the solution should be acidic, basic, or neutral) are all important. Each enzyme has a pH at which the speed of the reaction is optimum. Any pH higher or lower than the optimum affects the shape of the enzyme, leading to reduced activity.

Experiment with the Enzyme Catalase

In the Experimental Procedure that follows, you will be working with the enzyme catalase. Catalase is present in cells, where it speeds the breakdown of the toxic chemical hydrogen peroxide (H₂O₂) to water and oxygen:

\[
2\text{H}_2\text{O}_2 \xrightarrow{\text{catalase}} 2\text{H}_2\text{O} + \text{O}_2
\]

In this example, the enzyme is catalase; the substrate that fits within the active site of the enzyme is hydrogen peroxide; and the products are water and oxygen. Catalase performs a useful function in organisms because hydrogen peroxide is harmful to cells. Hydrogen peroxide is a powerful oxidizer that can attack and denature cellular molecules such as DNA. Knowing its harmful nature, humans use hydrogen peroxide as a commercial antiseptic to kill germs. In reduced concentration, hydrogen peroxide is a whitening agent used to bleach hair and teeth. It is also used industrially to clean most anything from tubs to sewage.

Experimental Procedure: Catalase Activity

This Experimental Procedure tests the effects of pH on the activity of catalase. Potato will be the source of catalase. As the reaction occurs, easily observable bubbling will develop. Label two clean test tubes and use the appropriate graduated transfer pipets to follow these directions.

**Tube 1**
1. Add 2 ml of distilled water to Tube 1. (This is neutral pH.)
2. Macerate a cube (1 cc) of potato using a mortar and pestle. Transfer to the tube.
3. Wait 3 minutes.
4. Add 4 ml of hydrogen peroxide. Record bubbling in Table 5.5 using 0 (no bubbling) or + signs (e.g., +, ++, ++++, most bubbling).

**Tube 2**
1. Carefully add 2 ml of hydrochloric acid (5M HCl) to this tube.
2. Macerate a cube (1 cc) of potato using a mortar and pestle. Transfer to the tube.
3. Wait 3 minutes.
4. Add 4 ml hydrogen peroxide. Record the degree of bubbling in Table 5.5.
### Table 5.5 Effect of pH on Catalase Activity

<table>
<thead>
<tr>
<th>Tube</th>
<th>Contents</th>
<th>Bubbling*</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Distilled water</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Potato, macerated</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hydrogen peroxide</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Hydrochloric acid</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Potato, macerated</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hydrogen peroxide</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Ignore large bubbles and look for small bubbles.

### Conclusions: Catalase Activity
- Give explanations for your results in Table 5.5.
- From your test results, decide whether enzymes can be negatively affected by environmental conditions and explain your answer.

### Application for Daily Living

#### Dehydration and Water Intoxication

Most people have heard of dehydration, but they may not realize that dehydration occurs because blood has become hypertonic to cells and, in response, the cells lose water. Dehydration can be due to excessive sweating, perhaps during exercise, or it can be a side effect of many illnesses that cause prolonged vomiting or diarrhea. The signs of moderate dehydration are a dry mouth, sunken eyes, and skin that will not bounce back after light pinching. Most people have never heard of water intoxication, which occurs when blood becomes hypotonic to cells. In response to hypotonicity, cells gain water. Water intoxication can lead to pulmonary edema (the lungs gain water) and swelling in the brain. In extreme cases, it is fatal. It can be due to an intake of too much pure water during vigorous exercise, such as a marathon race. The cure is introducing an intravenous solution containing high amounts of sodium in a hospital setting. To prevent both dehydration and water intoxication, athletes should replace lost fluids slowly. Pure water is a good choice if the exercise period is short. Low-sodium solutions, such as sports drinks, are a good choice for longer-duration events like marathons.
Laboratory Review 5

1. What is the function of rough endoplasmic reticulum?
2. Which organelle carries on intracellular digestion?
3. What is the function of the nucleus?
4. Which organelle is responsible for protein synthesis?
5. What term is used to describe the movement of molecules from an area of higher concentration to an area of lower concentration?
6. What is the name for the movement of water across a selectively permeable membrane?
7. Is 10% NaCl isotonic, hypertonic, or hypotonic to red blood cells?
8. What appearance will red blood cells have when they are placed in 0.0009% NaCl?
9. In which direction does water move when cells are placed in a hypertonic solution?
10. The active site of an enzyme brings together the __________ of a reaction.
11. In general, what does unfavorable environmental conditions due to the speed of an enzymatic reaction?
12. An unfavorable pH causes an enzyme to lose its normal __________.

Thought Questions

13. If a dialysis bag filled with water is placed in a starch solution, what do you predict will happen to the weight of the bag over time? Why?

14. Ocean water is hypertonic to the internal environment of the body. Predict what would happen to your cells if you consumed large quantities of ocean (salt) water.
17
DNA and Biotechnology

Learning Outcomes

17.1 DNA Structure and Replication
- Explain how the structure of DNA facilitates replication.
- Explain how DNA replication is semi-conservative.
Prelab Question: What does semi-conservative replication mean?

17.2 RNA Structure
- Compare DNA and RNA, discussing their similarities as well as what distinguishes one from the other.
Prelab Question: The "R" in RNA stands for what?

17.3 DNA and Protein Synthesis
- Describe how DNA is able to store the information that specifies a protein.
- Compare the events of transcription with those of translation during protein synthesis.
Prelab Question: Which one, transcription or translation, produces a protein?

17.4 Isolation of DNA and Biotechnology
- Describe the procedure for isolating DNA in a test tube.
- Understand the process of DNA gel electrophoresis.
Prelab Question: Give an example to show that DNA can be manipulated in the laboratory like any other chemical.

17.5 Detecting Genetic Disorders
- Understand the relationship between an abnormal DNA base sequence and a genetic disorder.
- Suggest two ways to detect a genetic disorder.
Prelab Question: If the DNA base sequence changes, the protein changes. How?

Application for Daily Living: Personal DNA Sequencing

Introduction

This laboratory pertains to molecular genetics and biotechnology. Molecular genetics is the study of the structure and function of DNA (deoxyribonucleic acid), the genetic material. Biotechnology is the manipulation of DNA for the benefit of human beings and other organisms. Significant advances in medicine, agriculture, and science in general can be attributed to the fields of molecular genetics and biotechnology.

First we will study the structure of DNA and see how that structure facilitates DNA replication in the nucleus of cells. DNA replicates prior to cell division; following cell division, each daughter cell has a complete copy of the genetic material. DNA replication is also needed to pass genetic material from one generation to the next. You may have an opportunity to use models to see how replication occurs.

Then we will study the structure of RNA (ribonucleic acid) and how it differs from that of DNA, before examining how DNA and RNA specify protein synthesis. The linear construction of DNA, in which nucleotide is linked to nucleotide, is paralleled by the linear construction of the primary structure of protein, in which amino acid is linked to amino acid. Essentially, we will see that the sequence of nucleotides in DNA codes for the sequence of amino acids in a protein. We will also review the role of three types of RNA in protein synthesis. DNA’s code is passed to messenger RNA (mRNA), which moves to the ribosomes containing ribosomal RNA (rRNA). Transfer RNA (tRNA) brings the amino acids to the ribosomes.

We now understand that a mutated gene has an altered DNA base sequence, which can lead to a genetic disorder. You will have an opportunity to carry out a laboratory procedure that detects whether an individual is normal, has sickle-cell disease, or is a carrier.
17.1 DNA Structure and Replication

The structure of DNA lends itself to replication, the process that makes a copy of a DNA molecule. Accurate DNA replication is a necessary part of chromosome duplication, which precedes cell division. It also makes possible the passage of DNA from one generation to the next.

**DNA Structure**

DNA is a polymer of nucleotide subunits (Fig. 17.1). Each nucleotide is composed of three molecules: deoxyribose (a 5-carbon sugar), a phosphate, and a nitrogen-containing base, and is attached to its complementary nucleotide by hydrogen bonds.

![Diagram of DNA structure](image)

**Figure 17.1 Overview of DNA structure.** Diagram of DNA double helix shows that the molecule resembles a twisted ladder. Sugar-phosphate backbones are the uprights of the ladder, and hydrogen-bonded bases are the rungs of the ladder. Complementary base pairing dictates that A is bonded to T and G is bonded to C and vice versa. Label the boxed nucleotide pair as directed in the next Observation.
**Observation: DNA Structure**

1. A boxed nucleotide pair is shown in Figure 17.1a. If you are working with a kit, draw a representation of one of your nucleotides here. *Label phosphate, base pair, and deoxyribose in your drawing and in Figure 17.1a.*

2. Notice the four types of bases: cytosine (C), thymine (T), adenine (A), and guanine (G). What is the color of the four types of bases in Figure 17.1? In your kit? Complete Table 17.1 by writing in the colors of the bases.

<table>
<thead>
<tr>
<th>Table 17.1 Base Colors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td><strong>In Figure 17.1</strong></td>
</tr>
<tr>
<td>Cytosine</td>
</tr>
<tr>
<td>Thymine</td>
</tr>
<tr>
<td>Adenine</td>
</tr>
<tr>
<td>Guanine</td>
</tr>
</tbody>
</table>

3. Using Figure 17.1 as a guide, join several nucleotides together. Observe the entire DNA molecule. What types of molecules make up the backbone of DNA (Fig. 17.1b)? __________ and _________

   In the backbone, the phosphate of one nucleotide is bonded to a sugar of the next nucleotide by a covalent bond.

4. Using Figure 17.1 as a guide, join the bases together with hydrogen bonds. *Label a hydrogen bond in Figure 17.1b.* Dashes are used to represent hydrogen bonds in Figure 17.1 because hydrogen bonds are (strong or weak) __________.

5. In Figure 17.1b and in your model, the base A is always paired with the base __________, and the base C is always paired with the base __________. This is called complementary base pairing.

6. The DNA molecule resembles a twisted ladder. The sugar-phosphate backbones equate to the uprights of the ladder. What molecules equate to the rungs of the ladder?

7. Each half of the DNA molecule is a DNA strand. Why is DNA also called a double helix (Fig. 17.1b)?
**DNA Replication**

During replication, the DNA molecule is duplicated so that there are two DNA molecules. We will see that complementary base pairing makes replication possible.

**Observation: DNA Replication**

1. Before replication begins, DNA is unzipped. Using Figure 17.2a as a guide, break apart your two DNA strands. What bonds are broken to unzip the DNA strands?

2. Using Figure 17.2b as a guide, attach new complementary nucleotides to each strand using complementary base pairing.

3. Complete Table 17.2 to show that you understand complementary base pairing. You now have two DNA molecules (Fig. 17.2c). Are your molecules identical?

4. Because of complementary base pairing, each new double helix is composed of an ____________ strand and a ____________ strand.

   Write _old_ or _new_ beside each strand in Figure 17.2a, b, and c, 1–10. _Conservative_ means to save something from the past. Why is DNA replication called semiconservative?

---

**Figure 17.2 DNA replication.**

Use of the ladder configuration better illustrates how replication takes place. **a.** The parent DNA molecule. **b.** The "old" strands of the parent DNA molecule have separated. New complementary nucleotides available in the cell are pairing with those of each old strand. **c.** Replication is complete.

---

**Table 17.2 DNA Replication**

<table>
<thead>
<tr>
<th>Old strand</th>
<th>G G G T T C C A T T A A A T T C C A G A A A T C A T A</th>
</tr>
</thead>
<tbody>
<tr>
<td>New strand</td>
<td></td>
</tr>
</tbody>
</table>

---

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5. Genetic material has to be inherited from cell to cell and organism to organism. Consider that because of DNA replication, a chromosome is composed of two chromatids, and each chromatid is a complete DNA molecule. The chromatids separate during cell division so that each daughter cell receives a copy of each chromosome. Does replication provide a means for passing DNA from cell to cell and organism to organism? Explain.

17.2 RNA Structure

Like DNA, RNA is a polymer of nucleotides (Fig. 17.3). In an RNA nucleotide, the sugar ribose is attached to a phosphate molecule and to a nitrogen-containing base, C, U, A, or G. In RNA, the base uracil replaces thymine as one of the pyrimidine bases. RNA is single stranded, whereas DNA is double stranded.

Figure 17.3  Overview of RNA structure.
RNA is a single strand of nucleotides. Label the boxed nucleotide as directed in the next Observation.

1. Describe the backbone of an RNA molecule.
2. Where are the bases located in an RNA molecule?
3. Complete Table 17.3 to show the complementary DNA bases for the RNA bases.

<table>
<thead>
<tr>
<th>Table 17.3  DNA and RNA Bases</th>
</tr>
</thead>
<tbody>
<tr>
<td>RNA Bases</td>
</tr>
<tr>
<td>DNA Bases</td>
</tr>
</tbody>
</table>
**Observation: RNA Structure**

1. If you are using a kit, draw a nucleotide for the construction of mRNA. *Label the ribose (the sugar in RNA), the phosphate, and the base in your drawing and in Figure 17.3, page 235.*

2. Complete Table 17.4 by writing in the colors of the bases in Figure 17.3 and in your kit.

<table>
<thead>
<tr>
<th>Cytosine</th>
<th>In Figure 17.3</th>
<th>In Your Kit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uracil</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adenine</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Guanine</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3. The base uracil substitutes for the base thymine in RNA. Complete Table 17.5 to show several other ways RNA differs from DNA.

<table>
<thead>
<tr>
<th>DNA</th>
<th>RNA Structure Compared with RNA Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugar</td>
<td>Deoxyribose</td>
</tr>
<tr>
<td>Bases</td>
<td></td>
</tr>
<tr>
<td>Helix</td>
<td>Yes</td>
</tr>
</tbody>
</table>

**17.3 DNA and Protein Synthesis**

Protein synthesis requires the processes of transcription and translation. During **transcription**, which takes place in the nucleus, an RNA molecule called **messenger RNA** (mRNA) is made complementary to one of the DNA strands. This mRNA leaves the nucleus and goes to the ribosomes in the cytoplasm. Ribosomes are composed of **ribosomal RNA** (rRNA) and proteins in two subunits.

During **translation**, RNA molecules called **transfer RNA** (tRNA) bring amino acids to the ribosome, and they join in the order prescribed by mRNA. In the end, the final sequence of amino acids in a protein is specified by DNA. This is the information that DNA, the genetic material, stores. What is the role of each of these participants in protein synthesis?

DNA

mRNA

rRNA
**Transcription**

During transcription, complementary RNA is made from a DNA template (Fig. 17.4). A portion of DNA unwinds and unzips at the point of attachment of RNA polymerase. A strand of mRNA is produced when complementary nucleotides join in the order dictated by the sequence of bases in DNA. Transcription occurs in the nucleus, and the mRNA passes out of the nucleus to enter the cytoplasm.

*Label Figure 17.4. For number 1, note the name of the enzyme that carries out mRNA synthesis. For number 2, note the name of the entire molecule.*

**Observation: Transcription**

1. If you are using a kit, unzip your DNA model so that only one strand remains. This strand is the **template strand**, the strand transcribed or copied into complementary base pairs of RNA.

2. Using Figure 17.4 as a guide, construct a messenger RNA (mRNA) molecule by first lining up RNA nucleotides complementary to the template strand of your DNA molecule. Join the nucleotides together to form mRNA.

3. A portion of DNA has the sequence of bases shown in Table 17.6. Complete Table 17.6 to show the sequence of bases in mRNA.

4. If you are using a kit, unzip the mRNA transcript from the DNA. Locate the end of the strand that will move to the

   ________________________ in the cytoplasm.

**Table 17.6 Transcription**

<table>
<thead>
<tr>
<th>DNA</th>
<th>T A C A C G A G C A A C T A A C A T</th>
</tr>
</thead>
<tbody>
<tr>
<td>mRNA</td>
<td></td>
</tr>
</tbody>
</table>
Translation

DNA specifies the sequence of amino acids in a polypeptide because every three bases stand for an amino acid. Therefore, DNA is said to have a **triplet code**. The bases in mRNA are complementary to those in DNA, and therefore every three bases in mRNA (called a **codon**) stand for the same sequence of amino acids as does DNA. The correct sequence of amino acids in a polypeptide is the message that mRNA carries.

Messenger RNA leaves the nucleus and proceeds to the ribosomes, where protein synthesis occurs. Transfer RNA (tRNA) molecules are so named because they transfer amino acids to the ribosomes. Each tRNA has a specific amino acid at one end and a matching **anticodon** at the other end (Fig. 17.5). The anticodon is complementary to the codon for this amino acid, as we shall soon see. Label Figure 17.5, where the amino acid is represented as a colored ball, the tRNA is green, and the anticodon is the sequence of three bases.

**Figure 17.5  Transfer RNA (tRNA).**
Transfer RNA carries amino acids to the ribosomes.

![Transfer RNA (tRNA) diagram]

1. ____________ Val  
2. ___________  
3. __________

**Observation: Translation**

1. Figure 17.6 shows seven tRNA–amino acid complexes. Every amino acid has a name; in the figure, only the first three letters of the name are inside the ball. Using the mRNA sequence given in Table 17.7, number the tRNA–amino acid complexes in the order they will come to the ribosome.
2. If you are using a kit, arrange your tRNA–amino acid complexes in the proper order. Complete Table 17.7. Why are the codons and anticodons in groups of three?

**Figure 17.6  Transfer RNA diversity.**
Each type of tRNA carries only one particular amino acid, designated here by the first three letters of its name.

![Transfer RNA diversity diagram]
Table 17.7: Translation

<table>
<thead>
<tr>
<th>mRNA codons</th>
<th>AUG</th>
<th>CCC</th>
<th>GAU</th>
<th>GUU</th>
<th>GAG</th>
<th>UUG</th>
<th>UCU</th>
</tr>
</thead>
<tbody>
<tr>
<td>tRNA anticodons</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Amino acid*

*Use three letters only. See Table 17.8 for the full names of these amino acids.

Table 17.8: Names of Amino Acids

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Met</td>
<td>methionine</td>
</tr>
<tr>
<td>Pro</td>
<td>proline</td>
</tr>
<tr>
<td>Asp</td>
<td>aspartic acid</td>
</tr>
<tr>
<td>Val</td>
<td>valine</td>
</tr>
<tr>
<td>Glu</td>
<td>glutamic acid</td>
</tr>
<tr>
<td>Leu</td>
<td>leucine</td>
</tr>
<tr>
<td>Ser</td>
<td>serine</td>
</tr>
</tbody>
</table>

3. Figure 17.7 shows the manner in which the polypeptide grows. A ribosome has room for two tRNA complexes at a time. As the first tRNA leaves, it passes its amino acid or peptide to the next tRNA–amino acid complex. Then the ribosome moves forward, making room for the next tRNA–amino acid complex. This sequence of events occurs over and over until the entire polypeptide is borne by the last tRNA to come to the ribosome. In Figure 17.7, label the ribosome, the mRNA, and the peptide chain.

Figure 17.7: Protein synthesis.
1. A ribosome has room for two tRNA–amino acid complexes. 2. Before tRNA leaves, an RNA passes its attached peptide to its neighboring tRNA–amino acid complex. 3. The ribosome moves forward, and the next tRNA–amino acid complex arrives.
Summary of Protein Synthesis

Examine Figure 17.8 and complete Table 17.9 to show that you understand the role of the participants in protein synthesis.

**Figure 17.8 Participants in synthesis.**
The two steps required for protein synthesis are transcription, which occurs in the nucleus, and translation, which occurs in the cytoplasm at the ribosomes.

**Table 17.9 Participants in Protein Synthesis**

<table>
<thead>
<tr>
<th>Special Role</th>
<th>Explain</th>
</tr>
</thead>
<tbody>
<tr>
<td>DNA</td>
<td></td>
</tr>
<tr>
<td>mRNA</td>
<td></td>
</tr>
<tr>
<td>tRNA</td>
<td></td>
</tr>
<tr>
<td>rRNA</td>
<td></td>
</tr>
<tr>
<td>Amino acid</td>
<td></td>
</tr>
<tr>
<td>Protein</td>
<td></td>
</tr>
</tbody>
</table>
17.4 Isolation of DNA and Biotechnology

In the following experiment, you will isolate DNA from the cells of a fruit or vegetable. It will only be necessary to expose the cells to an agent (dishwashing detergent) that emulsifies membrane in order to “free” the DNA from its enclosures (plasma membrane and nuclear envelope). When transferred to a tube, the presence of NaCl allows DNA to precipitate as a sodium salt. The precipitate forms at the interface between ethanol and the salt solution, and then it floats to the top of the tube where it may be collected.

**Experimental Procedure: Isolation of DNA**

1. You will need a slice of fruit or vegetable (i.e., tomato, onion, or apple), a mortar and pestle, and a large clean glass test tube on ice.
2. Crush and grind a slice of fruit or vegetable in a mortar and pestle. Remove the pestle and set aside. Add enough 0.9% NaCl solution to achieve a “soupy” consistency.
3. Add two drops of dishwashing detergent (such as blue Dawn) to the mixture in the mortar. Swirl until the color of the detergent disappears. Wait 3 to 5 minutes. The solution becomes clear and viscous as the DNA escapes its enclosures.
4. Check the viscosity of the solution in the mortar, and if it is too viscous for you to pipet, add a few more ml of NaCl solution. Use a transfer pipet to move 2 to 3 ml of the DNA from the mortar to the glass tube. Try to pick up clear zones of the solution WITHOUT CELL DEBRIS.
5. Slowly add 5 to 7 ml of ice-cold ethanol down the side of the tube on ice. As you do so, DNA will precipitate between the ethanol and the NaCl solutions. Then it will float to the top, where it can be picked up by a fresh transfer pipet. Any “white dust” you see consists of RNA molecules.
6. Use a transfer pipet to place the DNA in a small, clean test tube. Pipet away any extra water/ethanol and air-dry the DNA for a few minutes. Dissolve the DNA in 3 to 4 ml distilled H₂O.
7. Add five drops of phenol red, a pH indicator. The resulting dark pink color confirms the presence of nucleic acid (i.e., the DNA).

**Experimental Procedure: Gel Electrophoresis**

During gel electrophoresis, charged DNA molecules migrate across a span of gel (gelatinous slab) because they are placed in a powerful electrical field. In the present experiment, each DNA sample is placed in a small depression in the gel called a well. The gel is placed in a powerful electrical field. The electricity causes DNA fragments, which are negatively charged, to move through the gel according to their size.
Almost all DNA gel electrophoresis is carried out using horizontal gel slabs (Fig. 17.9). First, the gel is poured onto a plastic plate, and the wells are formed. After the samples are added to the wells, the gel and the plastic plate are put into an electrophoresis chamber, and buffer is added. The DNA samples begin to migrate after the electrical current is turned on. With staining, the DNA fragments appear as a series of bands spread from one end of the gel to the other according to their size because smaller fragments move faster than larger fragments.

Answer the following questions:

a. What is biotechnology? (See page 231.)

b. Speculate how the ability to isolate DNA and run gel electrophoresis of DNA relates to biotechnology.

c. Name a biotechnology product someone you know is now using or taking as a medicine. (Examples include insulin, vaccines, ingredients of ice cream, cheese, make-up, detergents, dye for blue jeans, etc.)
17.5 Detecting Genetic Disorders

The base sequence of DNA in all the chromosomes is an organism’s genome. Now that the Human Genome Project is finished, we know the usual order of all the 3.6 billion nucleotide bases in the human genome. Someday it will be possible to sequence anyone’s genome within a relatively short time, and thereby determine what particular base sequence alterations signify that he or she has a disorder or will have one in the future.

In this laboratory, you will study the alteration in base sequence that causes a person to have sickle-cell disease.

In persons with sickle-cell disease, the red blood cells aren’t biconcave disks like normal red blood cells—they are sickle-shaped. Sickle-shaped cells can’t pass along narrow capillary passageways. They clog the vessels and break down, causing the person to suffer from poor circulation, anemia, and poor resistance to infection. Internal hemorrhaging leads to further complications, such as jaundice, episodic pain in the abdomen and joints, and damage to internal organs.

Sickle-shaped red blood cells are caused by an abnormal hemoglobin (HbS). Individuals with the HbA/HbA genotype are normal; those with the HbS/HbS genotype have sickle-cell disease, and those with the HbS/HbA have sickle-cell trait. Persons with sickle-cell trait do not usually have sickle-shaped cells unless they experience dehydration or mild oxygen deprivation.

Genetic Sequence for Sickle-Cell Disease

Examine Figure 17.10, a and b, which shows the DNA base sequence, the mRNA codons, and the amino acid sequence for a portion of the gene for HbA and the same portion for HbS. Today many genetic disorders can be detected by genomic sequencing.

1. In what one base does HbA differ from HbS?

   HbA _______  HbS _______

2. What are the codons that contain this base?

   HbA _______  HbS _______

3. What is the amino acid difference?

   HbA _______  HbS _______

Figure 17.10
Sickle-cell disease.

Sickle-cell disease occurs when (a) the DNA base sequence in one location has changed from CTC (b) to CAC in both alleles for HbA.

DNA

TGA'GGA'CTC/CTC'TTC

transcription

mRNA

ACU'CCU'GAG'GAG'AAG

translation

polypeptide Thr Pro Glu Glu Lys

DNA

TGA'GGA'CAC/CTC'TTC

transcription

mRNA

ACU'CCU'GUG'GAG'AAG

translation

polypeptide Thr Pro Val Glu Lys

a. Normal red blood cells

b. Sickle-shaped red blood cell
This amino acid difference causes the polypeptide chain in sickle-cell hemoglobin to pile up as firm rods that push against the plasma membrane and deform the red blood cell into a sickle shape:

Detection of Sickle-Cell Disease by Gel Electrophoresis

Three samples of hemoglobin (A, B, and C) have been subjected to protein gel electrophoresis. Protein gel electrophoresis is carried out in the in the same manner as DNA gel electrophoresis (Fig. 17.9) except the gel has a different composition.

1. Sickle-cell hemoglobin ($Hb^S$) migrates slower toward the positive pole than normal hemoglobin ($Hb^A$) because the amino acid valine has no polar R groups, whereas the amino acid glutamate does have a polar R group.

2. In Figure 17.11, which lane contains only $Hb^S$, signifying that the individual is $Hb^S$?  

3. Which lane contains only $Hb^A$, signifying that the individual is $Hb^A$?  

4. Which lane contains both $Hb^S$ and $Hb^A$, signifying that the individual is $Hb^A$ $Hb^S$?  

![Figure 17.11  Gel electrophoresis of hemoglobins.](image)

Detection by Genomic Sequencing

You are a genetic counselor. A young couple seeks your advice because sickle-cell disease occurs among the family members of each. You order DNA base sequencing to be done. The results come back that at one of the loci for normal hemoglobin, each has the abnormal sequence CAC instead of CTC. The other locus is normal. What are the chances that this couple will have a child with sickle-cell disease?
Conclusion: Detecting Genetic Disorders

- What two methods of detecting sickle-cell disease were described in this section?

- Which method is more direct and probably requires more expensive equipment to do?

- Which method probably preceded the other method as a means to detect sickle-cell disease?

Application for Daily Living

Personal DNA Sequencing

You may know that it took many years to get the human genome sequenced, but now personal DNA base sequencing can be done within days, and it is relatively affordable. The information can allow a trained geneticist to predict which genetic disorders you are susceptible to, and then you can choose either prevention and/or early detection to avoid a serious illness. DNA sequencing may also tell you which drugs might be especially useful to you in case of illness.

The move is on to require people to go through their personal physician to get their DNA sequenced. Why? It is always a good idea to have it done by a reputable company and to have someone help you sift through the data that might be made available. It’s not always easy to learn that you may come down with a disorder, and you would want to know what your options are right away.

---

Laboratory Review 17

1. The DNA structure resembles a twisted ladder. What molecules make up the uprights of the ladder?

2. What makes up the rungs of the ladder?

3. Do the two DNA double helices following DNA replication have the same, or a different, composition?

4. If the adenine bases account for 20% of the DNA bases, what would be the percentage of thymine?

5. If the codons are AUG, CGC, and UAC, what are the anticodons?

6. Where does protein synthesis take place?

7. During transcription, what type of RNA is formed that carries the codons?

8. In what part of the cell does translation occur?

9. During translation, what type of RNA carries amino acids to the ribosomes?

10. A person with genotype $Hb^S Hb^S$ has what genetic disorder?

11. Sickle-cell disease illustrates that a mutation is a change in what?

12. During gel-electrophoresis normal hemoglobin separates from sickle-cell hemoglobin because of a _______ difference.

13. What procedure allows investigations to determine the present or future genetic disorders of an individual?
Thought Questions

14. What role does mRNA play in transcription and translation?

15. Explain the manner in which gel electrophoresis identifies a person with sickle-cell disease.

16. Below is a sequence of bases associated with the template DNA strand:
   TAC CCC GAG CTT
   
   a. Identify the sequence of bases in the mRNA resulting from the transcription of the above DNA sequence.
   
   b. Identify the sequence of bases in the tRNA anticodon that will bind with the first codon of the mRNA identified above.
15

Mitosis and Meiosis

Learning Outcomes

15.1 The Cell Cycle
- Name and describe the stages of the cell cycle.
- Identify the phases of mitosis in models and microscope slides. Explain how the chromosome number stays constant.
- Describe cytokinesis.

Prelab Question: During what stage of the cell cycle does chromosome duplication occur, and why is this critical to mitosis?

15.2 Meiosis
- Name and describe the phases of meiosis I and meiosis II with attention to the movement of chromosomes.
- Explain how the chromosome number is reduced.

Prelab Question: What is synapsis, and why is it critical to meiosis?

15.3 Mitosis Versus Meiosis
- Compare the effects of mitosis to meiosis.
- Contrast the behavior of chromosomes during mitosis with the behavior of chromosomes during meiosis I and II.

Prelab Question: How are mitosis and meiosis II similar? How are they different?

15.4 Gametogenesis
- Contrast spermatogenesis with oogenesis using diagrams and models.

Prelab Question: What differences between spermatogenesis and oogenesis help explain why males produce so many more sperm than females produce eggs?

Application for Daily Living: Mitosis and Cancer

Introduction

Dividing cells experience nuclear division, cytoplasmic division, and a period between divisions called interphase. During interphase, the nucleus appears normal, and the cell is performing its usual cellular functions. Also, the cell is increasing all of its components, including such organelles as the mitochondria, ribosomes, and centrioles. DNA replication (making an exact copy of the DNA) occurs toward the end of interphase. Thereafter, the chromosomes, which contain DNA, are duplicated and contain two chromatids held together at a centromere. These chromatids are called sister chromatids.

When the nucleus divides during mitosis, the daughter nuclei receive the same number of chromosomes and genetic material as the parent cell. During cytokinesis, the cytoplasm divides and two daughter cells are produced. Mitosis in humans permits growth and repair of tissues. During sexual reproduction, another form of division called meiosis occurs. Meiosis is a part of gametogenesis, the production of gametes (sex cells called sperm in males and eggs in females). As a result of meiosis, the daughter cells have half the number of chromosomes as the parent cell. Also, the chromatids sometimes exchange genetic material during crossing-over; therefore, the daughter cells do not have the same number of chromosomes and are not genetically identical to the parent cell, following meiosis.
15.1 The Cell Cycle

As stated in the introduction, the period between cell divisions is known as interphase. Early investigators noted little visible activity between cell divisions, so they dismissed this period as a resting state. But when they discovered that DNA replication occurs (and the chromosomes become duplicated) during interphase, the cell cycle concept was proposed. Investigators have also discovered that cytoplasmic organelle duplication occurs during G_1 and synthesis of the proteins involved in regulating cell division occurs during G_2. Thus, the cell cycle can be broken down into four stages (Fig. 15.1).

State the event of each stage on the line provided:

G_1 ____________________________
S ____________________________
G_2 ____________________________
M ____________________________

Why is the entire process called the “cell cycle”?

Duration of the Cell Cycle

If mature human cells are speedily dividing, the length of the cell cycle is about 22–24 hours. Embryonic cells go through the cell cycle much more rapidly by omitting G_1 and G_2, so that the cell cycle includes only DNA replication and mitosis. Mature cells usually take this amount of time per phase: G_1 = 10 hours; S = 5–6 hours; G_2 = 3–4 hours; mitosis and cytokinesis = 2 hours.

Mitosis

Mitosis is nuclear division that results in two new nuclei, each having the same number of chromosomes as the original nucleus. The parent cell is the cell that divides, and the resulting cells are called daughter cells. If a parent cell has 46 chromosomes, how many chromosomes does each daughter cell have following mitosis?

When cell division is about to begin, chromatin starts to condense and compact to form visible, rodlike sister chromatids held together at the centromere (Fig. 15.2a). Label the sister chromatids and the centromere in Figure 15.2b. This illustration represents a duplicated chromosome as it would appear just before nuclear division occurs.

Spindle

Table 15.1 lists the structures that play a role during mitosis. The spindle is a structure that appears and brings about an orderly distribution of daughter chromosomes to the daughter cell nuclei. A spindle has fibers that stretch between two poles (ends) (Fig. 15.3). Spindle fibers are bundles of microtubules, protein cylinders found in the cytoplasm that can assemble and disassemble. The centrosome, which is the main microtubule-organizing center of the cell, divides before mitosis so that each pole of the spindle has a pair of centrosomes. Human cells contain two barrel-shaped organelles called centrioles in each centrosome and asters, arrays of short microtubules radiating from the poles. Thus, centrioles mark the location of the spindle poles.
**Figure 15.2** Duplicated chromosomes.
DNA replication results in a duplicated chromosome that consists of two sister chromatids held together at a centromere. **a.** Scanning electron micrograph of a duplicated chromosome. **b.** Drawing of a duplicated chromosome. During mitosis, each chromatid becomes a daughter chromosome.

<table>
<thead>
<tr>
<th><strong>Table 15.1</strong> Structures Associated with Mitosis</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Structure</strong></td>
</tr>
<tr>
<td>Nucleus</td>
</tr>
<tr>
<td>Chromosome</td>
</tr>
<tr>
<td>Nucleolus</td>
</tr>
<tr>
<td>Spindle</td>
</tr>
<tr>
<td>Chromatids</td>
</tr>
<tr>
<td>Centromere</td>
</tr>
<tr>
<td>Centrosome</td>
</tr>
<tr>
<td>Centriole</td>
</tr>
<tr>
<td>Aster</td>
</tr>
</tbody>
</table>

**Figure 15.3** The spindle.
Spindle fibers (bundles of microtubules) help distribute the daughter chromosomes during mitosis.
Figure 15.4 Phases of mitosis in human cells.
This illustration extends across two pages. The colors signify that the chromosomes were inherited from different parents.

Observation: Mitosis

Mitosis Models

1. Using the descriptions given in Figure 15.4 as a guide, identify the phases of human cell mitosis in models of human cell mitosis.
2. Each species has its own chromosome number. Counting the number of centromeres tells you the number of chromosomes in the models. What is the number of chromosomes observed in each nucleus of the cells?

Whitefish Blastula Slide

The blastula is an early embryonic stage in the development of humans. The blastomeres (blastula cells) that are in the top row of Figure 15.4 are in the illustrated phases of mitosis.

1. Examine a prepared slide of whitefish blastula cells undergoing mitotic cell division.
2. Try to find a cell in each phase of mitosis. Have a partner or your instructor check your identification.
3. Determine if you find more cells in prophase than the other phases. If so, what does that tell you about the length of time a cell stays in prophase?
Mitosis Phases

The phases of mitosis are **prophase, metaphase, anaphase, and telophase**—in that order (Fig. 15.4). Early stages of prophase and metaphase are also shown in this figure.

**Prophase**

During early prophase, the chromosomes continue to condense, the **nucleolus** disappears, and the nuclear envelope fragments. Still during prophase, the chromosomes have no apparent orientation within the cell. The already duplicated chromosomes are composed of two sister chromatids held together at a centromere. Counting the number of centromeres in diagrammatic drawings gives the number of chromosomes for the cell. What is the chromosome number for the cells in Figure 15.4?

The spindle begins to assemble as the centrosomes, each containing two centrioles, migrate to the poles.

Contrast the appearance of a cell in prophase with one in interphase. (*Hint: See Fig. 15.1 and compare the nuclei and their contents.)*

**Metaphase**

The sister chromatids are now attached to the spindle, and the chromosomes are aligned at the equator of the spindle. The mitotic spindle occupies the region formerly occupied by the nucleus. Short microtubules radiate out in a starlike aster from the pair of centrioles located in each centrosome. The spindle consists of poles, asters, and fibers, bundles of parallel microtubules.
Contrast the appearance of a cell in metaphase with one in prophase.

**Anaphase**

At the start of anaphase, the centromeres split, and the sister chromatids of each chromosome separate, giving rise to two daughter chromosomes. The daughter chromosomes begin to move toward opposite poles of the spindle. Each pole receives the diploid number of daughter chromosomes.

Contrast the appearance of a cell in anaphase with one in metaphase.

**Telophase**

New nuclear envelopes form around the daughter chromosomes at the poles. Each daughter nucleus contains the same number and types of chromosomes as the parental cell. The chromosomes become more diffuse chromatin once again, and a nucleolus reappears in each daughter nucleus. Division of the cytoplasm by formation of a cleavage furrow is nearly complete.

Contrast the appearance of a cell in telophase with one in anaphase.

**Cytokinesis**

Cytokinesis, division of the cytoplasm, usually accompanies mitosis. During cytokinesis, each daughter cell receives a share of the organelles that duplicated during interphase. Cytokinesis begins in anaphase, continues in telophase, and reaches completion by the start of the next interphase.

**Cytokinesis in Human Cells**

In human cells, a cleavage furrow, an indentation of the membrane between the daughter nuclei, begins as anaphase draws to a close. The cleavage furrow deepens as a band of actin filaments called the contractile ring slowly constricts the cell, forming two daughter cells (Fig. 15.5).

Were any of the cells of the whitefish blastula slide undergoing cytokinesis?

How do you know?

**Summary of Mitotic Cell Division**

1. The nuclei in the daughter cells have the ___________ number of chromosomes as the parent cell had.

2. Mitosis is cell division in which the chromosome number ___________.

---

**Figure 15.5 Cytokinesis in human cells.**

A single cell becomes two cells by a furrowing process. A contractile ring composed of actin filaments gradually gets smaller, and the cleavage furrow pinches the cell into two cells.
15.2 Meiosis

Meiosis is a form of nuclear division in which the chromosome number is reduced by half. The nucleus of the parent cell has the diploid (2n) number of chromosomes; the daughter nuclei, after meiosis is complete, have the haploid (n) number of chromosomes. In sexually reproducing species, meiosis must occur or the chromosome number would double with each generation.

A diploid cell nucleus contains homologues, also called homologous chromosomes. The homologues of each pair look alike and carry the genes for the same traits. Before meiosis begins, the chromosomes are already double stranded—they contain sister chromatids. Meiosis requires two divisions, called meiosis I and meiosis II (Fig. 15.6).

Meiosis I

During prophase of meiosis I, the spindle appears and the nuclear envelope and nucleolus disappear. Homologues line up next to one another during a process called synapsis. During crossing-over, the nonsister chromatids of a homologue pair exchange genetic material. At metaphase I, the homologue pairs line up at the equator of the spindle. During anaphase I, homologues separate and the chromosomes (still having two chromatids) move to each pole. In telophase I, the nuclear envelope and the nucleolus reappear as the spindle disappears. Each new nucleus contains one homologue from each pair of homologues.

Prophase I

Use Figure 15.6 to learn the major events of each phase of meiosis I. In prophase I the chromosomes are in a fragmented nuclear envelope and the homologues undergo synapsis and nonsister chromatids undergo crossing-over. (The red-short and blue-short are homologues; red-long and blue-long are also homologues.)

Metaphase I

The homologues are at the equator, prepared to move apart toward the poles. Each homologue pair acts independently and either homologue can be facing either pole. Notice that crossing-over is represented by an exchange of color between nonsister chromatids. Why do nonsister chromatids participate in crossing-over but sister chromatids do not?

(The difference in color between nonsister chromatids represents different genetic material.)

Anaphase I

The members of each homologue pair separate, and they move toward opposite poles. Now the nuclei will be haploid: they no longer have homologue pairs.

Telophase I

1. During telophase I, the chromosomes are at the poles. Disregard any crossing-over and state what combinations of chromosomes are at the poles? Fill in the following blanks with the words red-long, red-short, blue-long, and blue-short:
   Pole A: ________________ and ________________
   Pole B: ________________ and ________________

2. What other combinations would have been possible? (Hint: Alternate the colors at metaphase I.)
   Pole A: ________________ and ________________
   Pole B: ________________ and ________________

All possible combinations of chromosomes can occur in daughter nuclei following meiosis I. Why would you not find two short chromosomes nor two long chromosomes at the poles of the spindle following telophase I?
Figure 15.6  Melosis I and II in human cell drawings.
This illustration extends across two pages. Melosis I begins on this page and continues on the next page; melosis II begins on this page and continues on the next page. Note that only by coloring the homologues differently (red and blue) is it possible to show that the daughter cells following melosis I vary genetically and to show the increased variation caused by crossing-over.

MEIOSIS I

Interphase cell
Centrosome has centrioles.
Prophase I
Chromosomes have duplicated.
Homologue pair during synapsis and cross-over occurs.
Metaphase I
Homologue pairs align independently at the equator.
Anaphase I
Homologues separate and move toward the poles.

MEIOSIS II

First daughter cell from melosis I

Second daughter cell from melosis I

Prophase II
Cells have one chromosome from each homologue pair.
Metaphase II
Chromosomes align at the equator.
Anaphase II
Sister chromatids separate and become daughter chromosomes.
MEIOSIS I cont'd

Telophase I
Daughter cells have one homolog from each homologue pair.

Interkinesis
Chromosomes still consist of two chromatids.

MEIOSIS II cont'd

Telophase II
Spindle disappears, nuclei form, and cytokinesis takes place.

Daughter cells
Meiosis results in four haploid daughter cells.
Events of Meiosis I

Show the events of meiosis I by adding two pairs of simplified homologues (chromatids can be straight lines) to Figure 15.7. Remember that the members of a homologue pair are colored differently (red/blue) and are recognized by length. Assume that nonsister chromatids have already experienced crossing-over when you begin.

![Diagram of Meiosis I stages: Prophase I, Metaphase I, Anaphase I, Telophase I, Daughter Cell, Daughter Cell]

Figure 15.7 Meiosis I exercise art.

Conclusions: Meiosis I

- Do the chromosomes inherited from the mother (e.g., red) or father (e.g., blue) have to remain together following meiosis I? __________________________. Does the same genetic material have to remain together? __________________________.

- Name two ways that meiosis contributes to genetic recombination:
  a. __________________________
  b. __________________________
**Interkinesis**

*Interkinesis* is the period between meiosis I and meiosis II. In some species, daughter cells do not form and meiosis II follows right after meiosis I. Does DNA replication occur during interkinesis prior to meiosis II? Explain why not.

**Melosis II**

During prophase of meiosis II, a spindle appears. Each chromosome individually attaches to the spindle. During metaphase II, the chromosomes are lined up at the equator. During anaphase II, the centromeres divide and the chromatids separate, becoming daughter chromosomes that move toward the poles. In telophase II, the spindle disappears as the nuclear envelope reappears. Melosis II is exactly like mitosis (see Fig. 15.4) except that the nuclei of the parent cell and the daughter cells are haploid.

If so directed by your instructor, use the space below to create a series of drawings showing the stages of meiosis II. Otherwise, simply answer these questions. In Figure 15.6, how many chromosomes are in the nucleus during each phase of meiosis II, whether prophase II, metaphase II, telophase II, or the daughter cells? Explain how this is possible.

**Summary of Meiotic Cell Division**

1. The parent cell has the diploid (2n) number of chromosomes, and the daughter cells following meiosis have the \( n \) number of chromosomes.

2. Meiosis is cell division in which the chromosome number is halved.

3. If a parent cell has 16 chromosomes, the daughter cells will have how many chromosomes following meiosis?

4. Whereas meiosis reduces the chromosome number, *fertilization* restores the chromosome number. A zygote contains the same number of chromosomes as the parent, but are these exactly the same chromosomes?

5. What is another way that sexual reproduction results in genetic recombination?
15.3 Mitosis Versus Meiosis

In this section we will utilize Figure 15.8 to (1) compare the process of mitosis to the process of meiosis in general and then (2) to specifically compare mitosis to meiosis I and finally (3) to specifically compare mitosis to meiosis II.

General Differences

To fill in Table 15.2, look at the completion of mitosis and meiosis II on page 211 to see how many divisions were required for mitosis versus meiosis and the chromosome number \((2n/n)\) of the daughter cells and the number of daughter cells for each process. Now fill in Table 15.2

<table>
<thead>
<tr>
<th></th>
<th>Mitosis</th>
<th>Meiosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Number of divisions</td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>Chromosome number in daughter cells</td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>Number of daughter cells</td>
<td></td>
</tr>
</tbody>
</table>

Figure 15.8  Melosis I and meiosis II compared to mitosis.

Compare metaphase I of meiosis I to metaphase of mitosis. Only in metaphase I are the homologues paired at the equator. Members of each homologue pair separate during anaphase I, and therefore the daughter cells are haploid. The exchange of color between nonsister chromatids represents the crossing-over that occurred during meiosis I.
Specific Differences

To compare the specifics of mitosis to meiosis I, notice that phrases in the first column of Table 15.3 are correct for mitosis. If the phrase also applies to meiosis I, just repeat it in the second column. If it doesn’t apply, correct it for meiosis I. To get you started, the correct phrase has been supplied for prophase I.

Table 15.3 Mitosis Compared with Meiosis I

<table>
<thead>
<tr>
<th>Mitosis</th>
<th>Meiosis I</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prophase: no pairing of chromosomes</td>
<td>Prophase I: Pairing of homologues</td>
</tr>
<tr>
<td>Metaphase: duplicated chromosomes at equator</td>
<td>Metaphase I:</td>
</tr>
<tr>
<td>Anaphase: sister chromatids separate.</td>
<td>Anaphase I:</td>
</tr>
<tr>
<td>Telophase: chromosomes have one chromatid.</td>
<td>Telophase I:</td>
</tr>
</tbody>
</table>

MEIOSIS I cont’d

Telophase I
Daughter cells are forming and will go on to divide again.

Sister chromatids separate and become daughter chromosomes.

All phases

Daughter cells

Four haploid daughter cells. Their nuclei are genetically different from the parent cell.

MEIOSIS II

n = 2

n = 2

MITOSIS cont’d

n = 2

2n = 4

Telophase
Daughter cells are forming.

Daughter cells

Two diploid daughter cells. Their nuclei are genetically identical to the parent cell.
To compare mitosis to meiosis II, notice that the phrases in the first column of Table 15.4 are correct for mitosis. If the phrase also applies to meiosis II (see one daughter cell at the bottom of Fig. 15.6), just repeat it in the second column. To get you started, the correct phrase has been supplied for prophase II.

<table>
<thead>
<tr>
<th>Mitosis</th>
<th>Meiosis II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prophase: no pairing of chromosomes</td>
<td>Prophase II: No pairing of chromosomes</td>
</tr>
<tr>
<td>Metaphase: duplicated chromosomes at equator</td>
<td>Metaphase II:</td>
</tr>
<tr>
<td>Anaphase: sister chromatids separate.</td>
<td>Anaphase II:</td>
</tr>
<tr>
<td>Telophase: two diploid daughter cells</td>
<td>Telophase II:</td>
</tr>
</tbody>
</table>

**Change in Chromosome Structure**

Anomalies of chromosome structure can occur when cells divide, particularly if cells have been subject to environmental influences such as radiation or drug intake. Some of the more common structural anomalies that can be seen in a karyotype are:

- **Deletion**: The chromosome is shorter than usual because some portion is missing.
- **Duplication**: The chromosome is longer than usual because some portion is present twice over.
- **Inversion**: The chromosome is normal in length but some portion runs in the opposite direction.
- **Translocation**: Two chromosomes have switched portions and each switched portion is on the wrong chromosome.

Anomalies of chromosome structure can also result in recognized syndromes. A **syndrome** is characterized by a group of symptoms and conditions that always occur together (see page 225).

### 15.4 Gametogenesis

**Gametogenesis** is the formation of gametes (sex cells), the sperm and egg. **Fertilization** occurs when the nucleus of a sperm fuses with the nucleus of an egg.

**Gametogenesis**

Gametogenesis occurs in the testes of males, where **spermatogenesis** produces sperm. Gametogenesis occurs in the ovaries of females, where **oogenesis** produces oocytes (eggs).

Recall that a diploid (2n) nucleus contains the full number of chromosomes, and a haploid (n) nucleus contains half as many. Gametogenesis involves meiosis, the process that reduces the chromosome number from 2n to n. In sexually reproducing species, if meiosis did not occur, the chromosome number would double with each generation. Because meiosis consists of two divisions—the first meiotic division (meiosis I) and the second meiotic division (meiosis II)—you expect four haploid cells at the end of the process. Indeed, there are four sperm as a result of spermatogenesis (Fig. 15.9). However, in females, meiosis I results in a secondary oocyte and one polar body.

A **polar body** is a nonfunctioning cell that will disintegrate. A secondary oocyte does not undergo meiosis II unless fertilization (fusion of egg and sperm) occurs. At the completion of oogenesis, there is a single egg. The polar bodies die (Fig. 15.9). The egg has most of the cytoplasm.
SPERMATOGENESIS

Melosis I

Melosis II

Metamorphosis and maturation

primary spermatocyte

2n

secondary spermatocytes

n

spermatids

n

sperm

n

OOGENESIS

Melosis I

Melosis II

Fertilization

Egg

n

second polar body

n

dies

sperm nucleus

n

dies

fusion of sperm nucleus and egg nucleus

n

primary oocyte

2n

first polar body

n

secondary oocyte

n

Melosis II is completed after entry of sperm.

Figure 15.9 Spermatogenesis and oogenesis.
Spermatogenesis produces four viable sperm, whereas oogenesis produces one egg and two polar bodies. In humans, both sperm and egg have 23 chromosomes each; therefore, following fertilization, the zygote has 46 chromosomes.
**Observation: Gametogenesis**

Examine any available gametogenesis models and state here the diploid number of the parent cell and the haploid number of a gamete. Remember that counting the number of centromeres tells you the number of chromosomes.

Diploid number of parent cell: _____________________________________________

Haploid number of a gamete: _____________________________________________

**Summary of Gametogenesis**

1. What is gametogenesis?
   In general, how many chromosomes are in a human gamete? _______________________

2. What is spermatogenesis?
   How many chromosomes does a human sperm have? _____________________________

3. What is oogenesis?
   How many chromosomes does a human egg have? ______________________________

4. Following fertilization, how many chromosomes does the zygote, the first cell of the new individual, have?________________________

**Application for Daily Living**

**Mitosis and Cancer**

Mutations can upset the cell cycle and cause body cells to divide uncontrollably. Such mutations often lead to cancer. Two of the frequent causes of mutations are exposure to radiation or organic chemicals. Radiation is in sunlight, and we are all well aware that sitting in the sun for long hours can lead to skin cancer. Frequent X-rays can also be a matter of concern, and we should avoid any that are not medically necessary. Mutagenic organic chemicals can be found in certain food additives, industrial chemicals, and pesticides. That's why lawns sprayed with pesticides often carry a warning label. People sometimes show extreme concern about industrial chemicals and pesticides in our water supply, and yet they still smoke. Tobacco smoke contains a number of organic chemicals that are known carcinogens, and it is estimated that one-third of cancer deaths can be attributed to smoking. Lung cancer is the most frequently lethal cancer in the United States; smoking is also implicated in the development of cancers of the mouth, larynx, bladder, kidney, and pancreas. When smoking is combined with drinking alcohol, the risk of cancer increases.
Laboratory Review 15

1. During what stage of the cell cycle does DNA replication occur?
2. Name the phase of mitosis during which separation of sister chromatids occurs.
3. By what process does the cytoplasm of a human cell separate?
4. Name the phase of mitosis in which duplicated chromosomes first appear.
5. Where in humans would you expect to find meiosis taking place?
6. If there are 13 pairs of homologues at the start of spermatogenesis, how many chromosomes are there in a sperm?
7. What term refers to the production of an egg?
8. During which type of gametogenesis would you see polar bodies?
9. What do you call chromosomes that have the same length and carry genes for the same traits?
10. If homologues are separating, what phase is this?
11. If the parent cell has 24 chromosomes, how many does each daughter cell have at the completion of meiosis II?
12. Name the type of cell division during which homologues pair.
13. Name the type of cell division described by 2n → 2n.
14. Does metaphase of mitosis, meiosis I, or meiosis II have the haploid number of duplicated chromosomes at the equator of the spindle?

Thought Questions

15. Meiosis functions to reduce chromosome number. When, during the human life cycle, is the diploid number of chromosomes restored?

16. How does the alignment of chromosomes differ between metaphase of mitosis and metaphase of meiosis I?

17. A student is simulating meiosis I with homologues that are red-long and yellow-long. Describe the appearance of two nonsister chromatids following crossing-over.

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www.accessscience.com

LEARNSMART LABS®
The following LearnSmart Lab contains exercises that are related to the content of this chapter:
• Mitosis & Meiosis

15–17
6

Body Tissues

Learning Outcomes

6.1 Epithelial Tissue
- Identify slides and models or diagrams of various types of epithelium.
- Tell where a particular type of epithelium is located in the body, and state a function.

Prelab Question: Where in the digestive tract would you find epithelial tissue? What various functions could it have along the tract?

6.2 Connective Tissue
- Identify slides and models or diagrams of various types of connective tissue.
- Tell where a particular connective tissue is located in the body, and state a function.

Prelab Question: Name six types of connective tissue and give a location for each type in the body.

6.3 Muscular Tissue
- Identify slides and models or diagrams of three types of muscular tissue.
- Tell where each type of muscular tissue is located in the body, and state a function.

Prelab Question: Associate each type of muscular tissue with a particular organ (or organs) in the body.

6.4 Nervous Tissue
- Identify a slide and model or diagram of a neuron.
- Tell where nervous tissue is located in the body, and state a function.

Prelab Question: Which part of a neuron do you expect to see concentrated in the brain?

6.5 Tissues Form Organs
- Use a portion of the digestive tract to show that organs can contain four different types of tissue: epithelial, connective, muscular, and nervous tissues.

Prelab Question: Give an example of the levels of organization in the body.

*Application for Daily Living: Tissue Engineering*

Introduction

In our last laboratory, we studied a generalized cell, one that has no particular specialization. The cells in our body are usually specialized in structure and function, and these specialized cells congregate together in a tissue. So, for example, muscular tissue contains muscle cells that all have the same appearance and perform the same task. That is, each muscle cell can contract, and because of this, muscular tissue can contract.

While some organs of the body are known for having a particular type of tissue—for example, the brain contains nervous tissue and a muscle contains muscular tissue—other organs have several types of tissues. We will end this laboratory by taking a look at a portion of the digestive tract, which has several types of tissues. This will help you realize that tissues are not isolated in the body; instead, they are a part of a specialized organ.
6.1 Epithelial Tissue

Epithelial tissue (epithelium) forms a continuous layer, or sheet, over the entire body surface and most of the body's inner cavities. Externally, it forms a covering that protects the animal from infection, injury, and drying out. Some epithelial tissues produce and release secretions. Others absorb nutrients.

The name of an epithelial tissue includes two descriptive terms: the shape of the cells and the number of layers. The three possible shapes are squamous, cuboidal, and columnar. With regard to layers, an epithelial tissue may be simple or stratified. **Simple** means that there is only one layer of cells; **stratified** means that cell layers are placed on top of each other. Some epithelial tissues are **pseudostratified**, meaning that they only appear to be layered. Epithelium may also have cellular extensions called **microvilli**, or hairlike extensions called **cilia**. In the latter case, "ciliated" may be part of the tissue’s name.

**Observation: Simple Squamous Epithelium**

**Simple squamous epithelium** is a single layer of thin, flat, many-sided cells, each with a central nucleus. It lines internal cavities, the heart, and all the blood vessels. It also lines parts of the urinary, respiratory, and male reproductive tracts.

1. Study a model or diagram of simple squamous epithelium (Fig. 6.1). What does *squamous* mean?

2. Examine a prepared slide of squamous epithelium. Under low power, note the close packing of the flat cells. What shapes are the cells?

3. Under high power, examine an individual cell, and identify the plasma membrane, cytoplasm, and nucleus.

**Observation: Skin and Stratified Epithelium**

The skin covers the entire exterior of the human body, and because of its complex nature it is sometimes called the **integumentary system**. Skin functions include protection, water retention, sensory reception, body temperature regulation, and vitamin D synthesis.

**Skin Model**

Study a model or diagram and also a prepared slide of the skin. With the help of Figure 6.2, identify the two skin regions and the subcutaneous layer.

1. **Epidermis**: This region is composed of **stratified squamous epithelium**. The outer cells are nonliving and create a waterproof covering that prevents excessive water loss. These cells are always being replaced because an inner layer of the epidermis is composed of living cells that constantly produce new cells.
2. **Dermis:** This region is a connective tissue (p. 68) containing blood vessels, nerves, sense organs, and the expanded portions of oil (sebaceous) and sweat glands and hair follicles. List the structures you can identify on your slide:

3. **Subcutaneous layer:** This is a layer of loose connective tissue and adipose tissue (p. 68) that lies beneath the skin proper and serves to insulate and protect inner body parts. This layer is not part of the skin.

**Stratified Squamous Epithelium**

As would be expected from its name, stratified squamous epithelium consists of many layers of cells. The innermost layer produces cells that are first cuboidal or columnar in shape, but as the cells push toward the surface, they become flattened.

As mentioned, the outer region of the skin is stratified squamous epithelium. As the cells move toward the surface, they flatten, begin to accumulate a protein called **keratin**, and eventually die. Keratin makes the outer layer of epidermis tough, protective, and able to repel water.

The linings of the mouth, throat, anal canal, and vagina are also stratified epithelium. The outermost layer of cells surrounding the cavity is simple squamous epithelium. In these organs, this layer of cells remains soft, moist, and alive.

1. Examine a slide of stratified squamous epithelium.
2. Approximately how many layers of cells do you see? ________________________
3. Which layers of cells seem to be squamous epithelium? ________________________
**Observation: Simple Cuboidal Epithelium**

Simple cuboidal epithelium is a single layer of cube-shaped cells, each with a central nucleus. It is found in tubules of the kidney and in the ducts of many glands, where it has a protective function. It also occurs in the secretory portions of some glands, where the tissue produces and releases secretions.

1. Study a model or diagram of simple cuboidal epithelium (Fig. 6.3).
2. Examine a prepared slide of simple cuboidal epithelium. Move the slide until you locate cube-shaped cells that line a lumen (cavity).

**Observation: Simple Columnar Epithelium**

Simple columnar epithelium is a single layer of tall, cylindrical cells, each with a nucleus near the base. This tissue, which lines the digestive tract from the stomach to the anus, protects, secretes, and allows absorption of nutrients.

1. Study a model or diagram of simple columnar epithelium (Fig. 6.4).
2. Examine a prepared slide of simple columnar epithelium. Find tall and narrow cells that line a lumen. Under high power, focus on an individual cell. Identify the plasma membrane, the cytoplasm, and the nucleus. Epithelial tissues are attached to underlying tissues by a basement membrane composed of extracellular material containing protein fibers.
3. The tissue you are observing contains mucus-secreting cells. Search among the columnar cells until you find a goblet cell, so named because of its goblet-shaped, clear interior. This region contains mucus, which may be stained a light blue. In the living animal, the mucus is discharged into the gut cavity and protects the lining from digestive enzymes.

---

**Figure 6.3** Simple cuboidal epithelium.
Simple cuboidal epithelium lines kidney tubules and the ducts of many glands.

**Figure 6.4** Simple columnar epithelium.
Simple columnar epithelium lines the digestive tract. Goblet cells among the columnar cells secrete mucus.
**Observation: Pseudostratified Ciliated Columnar Epithelium**

**Pseudostratified ciliated columnar epithelium** appears to be layered, though actually all cells touch the basement membrane. Many cilia are located on the free end of each cell (Fig. 6.5). In the human trachea, the cilia wave back and forth, moving mucus and debris up toward the throat so that it cannot enter the lungs. Smoking destroys these cilia, but they will grow back if smoking is discontinued.

1. Study a model or diagram of pseudostratified ciliated columnar epithelium (Fig. 6.5).
2. Examine a prepared slide of pseudostratified ciliated columnar epithelium. Concentrate on the part of the slide that resembles the model. Identify the cilia.

**Figure 6.5** Pseudostratified ciliated columnar epithelium.
Pseudostratified ciliated columnar epithelium lines the trachea. The cilia help keep the lungs free of debris.

**Summary**
Identify the type of epithelial tissue.

---

**Laboratory 6  Body Tissues**  65
6.2 Connective Tissue

Connective tissue joins different parts of the body together. There are four general classes of connective tissue: connective tissue proper (loose fibrous, dense fibrous, and adipose), bone, cartilage, and blood. All types of connective tissue consist of cells surrounded by a matrix that usually contains fibers. Elastic fibers are composed of a protein called elastin. Collagenous fibers contain the protein collagen.

**Observation: Loose and Dense Fibrous Connective Tissue**

There are several different types of connective tissue. We will study loose fibrous connective tissue, dense fibrous connective tissue, adipose tissue, bone, cartilage, and blood. **Loose fibrous connective tissue** supports epithelium and many internal organs, such as muscles, blood vessels, and nerves (Fig. 6.6). Its presence allows organs to expand. **Dense fibrous connective tissue** contains many collagenous fibers packed together, as in tendons, which connect muscles to bones, and in ligaments, which connect bones to other bones at joints (Fig. 6.7).

1. Examine a slide of loose fibrous connective tissue, and compare it with Figure 6.7. What is the function of loose fibrous connective tissue?

2. Examine a slide of dense fibrous connective tissue, and compare it with Figure 6.8. What two types of structures in the body contain dense fibrous connective tissue?
Observation: Adipose Tissue

In adipose tissue, the cells have a large, central, fat-filled vacuole that causes the nucleus and cytoplasm to be at the perimeter of the cell (see Fig. 6.9). Adipose tissue occurs beneath the skin, where it insulates the body, and around internal organs, such as the kidneys and heart. It cushions and helps protect these organs.

1. Examine a prepared slide of adipose tissue. Why is the nucleus pushed to one side?

2. State a location for adipose tissue in the body.

What are two functions of adipose tissue at this location?

Observation: Compact Bone

Compact bone is found in the bones that make up the skeleton. It consists of osteons (Haversian systems), with a central canal, and concentric rings of spaces called lacunae, connected by tiny crevices called canaliculi. The central canal contains a nerve and blood vessels, which service bone. The lacunae contain bone cells called osteocytes, whose processes extend into the canaliculi. Separating the lacunae is a matrix that is hard because it contains minerals, notably calcium salts. The matrix also contains collagenous fibers.

1. Study a model or diagram of compact bone (Fig. 6.8). Then look at a prepared slide and identify the central canal, lacunae, and canaliculi.

2. What is the function of the central canal and canaliculi?

Figure 6.8  Compact bone.
Compact bone contains osteons, in which osteocytes within lacunae are arranged in concentric circles.

- vein
- nerve
- artery
- lamellae
- central canal
- canaliculi
- osteocyte in lacuna

enlarged portion of osteon

one osteon

Compact bone
- has cells in concentric rings
- occurs in bones of skeleton
- functions in support and protection.
**Observation: Hyaline Cartilage**

In hyaline cartilage, cells called **chondrocytes** are found in twos or threes in lacunae. The lacunae are separated by a flexible matrix containing weak collagenous fibers. Hyaline cartilage occurs in the nose and walls of respiratory passage; at ends of bone, including ribs. It functions in support and protection.

1. Study the diagram and photomicrograph of hyaline cartilage in Figure 6.9. Then study a prepared slide of hyaline cartilage, and identify the matrix, lacunae, and chondrocytes.

2. Compare slides of compact bone and hyaline cartilage. Which of these types of connective tissue is more organized? ____________________________

   Why? _____________________________________________________________________

3. Which of these two types of connective tissue lends more support to body parts? _____________________________________________________________________

---

**Figure 6.9  Connective tissues associated with the knee.**
The human knee provides examples of most types of connective tissue.
**Observation: Blood**

**Blood** is a connective tissue in which the matrix is an intercellular fluid called **plasma.** **Red blood cells** (erythrocytes) carry oxygen combined with the respiratory pigment hemoglobin. **White blood cells** (leukocytes) fight infection. Also present in blood are many small bodies, the **platelets,** which play a major role in clot formation.

1. Study a prepared slide of human blood. With the help of Figure 6.10, identify the numerous red blood cells and the less numerous but larger white blood cells, which appear faint because of the stain. As you scan your slide on high power, also look for the small platelets, the small objects scattered between the blood cells.

2. Try to identify a neutrophil, the most common type of white blood cell. A neutrophil has a multilobed nucleus.

**Figure 6.10 Neutrophil.**
*A neutrophil is a spherical white blood cell about 10–14 μm in diameter that has a multilobed nucleus and fine, pink granules in the cytoplasm. It is capable of phagocytizing pathogens.*

---

**6.3 Muscular Tissue**

Muscular (contractile) tissue is composed of cells called muscle fibers. Muscular tissue has the ability to contract, and contraction usually results in movement. The body contains skeletal, cardiac, and smooth muscle.

**Observation: Skeletal Muscle**

**Skeletal muscle** occurs in the muscles attached to the bones of the skeleton. The contraction of skeletal muscle is said to be **voluntary** because it is under conscious control. Skeletal muscle is striated; it contains light and dark bands. The striations are caused by the arrangement of contractile filaments (actin and myosin filaments) in muscle fibers. Each fiber contains many nuclei, all peripherally located.

1. Study a model or diagram of skeletal muscle (Fig. 6.11). Striations are present. You should see several muscle fibers, each marked with striations.

2. Examine a prepared slide of skeletal muscle. The striations may be difficult to make out, but bringing the slide in and out of focus may help.

**Figure 6.11 Skeletal muscle.**
*Skeletal muscle is striated and voluntary. Its cells are tubular and contain many nuclei.*
Observation: Cardiac Muscle

Cardiac muscle is found only in the heart. It is called involuntary because its contraction does not require conscious effort. Cardiac muscle is striated in the same way as skeletal muscle. However, the fibers are branched and bound together at intercalated disks, where their folded plasma membranes touch. This arrangement aids communication between fibers.

1. Study a model or diagram of cardiac muscle (Fig. 6.12). Striations are present.
2. Examine a prepared slide of cardiac muscle. Find an intercalated disk. What is the function of cardiac muscle?

Observation: Smooth Muscle

Smooth muscle is sometimes called visceral muscle because it makes up the walls of the internal organs, such as the intestines and the blood vessels. Smooth muscle is involuntary because its contraction does not require conscious effort.

1. Study a model or diagram of smooth muscle (Fig. 6.13), and note the shape of the cells and the centrally placed nucleus. Smooth muscle has spindle-shaped cells. What does spindle-shaped mean?

2. Examine a prepared slide of smooth muscle. Distinguishing the boundaries between the different cells may require you to bring the slide in and out of focus.

Figure 6.12 Cardiac muscle.
Cardiac muscle is striated and involuntary. Its branched cells join at intercalated disks.

Cardiac muscle
• has branching, striated cells, each with a single nucleus.
• occurs in the wall of the heart.
• functions in the pumping of blood.
• is Involuntary.

Figure 6.13 Smooth muscle.
Smooth muscle is nonstriated and involuntary. This type of muscle is composed of spindle-shaped cells.

Smooth muscle
• has spindle-shaped cells, each with a single nucleus.
• cells have no striations.
• functions in movement of substances in lumens of body.
• is Involuntary.
• is found in blood vessel walls and walls of the digestive tract.
6.4 Nervous Tissue

Nervous tissue is found in the brain, spinal cord, and nerves. Nervous tissue is composed of two types of cells: neurons that transmit messages and neuroglia that largely service the neurons. Motor neurons, which take messages from the spinal cord to the muscles, are often used to exemplify typical neurons (Fig. 6.14). Motor neurons have several dendrites, processes that take signals to a cell body, where the nucleus is located, and an axon that takes nerve impulses away from the cell body. Long axons are called nerve fibers.

Observation: Nervous Tissue

1. Study a model or diagram of a neuron, and then examine a prepared slide. Depending on the magnification, you may not be able to see neuroglial cells because they are small and cannot be seen at low magnification.
2. Identify the the parts of a motor neuron in Figure 6.14 and also the neuroglia. Label Figure 6.14a.
3. Explain the appearance and function of the parts of a motor neuron:
   a. Dendrites
   b. Cell body
   c. Axon

Figure 6.14 Motor neuron anatomy.

1. 
2. 
3. 
4. 
5. 
   a. Photomicrograph of a neuron 200x
   b. Drawing
6.5 Tissues Form Organs

There are only four types of tissues in the body: epithelial, connective, muscular, and nervous. To simplify matters, epithelial tissues form protective coverings; connective tissues connect other tissues; muscular tissues contract; and nervous tissues are sensitive to stimuli. None of these tissues occur in a vacuum. They are integral parts of an organ. We will take as our example a portion of the digestive tract shown in Figure 6.15.

The inner layer of the tract is called the mucosa. The mucosa is an inner lining of epithelial cells, some of which are glandular and secrete mucus. Epithelium performs a protective function; the mucus protects the other layers of the tract. Occasionally along the tract, some other epithelial cells are glandular and secrete digestive juices.

Beneath the epithelial lining, the submucosa is a connective tissue layer. Connective tissue binds together other tissues. As is often the case, lymphatic vessels, blood vessels, and nerves run along within the connective tissue layer.

Next, the muscularis has two layers of muscle tissue; the contraction of these layers mixes food and digestive juices in the tract. It also pushes the food along the tract. Muscles don’t contract unless they are stimulated to do so by nerves; nerves occur between the two layers of muscle.

Finally, the serosa is connective tissue that supports the digestive organs within the abdominal cavity.

Figure 6.15 Wall of the gastrointestinal tract.
The wall of the gastrointestinal tract contains the four layers noted.
You can apply what you know about the tissues in the digestive tract to any other organ in the body. No matter where you find these tissues, what do you expect them to do?

<table>
<thead>
<tr>
<th>Tissue</th>
<th>General Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epithelial tissue</td>
<td></td>
</tr>
<tr>
<td>Connective tissue</td>
<td></td>
</tr>
<tr>
<td>Muscular tissue</td>
<td></td>
</tr>
<tr>
<td>Nervous tissue</td>
<td></td>
</tr>
</tbody>
</table>

In the next laboratory, we will study the various systems of the body and learn that each organ system, such as the digestive system, contains several different types of organs. The digestive system contains the esophagus, stomach, small intestine, and large intestine. Use the digestive system to illustrate the levels of organization of the human body from an organ system to cells:

Name of organ system: ________________________________

Name of organs: __________________________________

Types of tissues in each organ: ______________________

Type of cell in a particular tissue type: ______________

---

**Application for Daily Living**

**Tissue Engineering**

Just a few years ago, scientists believed that transplant tissues and organs had to come directly from humans. Now, however, tissue engineering is demonstrating that it is possible to make replacement tissues and organs in the lab. For example, skin products have now been approved for use in humans. One is composed of dermal cells growing on a degradable polymer, which can be used to temporarily cover the wounds of burn patients while their own skin regenerates (Fig. 6.16). The other uses only live human skin cells to treat diabetic leg and foot ulcers. Similarly, the damaged cartilage of a knee can be replaced with a tissue produced after chondrocytes are harvested from a patient. Soon to come is a host of other products, including replacement corneas, heart valves, bladder valves, and breast tissue.

After nine years, researchers were able to produce a working urinary bladder in the laboratory. This bladder can be implanted in humans whose bladders have been damaged by accident or disease. Another group of scientists have been able to grow arterial blood vessels in the lab using a pig’s small intestine as the mold. Tissue engineers recently announced they had produced a human heart in the lab.

**Figure 6.16 Acid burn victim.**

This young woman, whose face was damaged by acid, received skin, produced in the laboratory, as a transplant.
Laboratory Review 6

1. What is the name for a group of cells that has the same structural characteristics and performs the same functions?
2. Which type of epithelium has flattened cells?
3. Name a body location for pseudostratified ciliated columnar epithelium.
4. What is the function of goblet cells?
5. What type of tissue occurs in the epidermis of the skin?
6. Name a body location for hyaline cartilage.
7. The cells of which tissue have a large, central, fat-filled vacuole?
8. What type of muscular tissue is involuntary and striated?
9. Name a body location for smooth muscle.
10. What types of muscular tissue are striated?
11. Name a body location for nervous tissue.
12. Where is the nucleus located in a nerve cell?
13. What type of tissue accounts for the movement of food along the digestive tract?
14. Which skin layer contains blood vessels?
15. What portion of a nerve cell transmits information away from the cell body?

Thought Questions

16. List the four major types of human body tissues and the distinguishing characteristics of each. Of what benefit does the human body contain all four types rather than a single type?

17. List five types of epithelial tissue and the distinguishing characteristics of each.

18. Your lab instructor gives you a slide containing prepared muscle tissue. How would you identify the type of muscle tissue located on the slide?

19. Why might an injury to a bone have a faster recovery/healing time when compared to a muscle or nerve cell?
7

Organization of the Body

Learning Outcomes

7.1 Human Torso Model
- State and give a function for organs in the mouth, thoracic cavity, neck region, and abdominal cavity.
  Prelab Question: State the path of food from the mouth to the anus.

7.2 External Anatomy of the Fetal Pig
- State four directive terms used when dissecting.
- Describe the external anatomy of a fetal pig.
- Tell how you would identify the gender of a fetal pig.
  Prelab Question: Aside from the mouth, name two orifices of the human body.

7.3 Oral Cavity and Pharynx
- Describe the general anatomy of the oral cavity and pharynx.
  Prelab Question: Explain why food does not enter the trachea.

7.4 Thoracic and Abdominal Incisions
- For those doing fetal pig dissections, describe the proper procedure for making incisions.
  Prelab Question: Why is it important to point scissors up and not down?

7.5 Neck Region
- Describe and state a function for the thymus gland, the larynx, the trachea, and the thyroid gland.
  Prelab Question: When might a physician be sure to check the size of the thyroid gland if a patient complains of feeling tired?

7.6 Thoracic Cavity
- Describe the position of the diaphragm.
  Prelab Question: Which is more posterior, the lungs or the liver? Explain.
- Describe the anatomy of the thoracic cavity, paying particular attention to the path of air.

7.7 Abdominal Cavity
- Describe the organs of the abdominal cavity, paying particular attention to the organs of the digestive system, the liver, and the gallbladder.
  Prelab Question: What attribute accounts for the small intestine being called the small intestine?
- Describe the organs of the urinary system and also the male and female reproductive systems.

Application for Daily Living: The Systems Work Together

Introduction

This laboratory will give you an opportunity to observe the organs of the fetal pig, a mammal, just as you are a mammal. You will be interested to know that investigators are in the process of genetically modifying pigs so that fetal pig organs can be used as transplant organs in humans.

Your instructor will decide whether you are to follow the directions for dissecting the fetal pig yourself or whether you are to observe the organs in pigs that have already been dissected. Also, virtual dissection of a human cadaver is possible using Anatomy and Physiology Revealed, available from McGraw-Hill Education at www.aprevealed.com.

We begin this laboratory by observing the organs to be dissected or observed in a pig by identifying the same organs in a human torso model.
7.1 Human Torso Model

As you know, most organs of the human body function as part of a particular system. Examination of the human torso model (Fig. 7.1) will allow you to learn the path of food in the digestive system, the path of air in the respiratory system, and the path of urine in the urinary system.

Figure 7.1 Human internal organs.

**Digestive System**

To trace the path of food in the digestive system, identify these organs in the human torso model:

- **mouth**: teeth chew the food and the tongue forms a bolus (ball of food). Note the roof of the mouth consisting of the hard palate and soft palate.
• esophagus: conducts food to the stomach
• stomach: stores food, some digestion
• small intestine: digests food to small molecules that are absorbed into the body
• large intestine: absorbs water; stores undigested remains until feces are expelled from the anus

Accessory Organs of Digestion
These organs assist the digestive organs but never contain food:
• liver: produces bile, an emulsifier of fat
• gallbladder: stores bile
• pancreas: produces digestive enzymes that function in the small intestine

Respiratory System
To trace the path of air in the respiratory system, identify the
• nasal passages: in nose
• nasopharynx: takes air to pharynx
• pharynx: back of throat
• glottis: opening to trachea, closed by epiglottis
• larynx: (voice box) top part of trachea
• trachea: conducts air to bronchi
• bronchi: conducts air to lungs

Urinary System
To trace the path of urine, identify the
• kidneys: produce urine
• urinary bladder: stores urine
• urethra: conducts urine out of the body

Other Organs
Other organs include the
• heart, which is part of the cardiovascular system, which also contains blood vessels.
• thyroid gland, which produces the hormone thyroxin, and pancreas; which produces the hormones insulin and glucagon; the thyroid gland and pancreas which are part of the endocrine system.
• thymus gland, spleen, and appendix, which are part of the lymphatic system because they contain lymphatic tissue. The spleen also purifies the blood.

7.2 External Anatomy of the Fetal Pig
Perspective is important in dissections. If an animal is lying facedown, top and bottom mean something different than when the animal is lying on its back. For this reason, this manual uses the following terms, which are identified in Figure 7.2a:

Dorsal: a body part located toward the back
Ventral: a body part located toward the front
Anterior: a body part located toward the head
Posterior: a body part located toward the rear

Preparation of Pig for Dissection
1. Place the fetal pig on its back in the dissecting pan.
2. Tie a cord around one forelimb, and then bring the cord around underneath the pan to fasten back the other forelimb.
3. Spread the hindlimbs in the same way.
Figure 7.2  External anatomy of the fetal pig.
a. Directional terms and body regions. b, c. The sexes can be distinguished by the external genitals.

Observation: External Anatomy

These observations can be done by all students.

Body Regions

1. Externally, observe the following body regions: the rather large head; the short, thick neck; the cylindrical trunk with two pairs of appendages (forelimbs and hindlimbs); and the short tail (Fig. 7.2a).

Umbilical Cord

1. Fetal pigs have an umbilical cord arising from the ventral portion of the abdomen. Fetal pigs have not been born yet, and this is why they have a prominent umbilical cord. The function of the umbilical cord is to
bring oxygen and nutrients from the mother’s circulation to the fetus and return oxygen and waste to the mother’s circulation.

**Nipples and Hair**

Like all *mammals*, pigs and humans have mammary glands and hair.

1. Nipples, the external openings of the *mammary glands*, are not an indication of sex, because both males and females possess them.
2. Pigs have a few whiskers, the only indication of hair.

**Anus and External Genitals**

1. The anus, an opening under the tail, is a part of what system in the body? 

2. Females have a *urogenital opening*, just anterior to the anus, and a small, fleshy *urogenital papilla* projecting from the urogenital opening (Fig. 7.2b).
3. Males have a urogenital opening just posterior to the umbilical cord. The duct leading to it runs forward from between the legs in a long, thick tube, the *penis*, which can be felt under the skin. In males, the urinary system and the genital system are always joined (Fig. 7.2c).

### 7.3 Oral Cavity and Pharynx

All students will use Figure 7.3 to make these observations:

The **oral cavity** is the space in the **mouth** that contains the **tongue** and the **teeth**. What system of the body includes the tongue and teeth?

The **hard palate** is the ridged roof of the mouth that separates the oral cavity from the nasal passages. The **soft palate** is a smooth region posterior to the hard palate. An extension of the soft palate—the uvula—hangs down into the throat in humans. (A pig does not have an uvula.)

**Observation: Oral Cavity and Pharynx**

If you are doing a pig dissection, follow these directions. If you are observing a pig that has already been dissected or are doing a virtual dissection, answer the questions and proceed to Section 7.5.

**Oral Cavity**

1. Insert a sturdy pair of scissors into one corner of the specimen’s mouth, and cut posteriorly (toward the hind end) for approximately 4 cm. Repeat on the opposite side.
2. Place your thumb on the tongue at the front of the mouth, and gently push downward on the lower jaw. This will tear some of the tissue in the angles of the jaws so that the mouth will remain partly open (Fig. 7.3).
3. Note small, underdeveloped teeth in both the upper and lower jaws. Other embryonic, nonerupted teeth may also be found within the gums. The teeth are used to chew food.

**Figure 7.3 Oral cavity of the fetal pig.**
The roof of the oral cavity contains the hard and soft palates. The tongue lies above the floor of the oral cavity.
4. Examine the tongue, partly attached to the lower jaw region but extending posteriorly and attached to a bony structure at the back of the oral cavity (Fig. 7.3).
5. Locate the hard and soft palates (Fig. 7.3).

**Pharynx**

1. Push down on the tongue until you open the jaws far enough to see a slightly pointed flap of tissue pointing dorsally (toward the back) (Fig. 7.3). This flap is the epiglottis, which covers the glottis. The glottis leads to the trachea (Fig. 7.4).
2. Posterior and dorsal to the glottis, find the opening into the esophagus. Note the proximity of the glottis and the opening to the esophagus. Each time the pig—or a human—swallows, the epiglottis shifts position, closing the glottis to keep food and fluids from going into the lungs via the trachea.
3. Insert a blunt probe into the glottis, and it enters the trachea. Remove the probe, insert it into the esophagus, and note the position of the esophagus beneath, or dorsal to, the trachea.
4. Make a midline cut in the soft palate from the epiglottis to the hard palate. Then make two lateral cuts at the edge of the hard palate.
5. Posterior to the soft palate, locate the openings to the nasal passages.
6. Explain why it is correct to say that the air and food passages cross in the pharynx.

---

**Figure 7.4  Air and food passages in the fetal pig.**
The air and food passages cross in the pharynx.

---

**7.4 Thoracic and Abdominal Incisions**

Notice that there is a slash in the right neck region of preserved pigs, indicating the site of blood drainage. A red latex solution was injected into the arterial system, and a blue latex solution was injected into the venous system of the pig. Therefore, when a vessel appears red, it is an artery; and when a vessel appears blue, it is a vein. Do not confuse this color pattern with circulatory diagrams that differentiate O₂-rich blood flow and O₂-poor blood flow by using red- and blue-colored vessels, respectively.

If you are observing a pig that has been dissected or doing a virtual dissection, proceed to Section 7.5.

If you are doing a pig dissection, consult Figure 7.5 and make the following incisions with scissors pointing up and never down to expose the thoracic and abdominal cavities.

**Incisions**

1. Cut anteriorly up from the diaphragm, a muscle that separates the thoracic cavity from the abdominal cavity, until you reach the hairs in the throat region.
2. Make two lateral cuts, one on each side of the midline incision anterior to the forelimbs, taking extra care not to damage the blood vessels around the heart.
3. Make two lateral cuts, one on each side of the midline just posterior to the forelimbs and anterior to the diaphragm, following the ends of the ribs. Pull back the flaps created by these cuts to expose the thoracic cavity. List the organs you find in the thoracic cavity.
Figure 7.5 Ventral view of the fetal pig indicating incisions.
These incisions are to be made preparatory to dissecting the internal organs. The incisions are numbered here in the order they should be done.

4. With scissors pointing up, cut posteriorly from the diaphragm to the umbilical cord.
5. Make a flap containing the umbilical cord by cutting a semicircle around the cord and by cutting posteriorly to the left and right of the cord.
6. Make two cuts, one on each side of the midline incision posterior to the diaphragm. Examine the diaphragm, attached to the chest wall by radially arranged muscles. The central region of the diaphragm, called the central tendon, is a membranous area.
7. Make two more cuts, one on each side of the flap containing the umbilical cord and just anterior to the hindlimbs. Pull back the side flaps created by these cuts to expose the abdominal cavity.
8. Lifting the flap with the umbilical cord requires cutting the umbilical vein. Before cutting the umbilical vein, tie a thread on each side of where you will cut to mark the vein for future reference.
7.5 Neck Region
All students will use Figure 7.6 to make these observations:

1. The larynx, or voice box, is part of the trachea, or windpipe, which leads to the lungs. The glottis is the opening to the trachea in the pharynx. The trachea is held open by cartilaginous rings. Why is that advantageous?

2. Unlike humans, the thymus gland is located in the neck region of a fetal pig. The thymus gland is a part of the lymphatic system. Certain white blood cells called T (for thymus) lymphocytes mature in the thymus gland and help fight disease.

3. The thyroid gland is ventral to the trachea. It secretes hormones that travel in the blood and act upon other body cells, causing their metabolism to speed up. These hormones (e.g., thyroxine) regulate the rate at which metabolism occurs in cells.

4. The esophagus opens into the pharynx but it travels through the neck region and through the diaphragm to reach the stomach. Is the esophagus located ventral to or dorsal to the trachea?

---

Figure 7.6 The neck region of the fetal pig.
The trachea, including the larynx, is in the neck region. Various other organs are also in the neck region.

---

Observation: Neck Region
If you are doing a pig dissection or are observing a pig that has been dissected, follow these directions. If you are not doing either, proceed to Section 7.6.

Use Figure 7.6 as a guide, but keep all the flaps on your pig so you can close the thoracic and abdominal cavities at the end of the laboratory session. Never remove any organs from a fetal pig; you will want to review them later.
**Thymus Gland**

1. Move the skin apart in the neck region just below the hairs mentioned earlier. If necessary, laterally cut the body wall to make flaps. You will most likely be viewing exposed muscles.
2. Cut through and clear away muscle to expose the thymus gland, a diffuse gland that lies among the muscles. The thymus is particularly large in fetal pigs, because their immune systems are still developing.

**Trachea and Esophagus**

1. Probe down into the deeper layers of the neck. Medially (toward the center), beneath several strips of muscle, you will find the hard-walled larynx, the upper part of the trachea. Dorsal to the trachea, find the esophagus.
2. Open the mouth and insert a probe into the glottis and esophagus from the pharynx to better understand the orientation of these two organs.

**Thyroid Gland**

Locate the thyroid gland just posterior to the larynx, lying ventral to the trachea.

---

### 7.6 Thoracic Cavity

All students will use Figure 7.7 to make these observations:

The body cavity of mammals, including humans, is divided by the **diaphragm** (horizontal sheet of muscle and connective tissue) into the **thoracic cavity** (above) and the **abdominal cavity** (below). These organs are easily observable in the thoracic cavity:

1. The **heart** pumps the blood into attached arteries, blood vessels that take blood away from the heart. The heart is surrounded by the **pericardial membrane,** which prevents friction between organs. The heart is a part of which system in the body?  

2. The trachea divides into the **bronchi,** which enter the **lungs.** The lungs are enclosed by **pleural membrane.** The lungs are a part of which system in the body?  

3. The lungs carry on gas exchange with the external environment and with the blood. The right lung has four lobes and the left lung has three lobes.

**Observation: Thoracic Cavity**

If you are doing a pig dissection or are observing a pig that has been dissected, follow these directions. If you are doing a virtual dissection, proceed to Section 7.7.

**Heart and Lungs**

1. If you have not yet done so, fold back the chest wall flaps. To do this, you will need to tear the thin membranes that divide the thoracic cavity into three compartments: the left **pleural cavity** containing the left lung, the right pleural cavity containing the right lung, and the **pericardial cavity** containing the heart.
2. Examine the lungs. Locate the four lobes of the right lung and the three lobes of the left lung. The trachea, dorsal to the heart, divides into the bronchi, which enter the lungs. Later, when the heart is removed, you will be able to see the trachea and bronchi.

**Summary: Respiratory System**

Trace the path of air in the respiratory system from pharynx to lungs.
Figure 7.7 Internal anatomy of the fetal pig.
Most of the major organs are shown in this photograph. For the sake of visibility, the incisions have not preserved the entire diaphragm. The stomach has been removed. The spleen, gallbladder, and pancreas are not visible. **Do not remove any organs or flaps from your pig.**
7.7 Abdominal Cavity

All students will use Figure 7.7 to make these observations:

The abdominal wall and organs are lined by a connective tissue membrane called peritoneum. Double-layered sheets of peritoneum, called mesenteries, project from the body wall and support the organs.

1. The abdominal cavity contains organs of the digestive system, including the stomach, small intestine, and large intestine. The stomach stores food and has numerous gastric glands that secrete gastric juice, which digests protein. The small intestine is the part of the digestive tract that receives secretions from the pancreas and gallbladder. Ducts from these organs enter the duodenum, the first part of the small intestine. Besides being an organ for the digestion of all components of food—carbohydrate, protein, and fat—the small intestine absorbs the products of digestion: glucose, amino acids, glycerol, and fatty acids. The large intestine is the part of the digestive tract that absorbs water and prepares feces for defecation at the anus. The main portion of the large intestine is the colon, which first runs anteriorly and then horizontally before turning posteriorly again. In the pelvic region, the rectum is the last portion of the large intestine. The rectum leads to the anus.

2. The abdominal cavity also contains the accessory organs of digestion. These organs send substances to the digestive tract and never contain food. The liver, the largest organ in the abdomen (Fig. 7.7), performs numerous vital functions, including disposing of worn-out red blood cells, producing bile, storing glycogen, maintaining the blood glucose level, and producing blood proteins. The gallbladder stores and releases bile, which aids the digestion of fat. A duct from the gallbladder takes bile to the small intestine. Bile is an emulsifier that breaks up fat into smaller fat droplets, enabling better access by digestive enzymes. The pancreas is both an exocrine and an endocrine gland. As an exocrine gland, it produces and secretes pancreatic juice, which digests all the components of food in the small intestine. Both bile and pancreatic juice enter the duodenum by way of ducts. As an endocrine gland, the pancreas secretes the hormones insulin and glucagon into the bloodstream.

Observation: Abdominal Cavity

If you are doing a pig dissection or observing a pig that has already been dissected, follow these directions. If you are doing a virtual dissection, answer the questions.

Liver

1. If your particular pig is partially filled with dark, brownish material, take your animal to the sink and rinse it out. This material is clotted blood. Consult your instructor before removing any red or blue latex masses, because they may enclose organs you will need to study.

2. Locate the liver, a large, brown organ. Its anterior surface is smoothly convex and fits snugly into the concavity of the diaphragm.

3. Name several functions of the liver.

Stomach

1. Push aside and identify the stomach, a large sac dorsal to the liver on the left side.

2. Locate the point near the midline of the body where the esophagus penetrates the diaphragm and joins the stomach.

Small Intestine

1. Look posteriorly where the stomach makes a curve to the right and narrows to join the anterior end of the small intestine. The first part of the small intestine is called the duodenum.

2. From the duodenum, the small intestine runs posteriorly for a short distance and is then thrown into an irregular mass of bends and coils held together by a common mesentery.
3. The small intestine is a part of what system? ________________________________
   What is its function? ________________________________

**Gallbladder and Pancreas**

1. Locate the bile duct, which runs in the mesentery stretching between the liver and the duodenum.
   Find the gallbladder, embedded in the liver on the underside of the right lobe. It is a small, greenish sac.
2. Lift the stomach and locate the pancreas, the light-colored, diffuse gland lying in the mesentery between the stomach and the small intestine. The pancreas has a duct that empties into the duodenum of the small intestine.
3. What is the function of the gallbladder? ________________________________
4. How does the pancreas assist the digestion of food? ________________________________

**Large Intestine**

1. Locate the distal (far) end of the small intestine, which joins the large intestine posteriorly, in the left side of the abdominal cavity (right side in humans). At this junction, note the cecum, a blind pouch.
2. Follow the main portion of the large intestine, known as the colon, as it runs from the point of juncture with the small intestine into a tight coil (spiral colon), out of the coil anteriorly, and then posteriorly again along the midline of the dorsal wall of the abdominal cavity. In the pelvic region, the rectum is the last portion of the large intestine. The rectum leads to the anus.
3. The large intestine is a part of what system? ________________________________
4. What is the function of the large intestine? ________________________________

**Summary: Digestive System**

Trace the path of food from the mouth to the anus. ________________________________

**Kidneys and Associated Structures**

1. The large, paired kidneys (Fig. 7.8) are reddish organs covered by peritoneum, a membrane that lines the abdominal cavity. Clean the peritoneum away from one of the kidneys, and study it more closely.
2. Locate the ureters, which leave the kidneys and run posteriorly under the peritoneum.
3. Clean the peritoneum away, and follow a ureter to the urinary bladder, which normally lies in the posterior ventral portion of the abdominal cavity. The urinary bladder is on the inner surface of the flap of tissue to which the umbilical cord was attached.
4. The urethra, which arises from the bladder posteriorly, runs parallel to the rectum. Follow the urethra until it passes from view into the ring formed by the pelvic girdle.

**Summary: Urinary System**

Trace the path of urine from the kidneys to the urethral opening. ________________________________

**Ovaries and Associated Structures in Female Pigs**

1. Locate the paired ovaries, small bodies suspended from the peritoneal wall in mesenteries, posterior to the kidneys (Fig. 7.8).
2. Closely examine one ovary. Note the small, short, coiled oviduct, sometimes called the fallopian tube. The oviduct does not attach directly to the ovary but ends in a funnel-shaped structure with fingerlike processes (fimbriae) that partially enclose the ovary.
3. Locate the **uterine horns**. (Do not confuse the uterine horns with the oviducts; the latter are much smaller and are found very close to the ovaries.)

4. Find the median body of the uterus located at the joined posterior ends of the uterine horns.

5. Separate the hind limbs of your specimen, and cut down along the midventral line. The cut will pass through muscle and the cartilaginous pelvic girdle. With your fingers, spread the cut edges apart, and use blunt dissecting instruments to separate connective tissue.

6. Note three ducts passing from the body cavity to the animal’s posterior surface. One of these is the urethra, which leaves the bladder and passes into the **urogenital sinus**. The urethra is a part of the urinary system. The most dorsal of the three ducts is the **rectum**, which passes to its own opening, the **anus**. The rectum and anus are part of the digestive system, not the reproductive system.

7. Find the vagina, located dorsally to the urethra. The vagina is the birth canal and is also the organ of copulation. Anteriorly, it connects to the uterus, and posteriorly it enters the urogenital sinus. This sinus is absent in adult humans and several other female mammals.

**Testes and Associated Structures in Male Pigs**

1. Locate the opening of the left inguinal canal, which leads to the left scrotal sac (Fig. 7.9).

2. Expose the canal and sac by making an incision through the skin and muscle layers from a point over this opening back to the left scrotal sac.

3. Open the sac, and find the testis. Note the much-coiled tubule—the epididymis—that lies alongside the testis. This is continuous with the vas deferens, which passes back toward the abdominal cavity.

4. Trace a vas deferens as it loops over an umbilical artery and ureter and unites with the urethra dorsally at the posterior end of the urinary bladder. The urethra passes into the penis and ends at the urogenital opening (see Fig. 7.2c).
Figure 7.9  Male urinary and reproductive systems of the fetal pig.
In males, the urinary system and the reproductive system are joined. The vasa deferentia (sing. vas deferens) enter the urethra, which also carries urine.

If so directed by your instructor:
1. Cut through the ventral skin surface just posterior to the umbilical cord. This will expose the rather undeveloped penis, which extends from this point posteriorly toward the anus. The central duct of the penis is the urethra.
2. Lay the penis to one side, and then cut down through the ventral midline, laying the legs wide apart in the process (Fig. 7.9). The cut will pass between muscles and through pelvic cartilage (bone has not developed yet). Do not cut any of the ducts or tracts in the region.
3. You will now see the urethra passing ventrally above the rectum. It is associated with certain accessory glands:
   a. Bulbourethral glands, about 1 cm in diameter, lie laterally and well back toward the anal opening.
   b. The prostate gland, about 4 mm across and 3 mm thick, is located on the dorsal surface of the urethra, just posterior to the juncture of the bladder with the urethra. It is often difficult to locate and is not shown in Figure 7.9.
   c. Small, paired seminal vesicles may be seen on either side of the prostate gland.
4. Trace the urethra as it leaves the bladder. It proceeds posteriorly, but when it nears the posterior end of the body, it turns rather abruptly anteroventrally and runs forward just under the skin of the midventral body wall, where you have just dissected it. This latter portion of the urethra is, then, within the penis.
5. Now you should also be able to see the entrance of the vasa deferentia into the urethra. If necessary, dissect these structures free from surrounding tissue, and expose the point of entrance of these ducts into the urethra near the location of the prostate gland. In males, the urethra transports sperm, as well as urinary wastes from the bladder.
Application for Daily Living

The Systems Work Together
This laboratory has involved a number of different systems, including the respiratory system, the cardiovascular system, and the digestive system. Can one of these systems malfunction without negatively affecting the other systems? Likely not. For example, if you climb a high mountain and can’t breathe adequately, the cardiovascular system will not be able to deliver oxygen to your cells (Fig. 7.10). Or, if you go on a hunger strike, the cardiovascular system will not be able to deliver glucose to your cells. Without oxygen and glucose, even your heart will not be able to continue beating. Blood vessels not only deliver oxygen and glucose to the heart; they also take these molecules to the lungs and the walls of the digestive tract.

In the body as in the environment, everything is connected to everything else. The systems work together under the direction of the nervous and endocrine systems as a harmonious whole so that your cells and you can continue to function as you should.

Figure 7.10 The systems work together.
The cardiovascular system receives nutrients from the digestive tract and oxygen from the respiratory system, which it delivers to the cells. It also delivers CO₂ and other wastes from the cells to the respiratory system and urinary system respectively.

Storage of Pigs
1. Before leaving the laboratory, place your pig in the plastic bag provided.
2. Expel excess air from the bag, and tie it shut.
3. Write your name and section on the tag provided, and attach it to the bag. Your instructor will indicate where the bags are to be stored until the next laboratory period.
4. Clean the dissecting tray and tools, and return them to their proper location.
5. Wipe off your goggles. Wash your hands.
Laboratory Review 7

1. In the fetal pig, what sex has a urogenital opening beneath the papilla just superior to the anus?

2. What two anatomical features do all mammals, including pigs and humans, have?

3. The esophagus connects the pharynx with which organ?

4. What is the hard portion of the roof of the mouth called?

5. What is the opening to the trachea called?

6. Name the largest organ in the abdominal cavity.

7. What structure separates the thoracic cavity from the abdominal cavity?

8. Name the structure just dorsal to the thyroid gland.

9. What structure covers the glottis?

10. If a probe is placed through the glottis, it will enter what structure?

11. The heart is located in what major cavity?

12. What other major organs, surrounded by the pleural membranes, are in the same cavity?

13. The stomach connects to what part of the small intestine?

14. The pancreas belongs to what two systems of the body?

15. Where do air and food passages cross one another?

16. What organ releases bile?

Thought Questions

17. What difficulty would probably arise if a person were born without an epiglottis?

18. The small intestine exists as a series of folds and coils. What might be the advantage of such a configuration?

19. Difficulties maintaining blood glucose level, bile production, and the production of blood proteins might be associated with problems in what organ?

20. How do the male and female reproductive systems differ?

McGraw-Hill Access Science Website
An online encyclopedia of science and technology that provides information, including videos, that can enhance the laboratory experience.

www.accessscience.com
Cardiovascular System

Learning Outcomes

8.1 The Heart
- Name the four chambers of the heart and the blood vessels attached to these chambers.
- Trace the path of blood through the heart, naming the chambers and the valves in proper order.
- Describe the conduction system of the heart, including the nodes that control the heartbeat.
  Prelab Question: Which side of the heart pumps O$_2$-poor blood and which side pumps O$_2$-rich blood?

8.2 Heartbeat and Blood Pressure
- Describe the heartbeat, including the sounds that occur when the heart beats.
- Relate blood pressure to the beat of the heart.
- Show blood pressure rises with exercise and offer an explanation.
  Prelab Question: Relate normal blood pressure (120/80) to the beat of the heart.

8.3 The Blood and Blood Flow
- Distinguish between red blood cells and the various types of white blood cells.
- Explain the ABO system of blood typing and how blood type is determined.
- Describe the structure and function of arteries, veins, and capillaries.
- Name the major blood vessels and trace the path of blood in both the pulmonary and systemic circuits.
  Prelab Question: Relate the axiom “structure suits function” to the function of the different types of blood cells.

Application for Daily Living: High Blood Pressure

Introduction

The heart and blood vessels form the cardiovascular system. The heart is a double pump that (1) keeps the blood flowing in one direction—blood flows away from and then back to the heart; (2) keeps O$_2$-poor blood separate from O$_2$-rich blood; and (3) creates blood pressure, which moves the blood through the blood vessels. The blood vessels, on the other hand, (1) transport blood and its contents, (2) serve the needs of the body’s cells by carrying out exchanges with them, and (3) direct blood flow to those systemic tissues that most require it at the moment.

We will make note of these functions again as we first study the structure and beat of the heart and how its beat brings about blood pressure. Following that, we concentrate on the composition of blood, how it is typed, and how it circulates in the body.

A thoracic cavity contains the heart and lungs.
8.1 The Heart

The heart has right and left sides divided by the septum. To tell the right from the left side, position Figure 8.1 so it corresponds to your body. There are four chambers: two upper, thin-walled atria and two lower, thick-walled ventricles. The heart has valves that keep the blood flowing in one direction; special muscles and tendons secure the valves to prevent backflow from the ventricles to the atria. The right side of the heart sends blood to the lungs, and the left side sends blood into the body. Therefore, the heart is called a double pump.

Observation: External Anatomy of the Heart

1. In a heart model and/or a sheep heart, identify the right atrium and its attached blood vessels, the superior and inferior venae cavae (Fig. 8.1). The superior vena cava and the inferior vena cava return blood from the head and body, respectively, to the right atrium. Is the blood that enters the right atrium, O₂-poor or O₂-rich? Explain.

2. Identify the right ventricle and its attached blood vessel, the pulmonary trunk. The pulmonary trunk leaves the ventral side of the heart from the top of the right ventricle and then passes diagonally forward, before branching into the right and left pulmonary arteries.

3. Identify the left atrium and its attached blood vessels, the left and right pulmonary veins. The pulmonary veins return blood from the lungs to the left atrium. Is the blood that enters the left atrium O₂-poor or O₂-rich? Explain.

4. Identify the left ventricle and its attached blood vessel, the aorta, which arises from the anterior end of the left ventricle, just dorsal to the origin of the pulmonary trunk. The aorta soon bends to the animal’s left as the aortic arch. The aorta carries blood to the body proper.

Figure 8.1 External heart anatomy.

a. Human heart. b. Sheep heart.
5. Identify the **coronary arteries** and the **cardiac veins**, which service the needs of the heart wall. The coronary arteries branch off the aorta as soon as it leaves the heart and appear on the surface of the heart. The cardiac veins, also on the surface of the heart, join and then enter the right atrium through the coronary sinus on the dorsal side of the heart.

**Observation: Internal Anatomy of the Heart**

Remove the ventral half of the human heart model (Fig. 8.2) and/or sheep heart. You are going to remove the top portion of the heart to achieve a view similar to Figure 8.3b. Position the heart same as it is in Figure 8.2. Using a sharp scalpel, cut through the left atrium and the left ventricle to the apex of the heart, being sure your cut is deep enough to reach the septum. Now position the heart so that the apex is uppermost. Using a sharp scalpel, cut from the apex of the heart through the right atrium, being sure your cut is deep enough to reach the septum of the heart.

1. Identify the four chambers of the heart in longitudinal section: right atrium, right ventricle, left atrium, and left ventricle. *Label Figure 8.2.*

2. Which ventricle is more muscular? ____________________________
   Why is this appropriate? __________________________________________

3. Find the **right atrioventricular** (tricuspid) valve, located between the right atrium and the right ventricle.
4. Find the **left atrioventricular** (bicuspid or mitral) valve, located between the left atrium and the left ventricle.
5. Find the **pulmonary semilunar** valve, located in the base of the pulmonary trunk.
6. Find the **aortic semilunar** valve, located in the base of the aorta. What is the function of the heart valves? __________________________________________

7. Note the **chordae tendineae** ("heartstrings") that hold the atrioventricular valves in place while the heart contracts. These extend from the papillary muscles. The chordae tendineae prevent the atrioventricular valves from inverting into the atria when the ventricles contract.
8. If inspecting a sheep heart, insert a probe into the various vessels from the outside into the heart chambers. Identify the vessel and the chamber.

**Figure 8.2** Internal heart anatomy.

*a.* Human heart. *b.* Sheep heart.

---

*Latex gloves* Wear protective latex gloves when handling preserved animal organs. Use protective eyewear and exercise caution when using sharp instruments during this laboratory. Wash hands thoroughly upon completion of this laboratory.
Summary

To demonstrate that O₂-poor blood is kept separate from O₂-rich blood, trace the path of blood from the right side of the heart to the aorta by filling in the following blanks.

**Venae Cavae**

--- valv
e
--- valv
e
--- valv

**Lungs**

--- valv

**Aorta**

Which side of the heart (right or left) pumps O₂-poor blood?

Which side pumps O₂-rich blood?

---

Physiology of the Heart

The heartbeat is controlled by nodal tissue. The SA node is the pacemaker of the heart because it initiates the heartbeat and sends an excitation impulse every 0.85 seconds, causing the atria to contract. After the impulse reaches the AV node, it passes into large fibers and, thereafter, spreads out by way of the smaller Purkinje fibers (Fig. 8.3a). These fibers signal the ventricles to contract.

With the contraction of any muscle, including the heart, electrolyte changes occur that can be detected by electrical recording devices. Therefore, it is possible to study the heartbeat by recording voltage changes that occur when the heart contracts. The record that results is called an electrocardiogram (ECG). The first wave in the electrocardiogram, called the P wave, occurs prior to the excitation and contraction of the atria. The second wave, the QRS wave, occurs prior to ventricular excitation and contraction. The third wave, the T wave, is caused by the recovery of the ventricles. (Atrial relaxation is not apparent in an ECG.) Examination of an ECG indicates whether the heartbeat has a normal or an irregular pattern (Fig. 8.3b).

1. Note the SA (sinoatrial) node in Figure 8.3a.
2. Explain Figure 8.3b by answering these questions:

   Why is an arrow drawn between the SA node and the P wave?

   Why is an arrow drawn between the AV node and the QRS wave?

   The voltage changes in an ECG are related to the

---

**Figure 8.3 Control of the heartbeat.**

a. The SA node sends out a stimulus that causes the atria to contract. When this stimulus reaches the AV node, it signals the ventricles to contract by way of the atrioventricular bundle and Purkinje fibers. b. A normal ECG indicates that the heart is functioning properly. The P wave indicates that the atria are about to contract; the QRS wave indicates that the ventricles are about to contract; and the T wave indicates that the ventricles are recovering from contraction.
**Experimental Procedure: Electrocardiogram**

1. Electrodes will be placed on the wrists and ankles, so the subject should remove any jewelry from these areas. The subject then lies down on a cot or table close to the electrocardiograph.
2. Clean the electrode placement areas with alcohol swabs and apply a small quantity of electron cream to these areas.
3. Similarly spread electrode cream on the inner surfaces of four electrode plates before attaching one to each of the four sites on the subject. The electrode plate on the right ankle is the grounding system.
4. A selector switch allows various combinations of electrodes to be activated. Attach the leads from the electrodes to the corresponding cables of the lead selector switch.
   - Lead I measures the potential difference between the right wrist and the left wrist.
   - Lead II measures the potential difference between the right wrist and the left ankle.
   - Lead III measures the potential difference between the left wrist and the left ankle.
5. Record the ECG for Lead I, Lead II, and Lead III for one minute each. Then remove the electrodes and clean the cream from the metal and skin of the subject.
6. Do the ECGs you recorded resemble that in Fig. 8.3? Explain.

---

**8.2 Heartbeat and Blood Pressure**

In this section, we will examine the heartbeat and blood pressure. The beat of the heart creates blood pressure.

**Heartbeat**

During a heartbeat, first the atria contract and then the ventricles contract. When a chamber contracts, it is called **systole**; when a chamber relaxes, it is called **diastole**. The atria and ventricles take turns being in systole:

<table>
<thead>
<tr>
<th>Time</th>
<th>Atria</th>
<th>Ventricles</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.15 sec</td>
<td>Systole</td>
<td>Diastole</td>
</tr>
<tr>
<td>0.30 sec</td>
<td>Diastole</td>
<td>Systole</td>
</tr>
<tr>
<td>0.40 sec</td>
<td>Diastole</td>
<td>Diastole</td>
</tr>
</tbody>
</table>

Usually, there are two heart sounds with each heartbeat. The first sound (lub) is low and dull and lasts longer than the second sound. It is caused by the closure of the atroventricular valves following atrial systole. The second sound (dub) follows the first sound after a brief pause. The sound has a snapping quality of higher pitch and shorter duration. The sound is caused by the closure of the semilunar valves following ventricle systole.

**Experimental Procedure: Heartbeat at Rest**

In the following procedure, you will work with a partner and use a stethoscope to listen to the heartbeat. It will not be necessary for you to count the number of beats per minute.

1. Obtain a stethoscope, and properly position the earpieces. They should point forward. Place the bell of the stethoscope on the left side of your partner's chest between the fourth and fifth ribs. This is where the apex (tip) of the heart is closest to the body wall.
2. Which of the two sounds (lub or dub) is louder?

3. Now switch, and your partner will determine your heartbeat.

**Blood Pressure**

Blood pressure is highest just after ventricular systole, and it is lowest during ventricular diastole.

Why?

We would expect a person to have lower blood pressure readings at rest than after exercise.

Why?

---

**Experimental Procedure: Blood Pressure at Rest and After Exercise**

A number of different types of digital blood pressure monitors are available, and your instructor will instruct you on how to use the type you will be using for this Experimental Procedure. The normal resting blood pressure readings for a young adult are 120/80 (systolic/diastolic), as displayed on the monitor shown in Figure 8.4.

You may work with a partner or by yourself. If working with a partner, each of you will assist the other in taking blood pressure readings. After you have noted the blood pressure readings, also note the pulse reading.

**Blood Pressure at Rest**

1. Reduce your activity as much as possible.
2. Use the blood pressure monitor to obtain several blood pressure readings, average them, and record your results in Table 8.1.

**Blood Pressure After Exercise**

1. Run in place for 1 minute.
2. Immediately use the blood pressure monitor to obtain a blood pressure reading, and record it in Table 8.1.

---

![Image of blood pressure monitor](image)

**Figure 8.4 Measurement of blood pressure and pulse.**

There are many different types of digital blood pressure/pulse monitors now available. The one shown here uses a cuff to be placed on the arm. Others use a cuff for the wrist.

---

**Table 8.1 Blood Pressure**

<table>
<thead>
<tr>
<th></th>
<th>Blood Pressure at Rest</th>
<th>Blood Pressure After Exercise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Partner</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yourself</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Conclusion: Blood Pressure

- Recall that in Laboratory 1, you determined that exercise increases the heart rate. Knowing this, offer an explanation for your results.

- Under what conditions in everyday life would you expect the heart rate and the blood pressure to increase, even though you are not exercising? When might this be an advantage? A disadvantage?

8.3 The Blood and Blood Flow

Blood appears to be a somewhat viscous, homogeneous fluid. However, analysis shows it to be a fluid tissue, composed of plasma (the fluid portion) and formed elements (including the cells and platelets).

Red and White Blood Cells

There are two categories of blood cells: red blood cells (erythrocytes) and white blood cells (leukocytes). Red blood cells are smaller than white blood cells, and they lack a nucleus, which enables them to carry the maximum amount of oxygen. Red blood cells appear red because they contain the respiratory pigment hemoglobin. Each red blood cell lasts about 120 days in circulation.

White blood cells are larger than red blood cells, and they have a nucleus. The white blood cells are translucent if not stained; there are five different types (Fig. 8.5). White blood cells fight infection, and the white blood cell count is used by doctors to help diagnose diseases. The time white blood cells are in circulation is variable.

Figure 8.5 The white blood cells.

a. A neutrophil has a lobed nucleus with two to five lobes. b. An eosinophil has red-staining granules. c. A basophil has deep-blue-staining granules. d. A monocyte is the largest of the blood cells. e. A lymphocyte contains a large, round nucleus. (a–c, e: Magnification ×400; d: Magnification ×500)
**Observation: Blood Slide**

1. Observe a prepared blood smear slide on high power, and note the biconcave (concave on both sides) red blood cells and the less numerous white blood cells. Also, differentiate the two types of cells according to their size and the presence or absence of a nucleus.
2. Complete Table 8.2.

<table>
<thead>
<tr>
<th>Table 8.2 Slide of Blood</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Relative Number</strong></td>
</tr>
<tr>
<td>Red blood cells</td>
</tr>
<tr>
<td>White blood cells</td>
</tr>
</tbody>
</table>

**Observation: White Blood Cell Slide**

1. Observe the demonstration slides under oil immersion. With the help of Figure 8.5, identify the different types of white blood cells, which have been stained with Wright stain.
2. Identify the **granular leukocytes:**
   - Neutrophils have cytoplasmic granules; the nucleus is multilobed with two to five connected parts.
   - Neutrophils are, therefore, called polymorphonuclear leukocytes.
   - Eosinophils have granules that stain deep red. The nucleus is bilobed.
   - Basophils have granules that stain deep blue. The nucleus is bilobed.
3. Identify the **agranular leukocytes:**
   - Monocytes are the largest of the white blood cells. The nucleus varies in shape.
   - Lymphocytes are usually only slightly larger than red blood cells and typically have a relatively large, round nucleus surrounded by a thin rim of cytoplasm.

**ABO Blood Typing**

Red blood cells have surface molecules called antigens that indicate they belong to the person. In the ABO system, the presence or absence of an A antigen and/or a B antigen determines the blood type. In this system, there are four types of blood: A, B, AB, and O. Within the plasma, there are antibodies to the antigens that are not on the red blood cells as described in this chart.

<table>
<thead>
<tr>
<th>Blood Type</th>
<th>Antigen on Red Blood Cells</th>
<th>Antibody in Plasma</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>A</td>
<td>Anti-B</td>
</tr>
<tr>
<td>B</td>
<td>B</td>
<td>Anti-A</td>
</tr>
<tr>
<td>AB</td>
<td>A, B</td>
<td>None</td>
</tr>
<tr>
<td>O</td>
<td>None</td>
<td>Anti-A and Anti-B</td>
</tr>
</tbody>
</table>

Blood type also indicates whether the person has an Rh factor, another type of antigen, on the red blood cells. This designation is attached to the ABO blood type as in A-positive or A-negative. It is customary to simply attach a positive or negative sign to A-negative and A-positive, which are compound words.
Experimental Procedure: ABO Blood Typing

Use the precautions given in the warning box, because the synthetic products used in this exercise can be harmful to the skin.

1. Obtain 3 testing plates, each of which contains three depressions; vials of persons 1, 2, and 3 blood; vials of anti-A serum, anti-B serum, and anti-Rh serum.
2. Using a wax pencil, number the plates so you know which plate is for which person #1, #2, or #3. Look carefully at the plate and notice the wells are designated as A, B, or Rh.
3. Being sure to close the cap to each vial in turn,
   Add a drop of person #1 blood to all three wells of plate #1—close the cap.
   Add a drop of anti-A (blue) to the well designated A—close the cap.
   Add a drop of anti-B (yellow) to the well designated B—close the cap.
   Add a drop of anti-Rh (clear) to the well designated Rh—close the cap.
4. Stir the contents of each well with a mixing stick of the correct color. After a few minutes, examine the wells for agglutination, i.e., granular appearances that indicate the blood type. (Rh-positive takes the longest to react.) If a person is AB-positive, which wells would show agglutination? 
5. Record the blood type results for each person here:
   Person #1 ________
   Person #2 ________
   Person #3 ________

Blood Flow

Blood must circulate to serve the body. The heart pumps the blood, which moves away from the heart in arteries and arterioles and returns to the heart in venules and veins. Capillaries connect arterioles to venules. Capillaries branch to form capillary beds that close when precapillary sphencters contract; in this way, capillaries direct the blood flow to regions that need it most (Fig. 8.6). When a capillary bed is closed, blood moves directly from the arteriole to the venule by way of the arteriovenous shunt.

Figure 8.6  Anatomy of blood vessels.
Observation: Blood Vessel Comparison

1. Obtain a microscope slide that shows an artery and a vein in cross section.
2. View the slide, under both low and high power; with the help of Figure 8.6a, determine which is the artery and which is the vein. Identify the outer layer, which contains many collagen and elastic fibers and often appears white in specimens. Identify the middle layer, the thickest layer, composed of smooth muscle and elastic tissue. Does this layer appear thicker in arteries than in veins? __________

Identify the inner layer, a wavy lining of simple squamous epithelial cells called the endothelium. In veins, the endothelium forms valves that keep the blood moving toward the heart. Veins are larger and more "flabby" than arteries. Why might that be based on the structure of their walls?

Experimental Procedure: Blood Flow

Observe blood flow through arterioles, capillaries, and venules, either in a videoclip, in the tail of a goldfish, or in the webbed skin between the toes of a frog. Observe the pulse and the swiftly moving blood in the arterioles. Contrast this with the more slowly moving blood that circulates in the opposite direction in the venules. Many criss-crossing capillaries are visible. Look for blood cells floating in the bloodstream.

Do you see any? ____________________________

Conclusions: Blood Flow

- Which type of blood vessel (arteries or veins) has thicker walls? ____________________________ Why is this advantageous?
- Which type of blood vessel has thinner walls? ____________________________ Why is this advantageous?

- Which type of blood vessel has valves? ____________________________ Compare the direction of the flow of blood in the aorta to that in the inferior vena cava. Why is this advantageous for veins to have valves? ____________________________

Path of Blood in Adult Humans

The right side of the heart pumps blood into the pulmonary circuit—to the lungs and back to the heart (Fig. 8.7). While the blood is in the lungs, it gives up carbon dioxide and gains oxygen. The left side of the heart, consisting of two chambers, pumps blood to the systemic circuit—throughout the whole body except the lungs. Blood in the systemic circuit gives up oxygen and gains carbon dioxide.

Figure 8.7 shows how to trace the path of blood in both the pulmonary and systemic circuits in adult humans. It will also assist you in learning the names of some of the major blood vessels.

Pulmonary and Systemic Circuits

1. Trace the path of blood in the pulmonary circuit from a chamber of the heart to the lungs, and then from the lungs to a chamber of the heart. Follow the arrows in Figure 8.7, and use the names of the blood vessels provided there. ____________________________

2. Trace the path of blood in the systemic circuit from the heart to the kidneys, and then from the kidneys to the heart. ____________________________
Figure 8.7  Diagram of the human cardiovascular system.
In the pulmonary circuit, the pulmonary arteries take O₂-poor blood to the lungs, and the pulmonary veins return O₂-rich blood to the heart. In the systemic circuit, the aorta branches into the various arteries that go to all other parts of the body. After blood passes through arterioles, capillaries, and venules, it enters various veins and then the superior and inferior venae cavae, which return it to the heart.

3. Is it true that all arteries carry O₂-rich blood and all veins carry O₂-poor blood? Explain the color of the pulmonary blood vessels in Figure 8.7.

4. A portal system is a vein that begins in capillaries and ends in capillaries. For example, the hepatic portal vein begins in capillaries at the digestive tract and ends in capillaries at the liver. Trace the path of blood from the aorta to the inferior vena cava by way of the hepatic portal vein.
Names of Blood Vessels

Use Figures 8.7 and 8.8 to complete Table 8.3 by stating the name of the artery that takes blood to the body part and the name of the vein that takes blood away from the body part.

Figure 8.8  The major arteries and veins of the systemic circuit.
This illustration offers a more realistic representation of major blood vessels (arteries and veins) of the systemic circuit.
Table 8.3  Major Blood Vessels in the Systemic Circuit

<table>
<thead>
<tr>
<th>Body Part</th>
<th>Artery</th>
<th>Vein</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Head</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arms</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kidney</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Legs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intestines</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Application for Daily Living

High Blood Pressure

Blood pressure is an indication of cardiovascular health because high blood pressure at rest is associated with clogged arteries that impede blood flow. Blood should flow freely to all parts of the body and especially to the heart because it has to pump the blood to keep it moving about the body. Unfortunately, the carotid arteries, which serve the heart, are the ones most apt to become clogged with fatty deposits called plaque.

Optimal blood pressure at rest is at or below 120/80. (These numbers are in mm Hg, a way to measure pressure, and systolic blood pressure is given first.) Prehypertension occurs when systolic pressures are between 120 and 139 and diastolic pressures are between 80 and 89 mm Hg. Hypertension, or high blood pressure, occurs when systolic pressure exceeds 140 and diastolic pressure exceeds 90, as in 150/95.

Age (over 55), male gender, and African-American ethnicity are all risk factors for developing plaque in the arteries. However, blood pressure can be improved through adequate exercise, good diet, loss of weight, not smoking, and reduced stress.
Laboratory Review 8

1. What type of blood cells are lymphocytes and monocytes?
2. Nutrients exit and wastes enter which type of blood vessel?
3. Which blood cells contain a respiratory pigment?
4. Which chamber of the heart receives venous blood from the systemic circuit?
5. Identify the vessel that conducts blood from the left ventricle.
6. The pulmonary trunk leaves which chamber?
7. Identify the artery that nourishes the heart tissue.
8. Which heart chamber pumps blood to the body proper?
9. Which is higher—systolic or diastolic pressure?
10. Identify the pacemaker region of the heart.
11. Does the pulmonary artery in adults carry O₂-rich or O₂-poor blood?
12. Which type of blood shows no reaction to anti-A and anti-B serum.
13. Identify the artery that serves the kidney.
14. Identify the arteries that take blood from the aorta to the legs.
15. What part of the human body is served by a subclavian vessel?
16. Identify the large abdominal vein that runs alongside the aorta and enters the right atrium.
17. Which type of blood vessel (artery or vein) has valves?

Thought Questions

18. What might be the significant result of nonfunctional or defective chordae tendineae?

19. During a heart attack, cardiac muscle cells are deprived of their blood supply, yet the atria are still receiving blood. Explain.

20. Evaluate the following statement: All arteries carry O₂-rich blood and all veins carry O₂-poor blood. Based on what you have learned in this laboratory, is this statement correct? Explain.
11 Homeostasis

Learning Outcomes

Introduction
- Define homeostasis and the internal environment.

11.1 Kidneys
- Understand kidney and nephron structure and blood supply.
- State the three steps in urine formation and how they relate to the parts of a nephron.
- Perform a urinalysis and explain how the results are related to kidney functions.
- Prelab Question: What substance will be present in urine if a person has diabetes mellitus?

11.2 Lungs
- Describe the mechanics of breathing and the role of the alveoli in gas exchange.
- Explain how the excretion of CO\(_2\) helps stabilize the pH of the blood.
- Measure respiratory volumes (e.g., tidal volume) and explain their relationship to homeostasis.
- Prelab Question: When CO\(_2\) exits blood at the alveoli, how does the pH of blood change?

11.3 Liver
- Describe the anatomy of the liver, including the path of blood from the intestines, through the liver and to the heart.
- Compare the glucose level in the mesenteric artery, the hepatic portal vein, and the hepatic vein before and after eating.
- State two ways the liver contributes to homeostasis.
- Prelab Question: What hormone causes the liver to store glucose as glycogen?

Application for Daily Living: The Liver is a Vital Organ

Introduction
Homeostasis refers to the dynamic equilibrium of the body's internal environment. The internal environment of humans consists of blood and tissue fluid. To meet their needs, cells take nutrients (e.g., glucose) and O\(_2\) from the blood and return waste products, including CO\(_2\), to the blood by way of tissue fluid. Tissue fluid in turn exchanges molecules with the blood. Homeostasis also involves adjusting blood pH, ionic concentrations, and blood volume. All internal organs contribute to homeostasis, but this laboratory specifically examines the contributions of the kidneys, lungs, and the liver.
Negative Feedback

Two systems in the body, the endocrine (hormone) system and the nervous system, work together to regulate homeostasis, the relative constancy of the internal environment (blood and tissue fluid). Both systems operate by utilizing negative feedback. For example, when you eat a candy bar and your blood glucose rises, an endocrine gland called the pancreas senses the rise in blood sugar and releases the hormone insulin (Fig. 11.1). Insulin causes the liver to store glucose as glycogen, maintaining blood sugar level at a normal level. The drop in blood sugar level is negative feedback that causes the pancreas to stop secreting insulin. Similarly, when blood pressure lowers, the brain sends out impulses to the smooth muscles of arterioles to constrict, raising blood pressure. This rise in blood pressure is negative feedback that causes the brain to stop sending nerve impulses to the arterioles; they relax and the blood pressure lowers.

As you study the operation of the kidneys, lungs, and the liver in this laboratory, realize that negative feedback ultimately is what enables these organs to maintain homeostasis.

Figure 11.1 Examples of negative feedback.
a. After a nerve impulse is received, constriction of blood vessels raises the blood pressure. b. After insulin is received, blood sugar uptake lowers the amount of sugar in the blood to normal.
11.1 Kidneys

In Laboratory 7, we learned that the kidneys are bean-shaped organs that lie along the dorsal wall of the abdominal cavity. Now we wish to study kidney structure and function. Figure 11.2 shows the macroscopic and microscopic structure of a kidney. The macroscopic structure of a kidney is due to the placement of over 1 million nephrons. Nephrons are tubules that do the work of producing urine.

**Figure 11.2** Longitudinal section of a kidney.
- a. The kidneys are served by the renal artery and renal vein. 
- b. Macroscopically, a kidney has three parts: renal cortex, renal medulla, and renal pelvis. 
- c. Microscopically, each kidney contains over a million nephrons.

**Observation: Kidney Structure**

Study a model of a kidney, and with the help of Figure 11.2, locate the following:

1. **Renal cortex**: a granular region that contains most regions of the nephrons
2. **Renal medulla**: contains the renal pyramids consisting of the loops of nephrons and collecting ducts
3. **Renal pelvis**: where urine is received from the collecting ducts

**Observation: Nephron Structure**

Study the nephron model and with the help of Figure 11.3, identify the following parts of a nephron:

1. **Glomerular capsule** (Bowman’s capsule): closed end of the nephron pushed in on itself to form a cuplike structure; the inner layer has pores that allow glomerular filtration to occur; substances move from the blood to inside the nephron
2. **Proximal convoluted tubule**: The inner layer of this region has many microvilli that allow tubular reabsorption to occur; substances move from inside the nephron to the blood.
3. **Loop of the nephron:** Nephron narrows to form a U-shaped portion. Functions in water reabsorption.

4. **Distal convoluted tubule:** second convoluted section that lacks microvilli and functions in tubular secretion; substances move from blood to inside nephron.

Several nephrons enter one collecting duct. The **collecting ducts** also function in water reabsorption, and they conduct urine to the pelvis of a kidney.

---

**Figure 11.3  Nephron structure and blood supply.**

The three main processes in urine formation are described in boxes and color coded to arrows that show the movement of molecules out of or into the nephron at specific locations. In the end, urine is composed of the substances within the collecting duct (see brown arrow).
**Observation: Circulation About a Nephron**

Study a nephron model and with the help of Figure 11.3 and Table 11.1, trace the path of blood about a nephron:

1. **Afferent arteriole**: small vessel that conducts blood from the renal artery to a nephron.
2. **Glomerulus**: capillary network that exists inside the glomerular capsule; small molecules move from inside the capillary to the inside of the glomerulus during glomerular filtration.
3. **Efferent arteriole**: small vessel that conducts blood from the glomerulus to the peritubular capillary network.
4. **Peritubular capillary network**: surrounds the proximal convoluted tubule, the loop of the nephron, and the distal convoluted tubule.
5. **Venule** takes blood from the peritubular capillary network to the renal vein.

<table>
<thead>
<tr>
<th>Name of Structure</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Afferent arteriole</td>
<td>Brings arteriolar blood toward glomerular capsule</td>
</tr>
<tr>
<td>Glomerulus</td>
<td>Capillary tuft enveloped by glomerular capsule</td>
</tr>
<tr>
<td>Efferent arteriole</td>
<td>Takes arteriolar blood away from glomerular capsule</td>
</tr>
<tr>
<td>Peritubular capillary network</td>
<td>Capillary bed that envelopes the rest of the nephron</td>
</tr>
<tr>
<td>Venule</td>
<td>Takes venous blood away from the nephron</td>
</tr>
</tbody>
</table>

**Kidney Function**

The kidneys produce urine and in doing so help maintain homeostasis in several ways. Urine formation requires three steps: glomerular filtration, tubular reabsorption, and tubular secretion (see Fig. 11.3).

**Glomerular Filtration**

1. Blood entering the glomerulus contains blood cells, proteins, glucose, amino acids, salts, urea, and water. Blood cells and proteins are too large to pass through the glomerular wall and enter the filtrate.
2. Blood pressure causes small molecules of glucose, amino acids, salts, urea, and water to exit the blood and enter the glomerular capsule. The fluid in the glomerular capsule is called the filtrate.
3. In the list that follows, *draw an arrow* from left to right for the small substances that leave the glomerulus and become a part of the filtrate.

   - **Glomerulus**
   - Glomerular Filtrate
   - Cells
   - Proteins
   - Glucose
   - Amino acids
   - Urea
   - Water and salts

4. Complete the second and third columns in Table 11.2, p. 137. Use an X to indicate that the substance is at the locations noted.
**Tubular Reabsorption**

1. When the filtrate enters the proximal convoluted tubule, it contains glucose, amino acids, urea, water, and salts. Some water and salts remain in the nephron but enough are passively reabsorbed into the peritubular capillary to maintain blood volume and blood pressure. Use this information to state a way kidneys help maintain homeostasis.

2. The cells that line the proximal convoluted tubule are also engaged in active transport and usually completely reabsorb nutrients (glucose and amino acids) into the peritubular capillary. What would happen to cells if the body lost all its nutrients by way of the kidneys?

3. Which of the filtrate substances is reabsorbed the least and will become a part of urine? Urea is a nitrogenous waste. State here another way kidneys contribute to homeostasis.

4. In the list that follows, draw an arrow from left to right for all those molecules passively reabsorbed into the blood of the peritubular capillary. Use darker arrows for those that are reabsorbed completely by active transport.

   **Proximal Convoluted Tubule**  
   Water and salts
   Glucose
   Amino acids
   Urea

   **Peritubular Capillary**

**Tubular Secretion**

During tubular secretion, certain substances—for example, penicillin and histamine—are actively secreted from the peritubular capillary into the fluid of the tubule. Also, hydrogen ions (\(H^+\)) and ammonia (\(NH_3\)) are secreted as \(NH_4^+\) as necessary.

   The excretion of \(H^+\) in this way raises the pH of the blood. State here a third way the kidneys contribute to homeostasis.

   We learned earlier that the lungs help raise the pH of the blood by excreting \(CO_2\) but only the kidneys can excrete \(H^+\).

**Summary: Kidney Function and Homeostasis**

For each substance listed at the left in Table 11.2, place an X in the last column if you expect the substance to be present in urine.

Answer the following questions.

1. The presence of urea in the urine illustrates which of the kidney’s functions?

   Do the kidneys make urea?   What organ makes urea?

   What do the kidneys produce?

2. The presence of \(NH_4^+\) in the urine illustrates which of the kidney’s functions?

3. Regulation of the blood’s water and salt content by the kidneys helps maintain within normal limits.
Table 11.2  Urine Constituents

<table>
<thead>
<tr>
<th>Substance</th>
<th>In Blood of Glomerulus</th>
<th>In Filtrate</th>
<th>In Urine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protein (albumin)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glucose and amino acids</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urea</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water and salts</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NH₄⁺</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Urinalysis: A Diagnostic Tool

Urinalysis can indicate whether the kidneys are functioning properly or whether an illness such as diabetes mellitus is present. The procedure is easily performed with a Chemstrip test strip, which has indicator spots that produce specific color reactions when certain substances are present in the urine.

Experimental Procedure: Urinalysis

A urinalysis has been ordered, and you are to test the urine. (In this case, you will be testing simulated urine, just as you tested simulated blood sera earlier in this lab.)

Assemble Supplies

1. Obtain three Chemstrip urine test strips, each of which tests for leukocytes, pH, protein, glucose, ketones, and blood, as noted in Figure 11.4.
2. The color key on the diagnostic color chart or on the Chemstrip vial label will explain what any color changes mean in terms of the pH level and amount of each substance present in the urine sample. You will use these color blocks to read the results of your test.
3. Obtain three “specimen containers of urine” marked 1 through 3. Among them is a normal specimen and two that indicate the patient has an illness.

![Chemstrip test strip diagram]

Figure 11.4  Urinalysis test.
A Chemstrip test strip can help determine illness in a patient by detecting substances in the urine. The normal test results are given for comparative purposes.
Test the Specimen

1. Be sure the chemically treated patches on the test strip are totally immersed. Briefly (no longer than 1 second) dip a test strip into the first specimen of urine.
2. Draw the edge of the strip along the rim of the specimen container to remove excess urine.
3. Turn the test strip on its side, and tap once on a piece of absorbent paper to remove any remaining urine and to prevent the possible mixing of chemicals.
4. After 60 seconds, read the results as follows: Hold the strip close to the color blocks on the diagnostic color chart (Fig. 11.4) or vial label, and match carefully, ensuring that the strip is properly oriented to the color chart. Enter the test results in Figure 11.4. Use a negative symbol (−) for items that are not present in the urine, a plus symbol (+) for those that are present, and a number for the pH.
5. Test the other two specimens. Add these results to Figure 11.4.

Conclusion: Urinalysis

- State below if the urinalysis is normal or indicates a urinary tract infection (leukocytes, blood, and possibly protein in the urine) or the patient has diabetes mellitus (glucose in the urine).
  
  Test results 1
  
  Test results 2
  
  Test results 3

- The hormone insulin promotes the uptake of glucose by cells. When glucose is in the urine, either the pancreas is not producing insulin (diabetes mellitus type 1) or cells are resistant to insulin (diabetes mellitus type 2). Ketones (acids) are also in the urine because the cells are metabolizing fat instead of glucose.
  
  Explain why cells are metabolizing fat.
  
  Why is the pH of urine lower than normal?

- If urinalysis shows that proteins are excreted instead of retained in the blood, would capillary exchange in the tissues be normal? Why or why not?

11.2 Lungs

In Laboratory 7, we learned that air moves from the nasal passages to the trachea, bronchi, bronchioles, and finally, lungs. The right and left lungs lie in the thoracic cavity on either side of the heart. A lung is a spongy organ consisting of irregularly shaped air spaces called alveoli (sing., alveolus). The alveoli are lined with a single layer of squamous epithelium and are supported by a mesh of fine, elastic fibers. The alveoli are surrounded by a rich network of tiny blood vessels called pulmonary capillaries.

Observation: Lung Structure

1. Observe a prepared slide of a stained section of a lung. In stained slides, the nuclei of the cells forming the thin alveolar walls appear purple or dark blue (Fig. 11.5a).
2. Look for areas with groups of red- or orange-colored, disk-shaped erythrocytes (red blood cells). When these appear in strings, you are looking at capillary vessels in side view.
3. In some part of the slide, you may even observe an artery. Thicker, circular or oval structures with a lumen (cavity) are cross sections of bronchioles, tubular pathways through which air reaches the air spaces.
Lung Function

1. Lungs carry out gas exchange.

During gas exchange in the lungs, carbon dioxide (CO₂) leaves the blood within the pulmonary capillaries, and oxygen (O₂) leaves the alveoli and enters the blood. Show gas exchange in Figure 11.5b by writing O₂ or CO₂ on the lines provided. After the lungs take up O₂, it is transported by hemoglobin (Hb) inside red blood cells as HbO₂. In the tissues, Hb releases O₂ (Fig. 11.6). Why do cells require oxygen?

2. The lungs help maintain the pH of the blood.

Carbon dioxide is carried in the blood as bicarbonate ions:

\[
\text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{CO}_3 \rightarrow \text{HCO}_3^- + \text{H}^+ \\
\text{carbonic acid} \quad \text{bicarbonate ion} \quad \text{hydrogen ions}
\]

Hydrogen ions increase the acidity of blood. Is blood more acidic when it is carrying carbon dioxide? Explain your answer.

As CO₂ leaves the blood, this reaction reverses:

\[
\text{HCO}_3^- + \text{H}^+ \rightarrow \text{H}_2\text{CO}_3 \rightarrow \text{CO}_2 + \text{H}_2\text{O}
\]

Is blood less acidic when the carbon dioxide exits? Explain your answer.

During breathing cessation, it is the increase in acidity rather than the depletion of oxygen that first stimulates the urge to breathe. Chemoreceptors located in the aorta and carotid arteries detect changes in the blood’s acidity and stimulate the respiratory center, which triggers contractions in the diaphragm and thoracic muscles, causing alterations in the rate and depth of breathing.
**Figure 11.6** Exchange of gases at the pulmonary capillaries and at the systemic capillaries.

**Summary: Lung Function and Homeostasis**

1. Gas exchange assists homeostasis because it supplies cells with __________ needed for __________ and rids the body of __________, a metabolic waste.

2. When the lungs excrete CO₂, they help maintain the __________ of the blood. This is the second way that the lungs help maintain homeostasis.

**Human Respiratory Volumes**

Breathing in, called inspiration or inhalation, is the active part of breathing because that's when contraction of rib cage muscles causes the rib cage to move up and out, and contraction of the diaphragm causes the diaphragm to lower. Due to an enlarged thoracic cavity, air is drawn into the lungs. Breathing out, called expiration or exhalation, occurs when relaxation of these same muscles causes the thoracic cavity to resume its original capacity. Now air is pushed out of the lungs (Fig. 11.7).
Figure 11.7 Inspiration and expiration.

a. Inspiration occurs after the rib cage moves up and out and the diaphragm moves down. Air rushes in because of the expanded thoracic cavity. b. Expiration occurs as the rib cage moves down and in and the diaphragm moves up. As the thoracic cavity gets smaller, air is pushed out.

Experimental Procedure: Human Respiratory Volumes

During this Experimental Procedure you will be working with a spirometer, an instrument that measures the amount of exhaled air (Fig. 11.8). Normally, about 500–600 ml of air move into and out of the lungs with each breath. This is called the tidal volume (TV). You can inhale deeply after a normal breath and more air will enter the lungs; this is the inspiratory reserve volume (IRV). You can also force more air out of your lungs after a normal breath; this is the expiratory reserve volume (ERV). Vital capacity is the volume of air that can be forcibly exhaled after forcibly inhaling.

Tidal Volume (TV)

1. When it’s your turn to use the spirometer, install a new disposable mouthpiece and set the spirometer to zero.
2. Inhale normally, then exhale normally (with no extra effort) through the mouthpiece of the spirometer. Record your measurement in Table 11.3.

Figure 11.8 Nine-liter student wet spirometer.

<table>
<thead>
<tr>
<th>Tidal Volume (TV)</th>
<th>Expiratory Reserve Volume (ERV)</th>
<th>Vital Capacity (VC)</th>
<th>Inspiratory Reserve Volume (IRV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st</td>
<td>1st</td>
<td>1st</td>
<td></td>
</tr>
<tr>
<td>2nd</td>
<td>2nd</td>
<td>2nd</td>
<td></td>
</tr>
<tr>
<td>3rd</td>
<td>3rd</td>
<td>3rd</td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>ml</td>
<td>Average ml</td>
<td>Calculated value = ml</td>
</tr>
</tbody>
</table>

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3. Three readings are needed, so twice more set the spirometer to zero and repeat the same procedure. Record your measurements in Table 11.3.
4. Later, if necessary, change your readings to milliliters (ml), and calculate your average TV in ml.
   In your own words, what is tidal volume?

---

**Expiratory Reserve Volume (ERV)**

1. Make sure the spirometer is set to zero.
2. Inhale and exhale normally and then force as much air out as possible into the spirometer. Record your measurement in Table 11.3.
3. Three readings are needed, so twice more set the spirometer to zero and repeat the same procedure. Record your measurements in Table 11.3.
4. Later, if necessary, change your readings to ml, and calculate your average ERV.
   In your own words, what is expiratory reserve volume?

---

**Vital Capacity (VC)**

1. Make sure the spirometer is set to zero.
2. Inhale as much as possible and then exhale as much as possible into the spirometer.
3. Three readings are needed, so twice more set the spirometer to zero and repeat the same procedure. Record your measurements in Table 11.3.
4. Later, if necessary, change your readings to ml, and calculate your average VC.
   In your own words, what is vital capacity?

---

** Inspiratory Reserve Volume (IRV)**

It will be necessary for us to calculate IRV because a spirometer only measures exhaled air, not inhaled air. Explain:

From having measured vital capacity (VC) you can see that VC = TV + IRV + ERV. To calculate IRV, simply subtract the average TV + the average ERV from the value you recorded for the average VC:

\[
IRV = VC - (TV + ERV) = \underline{\text{ml}}. \text{ Record your IRV in Table 11.3.}
\]

**Conclusions: Human Respiratory Volumes**

• Vital capacity varies with age, sex, and height; however, typically for men vital capacity is about 5,200 ml and for women it is about 4,000 ml. How does your vital capacity compare to the typical values for your gender? \underline{\text{If smaller than normal, are you a smoker or is there any health reason why it would be smaller? If larger than normal, are you a sports enthusiast or do you play a musical instrument that involves inhaling and exhaling deeply?}}
• Diffusion alone accounts for pulmonary gas exchange. Therefore, how does good lung ventilation assist gas exchange? \underline{\text{}}

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11.3 Liver

As we learned in Laboratory 7, the liver, which is the largest organ in the body, lies mainly to the right under the diaphragm. The liver has two main lobes and the lobes are further divided into lobules, which contain the cells of the liver, called hepatic cells (Fig. 11.9a).

**Observation: Liver Structure**

Study a model of the liver, and identify the following:

1. **Right and left lobes:** The liver has two lobes. The right lobe is larger than the left lobe. Each lobe has many lobules. Each lobule has many cells.
2. **Hepatic artery:** the blood vessel that transports O₂-rich blood to the liver
3. **Hepatic portal vein:** the blood vessel that transports blood containing nutrients from the intestine to the liver (Fig. 11.9b).
4. **Hepatic veins:** the blood vessels that transport O₂-poor blood out of the liver to the inferior vena cava

**Liver Function**

The liver has many functions in homeostasis, and this lab will study two of these.

1. **The liver produces urea.**

The liver removes amino groups (—NH₂) from amino acids and converts them to urea. **Urea** is the primary nitrogenous end product of metabolism that is excreted by the kidneys. What remains of the amino acid (a hydrocarbon) can be used by the body in a number of ways.

**Figure 11.9 Anatomy of the liver.**

a. Liver lobule. b. The hepatic portal vein lies between the digestive tract and the liver. The hepatic portal vein lies between the digestive tract and the liver. The hepatic veins enter the inferior vena cava which returns blood to the heart.
In the chemical formula for urea that follows, circle the portions that would have come from amino groups:

\[
\begin{align*}
  &O \\
  &\parallel \\
  &\text{NH}_2\text{C}-\text{NH}_2
\end{align*}
\]

2. The liver regulates the blood glucose level.

After you eat, blood glucose level rises. This increase is detected by the pancreas, which in response releases the hormone insulin. Insulin causes the liver to store excess glucose as glycogen. Before your next meal, the drop in blood sugar causes the pancreas to release glucagon, a hormone that promotes the liver to break down glycogen and release glucose.

Complete the following equation by writing glucose and glycogen on the appropriate sides of the arrows.

\[\text{released by liver} \quad \underbrace{\text{(1) after eating}} \quad \text{stored in liver} \quad \underbrace{\text{(2) before next meal}}\]

If glucose is excreted in the urine, instead of being stored, the individual has the medical condition called diabetes mellitus, commonly known as diabetes. In type 1 diabetes, the pancreas is no longer making insulin; in type 2 diabetes, the plasma membrane receptors are unable to bind properly to insulin. In type 1 diabetes, but not type 2, ketones (strong organic acids), a breakdown product of fat metabolism, also appear in the urine.

**Experimental Procedure: Blood Glucose Level After Eating**

Study the diagram of the human cardiovascular system in Figure 8.7 (p. 101), and trace the path of blood from the mesenteric artery to the vena cava via the intestine and liver. Simulated serum samples have been prepared to correspond to these blood vessels in a person who ate a short time ago:

- A<sub>1</sub>: Serum from a mesenteric artery. The mesenteric arteries take blood from the aorta to the intestine.
- B<sub>1</sub>: Serum from the hepatic portal vein, which lies between the intestine and the liver.
- C<sub>1</sub>: Serum from the hepatic vein, which takes blood from the liver to the vena cava.

1. With a wax pencil, label three test tubes A<sub>1</sub>, B<sub>1</sub>, and C<sub>1</sub>, and mark them at 1 cm and 2 cm.
2. Fill Tube A<sub>1</sub> to the 1 cm mark with serum A<sub>1</sub> and to the 2 cm mark with Benedict’s reagent.
3. Fill Tube B<sub>1</sub> to the 1 cm mark with serum B<sub>1</sub> and to the 2 cm mark with Benedict’s reagent.
4. Fill Tube C<sub>1</sub> to the 1 cm mark with serum C<sub>1</sub> and to the 2 cm mark with Benedict’s reagent.
5. Place all three test tubes in the water bath at the same time. Heat the tubes in the same boiling water bath for 5 minutes.
6. Note any color change in the test tubes, and record the color and your conclusions in Table 11.4. The tube that shows color first has the most glucose, and so forth. Use the following chart to assist you in making your conclusions:

<table>
<thead>
<tr>
<th>Color Change</th>
<th>Amount of Glucose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Color is still blue</td>
<td>None</td>
</tr>
<tr>
<td>Green</td>
<td>Very low</td>
</tr>
<tr>
<td>Yellow-orange</td>
<td>Moderate</td>
</tr>
<tr>
<td>Orange</td>
<td>High</td>
</tr>
<tr>
<td>Orange-red</td>
<td>Very high</td>
</tr>
</tbody>
</table>
Table 11.4  Blood Glucose Level After Eating

<table>
<thead>
<tr>
<th>Test Tubes</th>
<th>Color (After Heating)</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>A₁ (mesenteric artery)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B₁ (hepatic portal vein)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C₁ (hepatic vein)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Conclusions: Blood Glucose Level After Eating

- Which blood vessel—a mesenteric artery, the hepatic portal vein, or the hepatic vein—contains the most glucose after eating?  
- Why do you suppose that the hepatic vein does not contain as much glucose as the hepatic portal vein after eating?

Experimental Procedure: Blood Glucose Level Before Next Meal

Simulated serum samples have been prepared to correspond to these blood vessels in a person who has not eaten for some time:

- A₂: Serum from a mesenteric artery
- B₂: Serum from the hepatic portal vein
- C₂: Serum from the hepatic vein

1. With a wax pencil, label three test tubes A₂, B₂, and C₂, and mark them at 1 cm and 2 cm.
2. Fill Tube A₂ to the 1 cm mark with serum A₂ and to the 2 cm mark with Benedict’s reagent.
3. Fill Tube B₂ to the 1 cm mark with serum B₂ and to the 2 cm mark with Benedict’s reagent.
4. Fill Tube C₂ to the 1 cm mark with serum C₂ and to the 2 cm mark with Benedict’s reagent.
5. Heat the tubes in the same boiling water bath for 5 minutes.
6. Note any color change in the test tubes, and record the color and your conclusions in Table 11.5. Use the following list to assist you in making your conclusions:

<table>
<thead>
<tr>
<th>Color Change</th>
<th>Amount of Glucose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Color is still blue.</td>
<td>None</td>
</tr>
<tr>
<td>Green</td>
<td>Very low</td>
</tr>
<tr>
<td>Yellow-orange</td>
<td>Moderate</td>
</tr>
<tr>
<td>Orange</td>
<td>High</td>
</tr>
<tr>
<td>Orange-red</td>
<td>Very high</td>
</tr>
</tbody>
</table>

Table 11.5  Blood Glucose Level Before Next Meal

<table>
<thead>
<tr>
<th>Test Tubes</th>
<th>Color (After Heating)</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>A₂ (mesenteric artery)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B₂ (hepatic portal vein)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C₂ (hepatic vein)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Conclusions: Blood Glucose Level Before Next Meal

- Which blood vessel—a mesenteric artery, the hepatic portal vein, or the hepatic vein—contains the most glucose before your next meal?

- Why do you suppose that the hepatic vein now contains more glucose than the hepatic portal vein?

Summary: Liver Function and Homeostasis

We studied two ways the liver contributes to homeostasis.

1. The liver produces ____________, which is excreted by the ____________. Urea is the way we excrete nitrogen from the body; it is a metabolic ____________.

2. The liver stores glucose as ____________ after eating and releases glucose in between eating so that the concentration of glucose in the blood stays relatively constant at 0.1%. What hormone promotes storage of glucose by the liver? ____________ What hormone promotes breakdown of glycogen to glucose by the liver? ____________

Conclusion: Homeostasis

1. As noted at the beginning of this laboratory, homeostasis is the dynamic equilibrium of the body’s internal environment, the blood and tissue fluid surrounding tissue cells. The lungs and kidneys have boundaries that interact with the external environment to refresh blood. The liver also regulates blood content. Fill in the following chart to show the activities of the kidneys, lungs, and liver.

<table>
<thead>
<tr>
<th>Processes</th>
<th>Kidneys</th>
<th>Lungs</th>
<th>Liver</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas exchange</td>
<td></td>
<td>O₂ enters and CO₂ exits the blood</td>
<td></td>
</tr>
<tr>
<td>pH maintenance</td>
<td>a.</td>
<td>e.</td>
<td></td>
</tr>
<tr>
<td>Glucose level</td>
<td>b.</td>
<td></td>
<td>g.</td>
</tr>
<tr>
<td>Waste removal</td>
<td>c.</td>
<td>f.</td>
<td>h.</td>
</tr>
<tr>
<td>Blood volume</td>
<td>d.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. Which of these organs contributes most to homeostasis?

3. As described throughout this lab, homeostasis is maintained when a change in the internal environment values triggers a response that restores the normal condition. Complete Table 11.6 to show how the kidneys, lungs, and liver specifically respond to changes in the internal environment. Under “Response,” also include any hormones involved.
<table>
<thead>
<tr>
<th>Change</th>
<th>Organ (kidneys, lungs, or liver)</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decrease in blood glucose level</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Decrease in blood volume and pressure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Increase in blood CO₂</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Application for Daily Living**

**The Liver Is a Vital Organ**

The liver is a vital organ because we can’t live without one. The liver is the gatekeeper to the blood. After the molecules enter the blood at the digestive tract, they go first to the liver, which performs these functions.

- As we studied in this lab, the liver maintains glucose in the blood so that cells always have a source of energy. After we eat, the liver stores glucose as glycogen and then it breaks down glycogen gradually so that the blood concentration of glucose stays within a normal range.
- The liver removes and breaks down poisons, i.e., chemicals that can harm the body. The liver destroys old enzymes and hormones that no longer function properly, drugs such as an antibiotics and pain killers that have done their job, and drugs of abuse that damage the brain.
- The liver produces several kinds of blood proteins whose functions are varied. Among these are proteins needed to make the blood clot and if these proteins are missing, a simple cut can cause severe bleeding.
- The liver produces bile, which is sent to the digestive tract, where it emulsifies fat. Without bile, eating ice cream, the icing on a cake, or a juicy steak can make you ill.

It is important to realize that your behavior can affect your liver. The liver ordinarily does a marvelous job but it can be overwhelmed. Alcohol is a poison the liver valiantly breaks down, but if you drink heavily for a long time, the liver can’t keep up and develops cirrhosis, characterized by scar tissue that has taken place of working liver cells. Another cause of liver failure is hepatitis, a infection that can be sexually transmitted or acquired by using dirty needles to shoot drugs into the body. When a liver is severely damaged, only a liver transplant can prevent death. The need for a healthy liver provides a good reason for a healthy lifestyle.
Laboratory Review 11

1. When molecules leave the glomerulus, they enter what portion of the nephron?
2. Name a substance that is in the glomerular filtrate but not in the urine.
3. Name the process by which molecules move from the proximal convoluted tubule into the blood.
4. \( \text{H}^+ \) is excreted in combination with what molecule?
5. What are the air spaces in the lungs called?
6. What molecule is removed by the lungs?
7. When we exhale, the diaphragm relaxes and moves in what direction?
8. When measuring tidal volume, should a student exhale normally or maximally?
9. Vital capacity is expected to have a higher or lower volume than tidal volume?
10. What blood vessel lies between the intestines and the liver?
11. In what form is glucose stored in the liver?
12. The liver removes the amino group from amino acids to form what molecules?

Thought Questions

13. Smoking cigarettes causes emphysema, in which the alveoli burst. Why would you expect the patient to have an abnormally low vital capacity and be tired?

14. Which systemic blood vessel would you expect to have a high glucose content immediately after eating? Explain your answer.

15. In what ways do the kidneys aid homeostasis?
12
Musculoskeletal System

Learning Outcomes

12.1 Anatomy of a Long Bone
- Locate and identify the portions of a long bone, and associate particular tissues with each portion.
- Identify significant features of compact bone, spongy bone, and hyaline cartilage.
  Prelab Question: Which portion of long bone and which type of bone contain osteons?

12.2 The Skeleton
- Locate and identify the bones of the appendicular and axial human skeletons.
  Prelab Question: To which division of the skeleton should you associate the limbs?

12.3 The Skeletal Muscles
- Locate and identify selected human skeletal muscles.
- Illustrate types of joint movements.
- Give examples of antagonistic pairs of muscles and the actions involved.
- Distinguish between isometric and isotonic contractions.
  Prelab Question: Why do muscles work in antagonistic pairs?

12.4 Mechanism of Skeletal Muscle Fiber Contraction
- Describe the structure of skeletal muscle.
- Describe an experiment that demonstrates the role of ATP and ions in the contraction of sarcomeres.
  Prelab Question: In general, what is the role of ATP in muscle contraction?

Application for Daily Living: Bone Marrow Transplants

Introduction

The human skeletal system consists of the bones (206 in adults) and joints, along with the cartilage and ligaments that occur at the joints. The muscular system contains three types of muscles: smooth, cardiac, and skeletal. The term musculoskeletal system recognizes that contraction of skeletal muscles causes the bones to move.

In humans, the skeletal muscles are most often attached across a joint (Fig. 12.1). The biceps brachii muscle has two origins, and the triceps brachii has three origins on the humerus and scapula. Find the tendon of insertion of the biceps brachii muscle by feeling on the anterior surface of your elbow while contracting your biceps muscle. Feel for the bone at your posterior elbow. This is the ulna, the site of insertion of the tendon for the triceps brachii muscle.

Figure 12.1 Muscular action.
Muscles, such as these muscles of the arm (which have their origin on the scapula and their insertion on the bones of the forearm), cause bones to move.
Muscles work in antagonistic pairs. For example, when the biceps brachii contracts, the bones of the forearm are pulled upward, while the triceps brachii relaxes; when the triceps brachii contracts, the bones of the forearm are pulled downward, while the biceps brachii relaxes.

12.1 Anatomy of a Long Bone

Although the bones of the skeletal system vary considerably in shape as well as in size, a long bone, such as the human femur, illustrates the general principles of bone anatomy (Fig. 12.2).

Figure 12.2 Anatomy of a bone from the macroscopic to the microscopic level.
A long bone is encased by the periosteum except at the ends, where it is covered by hyaline (articular) cartilage (see micrograph, top left). Spongy bone located at the ends may contain red bone marrow. The medullary cavity contains yellow bone marrow and is bordered by compact bone, shown in the enlargement and micrograph (right).
**Observation: Anatomy of a Long Bone**

Examine the exterior and a longitudinal section of a long bone or a model of a long bone, and with the help of Figure 12.2, identify the following:

1. **Periosteum**: tough, fibrous connective tissue covering continuous with the ligament and tendons that anchor bones; the periosteum allows blood vessels to enter the bone and service its cells
2. Expanded portions at each end of the bone (epiphysis) that contain spongy bone
3. Extended portion, or shaft (diaphysis) of a long bone that lies between the epiphyses; walls of diaphysis are compact bone
4. **Hyaline (articual) cartilage**: layer of cartilage where the bone articulates with (meets) another bone; decreases friction between bones during movement
5. **Medullary cavity**: cavity located in the diaphysis that stores yellow marrow, which contains a large amount of fat.

*Label the diaphysis and the epiphysis (twice) in Figure 12.2. Which of these contains the growth line where a long bone can grow in length?*

**Observation: Tissues of a Long Bone**

The medullary cavity is bounded at the sides by **compact bone** and at the ends by **spongy bone**. Beyond a thin shell of compact bone is the layer of articular cartilage. **Red marrow**, a specialized tissue that produces all types of blood cells, occurs in the spongy bone of the skull, ribs, sternum, and vertebrae and in the ends of the long bones.

1. Examine a prepared slide of compact bone, and with the help of Figure 12.2, identify
   a. **Osteons**: cylindrical structural units
   b. **Lamellae**: concentric rings of matrix
   c. **Matrix**: nonliving material maintained by osteocytes; contains mineral salts (notably calcium salts) and protein
   d. **Lacunae**: cavities between the lamellae that contain osteocytes (bone cells)
   e. **Central canal**: canal in the center of each osteon; Figure 12.2 shows that there are
      ____________________________________________ in a central canal.
   f. **Canaliculi**: tiny channels that contain the processes of cells; these processes allow nutrients to pass between the osteocytes (sing., canaliculus)

Describe how an osteocyte located near a central canal can pass nutrients to osteocytes located far from the central canal.  ____________________________________________

2. Examine a prepared slide of spongy bone, and with the help of Figure 12.2, identify
   a. **Trabeculae**: bony bars and plates made of mineral salts and protein
   b. **Lacunae**: cavities scattered throughout the trabeculae that contain osteocytes
   c. **Red bone marrow**: within large spaces separated by the trabeculae

   What activity occurs in red bone marrow? ____________________________________________

3. Examine a prepared slide of hyaline cartilage, and with the help of Figure 12.2, identify
   a. **Lacunae**: cavities in twos and threes scattered throughout the matrix, which contain chondrocytes (cells that maintain cartilage)
   b. **Matrix**: material more flexible than bone because it consists primarily of protein

Seniors tend to have joints that creak. What might be the matter? ____________________________________________
12.2 The Skeleton

The human skeleton is divided into axial and appendicular components (Fig. 12.3). The **axial skeleton** is the main longitudinal portion and includes the skull, the vertebral column, the sternum, and the ribs. The **appendicular skeleton** includes the bones of the appendages and their supportive pectoral and pelvic (shoulder and hip) girdles.

**Figure 12.3** The axial and appendicular skeletons.
- a. Axial skeleton bones are colored blue.
- b. Bones of the appendicular skeleton are tan.
**Observation: Axial Skeleton**

Examine a human skeleton, and with the help of Figure 12.4, identify the **foramen magnum**, a large opening through which the spinal cord passes, and the following bones:

1. The **skull** is composed of many bones fused together at fibrous joints called **sutures**. Note the following in the cranium:
   
a. **Frontal bone**: forms forehead  
b. **Parietal bones**: extend to sides of skull  
c. **Occipital bone**: curves to form base of skull  
d. **Temporal bones**: located on sides of skull  
e. **Sphenoid bone**: helps form base and sides of skull, as well as part of the orbits

Which of these bones contribute to forming the face? ________________________________________________________________________________

Which could best be associated with wearing glasses? ________________________________________________________________________________

---

**Figure 12.4 Skull.**

2. Facial bones (Fig. 12.5)
   The most prominent of the facial bones are the mandible, the maxillae (sing., maxilla), the zygomatic bones, and the nasal bones. As shown previously, certain of the cranial bones contribute to the face. The frontal bone forms the forehead and has supraorbital ridges where the eyebrows are located. The temporal bone and the wings of the sphenoid bone account for the flattened areas we call the temples. Note the following:
   a. **Mandible**: the lower jaw
   b. **Maxillae**: the upper jaw and anterior portion of the hard palate
   c. **Palatine bones**: posterior portion of hard palate and floor of nasal cavity
   d. **Zygomatic bones**: cheekbones
   e. **Nasal bones**: bridge of nose

Which of these is movable and allows you to chew your food? 

---

**Figure 12.5  Bones of the face.**
3. The **vertebral column** (Fig. 12.6) provides support and houses the **spinal cord**. It is composed of many vertebrae separated from one another by intervertebral disks. The vertebral column customarily is divided into five series:

- **a.** Seven **cervical vertebrae** (forming the neck region)
- **b.** Twelve **thoracic vertebrae** (with which the ribs articulate)
- **c.** Five **lumbar vertebrae** (in the abdominal region)
- **d.** Five fused sacral vertebrae, called the **sacrum**
- **e.** Four fused caudal vertebrae forming the **coccyx** in humans

Which of the vertebrae can be associated with the chest?  

Which of the vertebrae could be the cause of your aching back?  

---

**Figure 12.6** The vertebral column.
4. The twelve pairs of ribs and their associated muscles form a bony case that supports the thoracic cavity wall (Fig. 12.7). The ribs connect posteriorly with the thoracic vertebrae, and some are also attached by cartilage directly or indirectly to the sternum. Those ribs without any anterior attachment are called floating ribs.

Which of the ribs help form the protective part of the rib cage? 

Figure 12.7  The ribcage.
Observation: Appendicular Skeleton

Examine a human skeleton, and with the help of Figure 12.8, identify the following bones:

1. The pectoral girdles, which support the upper limbs, are composed of the clavicle (collarbone) and scapula (shoulder bone).

Why is the shoulder apt to become dislocated? ____________________________

2. The upper limb (arm plus the forearm) is composed of the following:
   a. Humerus: the large long bone of the arm
   b. Radius: the long bone of the forearm, with a pivot joint at the elbow that allows rotational motion
   c. Ulna: the other long bone of the forearm, with a hinge joint at the elbow that allows motion in only one plane. Take hold of your elbow, and twist the forearm to show that the radius rotates over the ulna but the ulna doesn’t move during this action.
   d. Carpals: a group of small bones forming the wrist
   e. Metacarpals: slender bones forming the palm
   f. Phalanges: the bones of the fingers

Which of these bones would you use to pick up a teacup? _____________________

---

Figure 12.8 The bones of the pectoral girdle and upper limb.
3. The **pelvic girdle** forms the basal support for the lower limbs and is composed of two **coxal** (hip) **bones** (Fig. 12.9). Each coxal bone consists of the ilium, which is superior to the other two: the pubis and the ischium. (The pubis is ventral to the ischium.)

The female pelvis is much broader and shallower than that of the male. The angle between the pubic bones looks like a U in females and a V in males. How is it advantageous for the female pelvis to be broader and more shallow than that of a male?

4. The lower limb (the thigh plus the leg) is composed of a series of loosely articulated bones, including the following:
   a. **Femur**: the long bone of the thigh
   b. **Patella**: kneecap
   c. **Tibia**: the larger of the two long bones of the leg; feel for the bump on the inside of the ankle
   d. **Fibula**: the smaller of the two long bones of the leg; feel for the bump on the outside of the ankle
   e. **Tarsals**: a group of small bones forming the ankle
   f. **Metatarsals**: slender anterior bones of the foot
   g. **Phalanges**: the bones of the toes

Which of these bones would you use to kick a soccer ball?

---

*Figure 12.9* The bones of the pelvic girdle and lower limb.
12.3 The Skeletal Muscles

This laboratory is also concerned with skeletal muscles—those muscles that make up the bulk of the human body. With the help of Figure 12.10, identify the major muscles of the body.

**Naming Muscles**

Muscles are named for various characteristics, as shown in the following list:

1. **Size**: The gluteus maximus is the largest muscle, and it forms the buttocks.
2. **Shape**: The deltoid is shaped like a Greek letter delta, or triangle.
3. **Direction of fibers**: The rectus abdominis is a longitudinal muscle of the abdomen (*rectus* means “straight”).
4. **Location**: The frontalis overlies the frontal bone.
5. **Number of attachments**: The biceps brachii has two attachments, or origins.
6. **Action**: The extensor digitorum extends the fingers, or digits.

---

**Figure 12.10 Human musculature.**
Superficial skeletal muscles in (a) anterior and (b) posterior view.

- Orbicularis oculi: blinking, winking, responsible for crow’s feet
- Orbicularis oris: “kissing” muscle
- Pectoralis major: brings arm forward and across chest
- Serratus anterior: pulls the scapula (shoulder blade) forward, as in pushing or punching
- External oblique: compresses abdomen, rotation of trunk
- Quadriceps femoris: straightens leg at knee; raises thigh
- Tibialis anterior: turns foot upward, as when walking on heels
- Masseter: a chewing muscle; clinches teeth
- Deltoid: brings arm away from the side of body; moves arm up and down in front
- Biceps brachii: bends forearm at elbow
- Rectus abdominis: bends vertebral column; compresses abdomen
- Flexor carpi group: bends wrist and hand
- Adductor longus: moves thigh toward midline; raises thigh
- Sartorius: moves the thigh away from the midline; raises and rotates leg close to body; these combined actions occur when “crossing legs” or soccer kick
- Extensor digitorum longus: raises toes; raises foot
- Trapezius: raises scapula, as whenshrugging shoulders; pulls head backward
- Latissimus dorsi: brings arm down and backward behind the body
- Triceps brachii: straightens forearm at elbow
- Extensor carpi group: straightens wrist and hand
- Extensor digitorum: straightens fingers and wrist
- Gluteus maximus: extends thigh back
- Biceps femoris: bends leg at knee; extends thigh back
- Gastrocnemius: turns foot downward, as when standing on toes; bends leg at knee
- Achilles tendon

---

Limbs:
- Arm: above the elbow
- Forearm: below the elbow
- Thigh: above the knee
- Leg: below the knee

12–11  
Laboratory 12 Musculoskeletal System 159
Match these muscles to these functions from Fig. 12.10.

Doing a pelvic tilt and curving the spine
Swinging movements of arms during walking and swimming
Pulls forearm toward you when rowing
Helps maintain the trunk in an erect posture
Extends and separates the fingers
Wrinkles the skin of the forehead

**Joint Movements**

Figure 12.11 demonstrates the following types of joint movements:

- **Flexion**  Moving jointed body parts toward each other
- **Extension**  Moving jointed body parts away from each other
- **Adduction**  Moving a part toward a vertical plane running through the longitudinal midline of the body
- **Abduction**  Moving a part away from a vertical plane running through the longitudinal midline of the body
- **Rotation**  Moving a body part around its own axis; **circumduction** is moving a body part in a wide circle.
- **Inversion**  A movement of the foot in which the sole is turned inward
- **Eversion**  A movement of the foot in which the sole is turned outward

**Figure 12.11  Joint movements.**

- a. Flexion and extension
- b. Adduction and abduction
- c. Rotation and circumduction
- d. Inversion and eversion
**Antagonistic Pairs**

Skeletal muscles are attached to the skeleton, and their contraction causes the movement of bones at a joint. Muscles shorten when they contract, so they can only pull; they cannot push. Therefore, muscles work in **antagonistic pairs**. Usually, contraction of one member of the pair causes a bone to move in one direction, and contraction of the other member of the pair causes the same bone to move in an opposite direction.

Are the muscles shown in Figure 12.1 antagonistic? ______ How so? _____________________________________________________________

---

**Observation: Antagonistic Pairs**

Locate the following antagonistic pairs in Figure 12.10. In each case, state their opposing actions by inserting one of these functions: *flexes, extends, adducts, or abducts.*

1. The biceps brachii ____________ the forearm.
   The triceps brachii ____________ the forearm.
2. The sartorius ____________ the thigh.
   The adductor longus ____________ the thigh.
3. The quadriceps femoris ____________ the leg.
   The biceps femoris ____________ the leg.

**Isometric and Isotonic Contractions**

A muscle contains many muscle fibers. When a muscle contracts, usually some fibers undergo isotonic contraction, and others undergo isometric contraction. When the tension of muscle fibers is sufficient to lift a load, many fibers change length as they lift the load. The muscle contraction is said to be **isotonic** (same tension). In contrast, when the tension of muscle fibers is used only to support rather than lift a load, the muscle contraction is said to be **isometric** (same length). The length of many fibers remains the same, but their tension still changes.

**Experimental Procedure: Isometric and Isotonic Contractions**

*Note:* The upper limb is composed of the arm plus the forearm.

**Isotonic Contraction**

1. Start with your left forearm resting on a table. Watch the anterior surface of your left arm while you slowly bend your elbow and bring your left forearm toward the arm. An isotonic contraction of the biceps brachii produces this movement.

2. If muscle contraction produces movement, is this an isometric or isotonic contraction? __________________________

**Isometric Contraction**

1. Place the palm of your left hand underneath a tabletop. Push up against the table while you have your right hand cupped over the anterior surface of your left arm so that you can feel the muscle there undergo an isometric contraction.
2. Is the biceps brachii or the triceps brachii located on the anterior surface of the arm?

3. What change did you notice in the firmness of this muscle as it contracted?

4. Did your forearm move as you pushed up against the table?

5. Given your answer to question 4, did this muscle's fibers shorten as you pushed up against the tabletop?

12.4 Mechanism of Skeletal Muscle Fiber Contraction

A whole skeletal muscle is made up of many cells, usually called muscle fibers. Muscle fibers can be examined using a light microscope and using an electron microscope.

Skeletal Muscle Fibers

Muscle fibers are striated—that is, they have alternating light and dark bands. These striations can be observed in a light micrograph of muscle fibers and in an electron micrograph in longitudinal section.

Observation: Skeletal Muscle Tissue

1. Examine a prepared slide of skeletal muscle using a light microscope. Identify the long, multinucleated fibers arranged in a parallel fashion. How do you know the muscle fibers are striated?

2. When a skeletal muscle fiber is examined using an electron microscope, it is possible to see that the fibers contain myofibrils which in turn contain actin and myosin filaments (Fig. 12.12). It is the placement of these filaments that cause muscle fibers to be striated.

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Skeletal Muscle Fiber Contraction

Electron microscopy helped investigators determine what causes the striated appearance of a muscle fiber and also its contraction. A muscle fiber contains hundreds, even thousands, of contractile portions called myofibrils divided into units called sarcomeres. Each sarcomere contains myosin filaments and actin filaments (Fig. 12.12). The sarcomeres contract when myosin cross-bridges attach to and pull the actin filaments to the center of the sarcomeres.

We are going to study muscle contraction with this data in mind:

1. Myosin is an enzyme that can break down ATP as an energy source for muscle contraction.
2. Enzymes often require cofactors, which can be coenzymes or certain ions, such as the $K^+$ and $Mg^{2+}$ required by myosin.
3. When ATP, $K^+$, and $Mg^{2+}$ are present, myosin cross-bridges attach to actin filaments and pull them to the center of sarcomeres within myofibrils. In this way, the actin filaments slide past myosin filaments and the sarcomeres, and a muscle fiber contracts.
**Experimental Procedure: Muscle Fiber Contraction**

During this procedure you are going to expose muscle fibers to different solutions:

1. Glycerol (A viscous liquid that keeps the muscle tissue moist.)
2. K⁺ and Mg²⁺ salt solution alone
3. ATP solution alone
4. ATP and salt solution

Hypothesize which of these (1-4) will produce contraction, and explain.

---

**The Procedure**

1. Label two slides, slide 1 and slide 2. Mount a strand of muscle fibers in a drop of glycerol on each slide. Place each slide on a millimeter ruler, and measure the length of the strand. Record these lengths in the first row in Table 12.1. If there is more than a small drop of glycerol on the slides, soak up the excess on a piece of lens paper held at the edge of the glycerol farthest from the fiber strand.
2. To slide 1, add a few drops of a salt solution containing potassium and magnesium ions (K⁺ and Mg²⁺), and note any change in strand length. Record your results in Table 12.1.
3. To slide 2, add a few drops of ATP solution, and note any change in strand length. Record your results in Table 12.1.
4. Now add ATP solution to slide 1. Note any change in strand length, and record your results in Table 12.1. To slide 2, add a few drops of the K⁺/Mg²⁺ salt solution, and note any change in strand length. Record your results in Table 12.1.

<table>
<thead>
<tr>
<th>Table 12.1 Glycerinated Muscle Contraction</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Solution</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>-----------------------------------</td>
</tr>
<tr>
<td>1. Glycerol alone</td>
</tr>
<tr>
<td>2. K⁺/Mg²⁺ salt solution alone</td>
</tr>
<tr>
<td>3. ATP alone</td>
</tr>
<tr>
<td>4. Both ATP and salt solution</td>
</tr>
</tbody>
</table>

**Conclusion: Muscle Fiber Contraction**

- Was your hypothesis stated above supported? _______________ Why or why not? _______________

- To demonstrate that you understand the requirements for contraction, state the function of each of the substances listed in Table 12.2.
Table 12.2  Summary of Muscle Fiber Contraction

<table>
<thead>
<tr>
<th>Substance</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Myosin</td>
<td></td>
</tr>
<tr>
<td>Actin</td>
<td></td>
</tr>
<tr>
<td>$\text{K}^+ / \text{Mg}^{2+}$ salt solution</td>
<td></td>
</tr>
<tr>
<td>ATP</td>
<td></td>
</tr>
</tbody>
</table>

**Application for Daily Living**

**Bone Marrow Transplants**

We are accustomed to thinking of a transplant as a procedure that replaces a nonfunctioning organ with one that works properly. A red bone marrow transplant doesn’t quite work like that. Instead, red bone marrow is injected into the bloodstream and the recipient is receiving the cells that occur in the red bone marrow. The red bone marrow contains the precious stem cells capable of producing all the various cells in the blood. And they aren’t ordinarily in the blood! However, these cells usually find their way home—the bones that ordinarily contain red bone marrow in adults, such as the sternum, breast bone, skull, hips, ribs, and spine.

The health reasons for needing a red bone marrow transplant are numerous, but chief among them are cancer patients whose own bone marrow was destroyed by treatment of cancer. As with any transplant, a careful match between donor and recipient is required.

**Laboratory Review 12**

1. Is compact bone located in the diaphysis or in the epiphyses?
2. Does compact bone or spongy bone contain red bone marrow?
3. What are bone cells called?
4. What are the vertebrae in the neck region called?
5. Name the strongest bone in the lower limb.
6. What bones are part of a pectoral girdle?
7. What type of joint movement occurs when a muscle moves a limb toward the midline of the body?
8. What type of joint movement occurs when a muscle moves a body part around its own axis?
9. Skeletal muscle is voluntary, and its appearance is ________ because of the placement of actin and myosin filaments.

10. Glycerinated muscle requires the addition of what molecule to supply the energy for muscle contraction?

11. Actin and myosin are what type of biological molecule?

12. Does the quadriceps femoris flex or extend the leg?

13. Does the biceps brachii flex or extend the forearm?

14. What muscle forms the buttocks?

15. Name the muscle group antagonistic to the quadriceps femoris group.

Thought Questions

16. What bones protect the thoracic cavity?

17. When you see glycerinated muscle shorten, what is happening microscopically?

18. Release of a neurotransmitter at a neuromuscular junction causes a muscle fiber to contract. Label the neurotransmitter in this figure.

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Chemical Aspects of Digestion

Learning Outcomes

Introduction
- Sequence the organs of the digestive tract from the mouth to the anus.
- State the contribution of each organ, if any, to the process of chemical digestion.

9.1 Protein Digestion by Pepsin
- Associate the enzyme pepsin with the ability of the stomach to digest protein.
- Explain why stomach contents are acidic and how a warm body temperature aids digestion.
  Prelab Question: An acid pH plays what role in digestion by pepsin?

9.2 Fat Digestion by Pancreatic Lipase
- Associate the enzyme lipase with the ability of the small intestine to digest fat.
- Explain why the emulsification process assists the action of lipase.
- Explain why a change in pH indicates that fat digestion has occurred.
- Explain the relationship between time and enzyme activity.
  Prelab Question: Sufficient time plays what role in digestion by any enzyme?

9.3 Starch Digestion by Pancreatic Amylase
- Associate the enzyme pancreatic amylase with the ability of the small intestine to digest starch.
  Prelab question: A denatured enzyme cannot carry out digestion. Explain why not.

9.4 Requirements for Digestion
- Assuming a specific enzyme, list four factors that can affect the activity of all enzymes.
  Prelab Question: Of the factors that can affect enzymatic action, which causes an enzyme to be unable to function to any degree?

Introduction
In Laboratory 7, you examined the organs of digestion in the fetal pig. Now we wish to further our knowledge of the digestive process by associating certain digestive enzymes with particular organs, as shown in Figure 9.1. This laboratory will also give us an opportunity to study the action of enzymes, much as William Beaumont did when he removed food samples through a hole in the stomach wall of his patient, Alexis St. Martin. Every few hours, Beaumont would see how well the food had been digested.

In Laboratory 5 we learned that enzymes are very specific and usually participate in only one type of reaction. The active site of an enzyme has a shape that accommodates its substrate, and if an environmental factor such as a boiling temperature or a wrong pH alters this shape, the enzyme loses its ability to function well, if at all. We will have an opportunity to make these observations with controlled experiments. The box on the next page reviews what is meant by a controlled experiment.

Planning Ahead Be advised that protein digestion (page 107) requires 1½ hours and fat digestion (page 109) requires 1 hour. Also a boiling water bath is required for starch digestion (page 111).
Figure 9.1 Organs of the digestive tract (right) and accessory organs (left).

**Digestive tract organs**
- **Mouth**: teeth chew food; tongue tastes and pushes food for chewing and swallowing
- **Pharynx**: passageway where food is swallowed
- **Esophagus**: passageway for food to enter stomach
- **Stomach**: secretes pepsin for protein digestion and acid to maintain stomach acidity; churns to encourage digestion and sends food to small intestine
- **Small Intestine**: contains bile from gallbladder to emulsify fat and digestive enzymes from pancreas: lipase digests fat; pancreatic amylase digests starch and another enzyme, not studied, digests protein; produces enzymes to finalize digestion to nutrient molecules that enter the blood
- **Large Intestine**: absorbs water and salt to form feces
- **Rectum**: stores and regulates elimination of feces
- **Anus**: 

**Accessory organs**
- **Salivary glands**: secretes saliva; contains digestive enzyme for carbohydrates
- **Liver**: major metabolic organ that, among other functions, produces bile for emulsification of fats
- **Gallbladder**: stores bile from liver and sends it via ducts to the small intestine
- **Pancreas**: produces pancreatic juice (contains digestive enzymes) and sends it via ducts to the small intestine

---

**What Is a Control?**

The experiments in today's laboratory have both a positive control and a negative control, which should be saved for comparison purposes until the experiment is complete. The **positive control** goes through all the steps of the experiment and does contain the substance being tested. Therefore, positive results are expected. The **negative control** goes through all the steps of the experiment, except it does not contain the substance being tested. Therefore, negative results are expected.

For example, if a test tube contains glucose (the substance being tested) and Benedict's reagent (blue) is added, a red color develops upon heating. This test tube is the positive control; it tests positive for glucose. If a test tube does not contain glucose and Benedict's reagent is added, Benedict's is expected to remain blue. This test tube is the negative control; it tests negative for glucose.

What benefit is a positive control? Positive controls give you a standard by which to tell if the substance being tested is present (or acting properly) in an unknown sample. Negative controls ensure that the experiment is giving reliable results; after all, if a negative control should happen to give a positive result, then the entire experiment may be faulty and unreliable.
9.1 Protein Digestion by Pepsin

Certain foods, such as meat and egg whites, are rich in protein. Egg whites contain albumin, which is the protein used in this Experimental Procedure. Protein is digested by pepsin in the stomach (Fig. 9.2), a process described by the following reaction:

\[
\text{protein} + \text{water} \xrightarrow{\text{pepsin (enzyme)}} \text{peptides}
\]

The stomach has a very low pH. Does this indicate that pepsin works effectively in an acidic or a basic environment? ________________ This is the pH that allows the enzyme to maintain its normal shape so that it will combine with the substrate. A warm temperature causes molecules to move about more rapidly and increases the encounters between enzyme and substrate. Therefore you would hypothesize that the yield from this enzymatic reaction will be higher if the pH is ________________ and the temperature is ________________ (body temperature 37°C).

Test for Protein Digestion

Biuret reagent is used to test for protein digestion. If digestion has not occurred, biuret reagent turns purple, indicating that protein is present. If digestion has occurred, biuret reagent turns pinkish-purple, indicating that peptides are present.

Experimental Procedure: Protein Digestion

1. Label four clean test tubes (1 to 4). Using the designated graduated pipet, add 2 ml of the albumin solution to all tubes. Albumin is a protein.
2. Add 2 ml of the pepsin solution to tubes 1 to 3, as listed in Table 9.1.
3. Add 2 ml of 0.2% HCl to tubes 1 and 2. HCl simulates the acidic conditions of the stomach.
4. Add 2 ml of water to tube 3 and 4 ml of water to tube 4, as listed in Table 9.1.
5. Swirl to mix the tubes. Tube 2 remains at room temperature, but the other three are incubated for 1½ hours. Record the temperature for each tube in Table 9.1.
6. Remove the tubes from the incubator and place all four tubes in a tube rack. Add 2 ml of biuret reagent to all tubes and observe. Record your results in Table 9.1 as + or − to indicate digestion or no digestion.

Figure 9.2 Digestion of protein.

Pepsin, produced by the gastric glands of the stomach, helps digest protein.
<table>
<thead>
<tr>
<th>Tube</th>
<th>Contents</th>
<th>Temperature</th>
<th>Digestion (+ or -)</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Albumin, Pepsin, HCl, Biuret reagent</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Albumin, Pepsin, HCl, Biuret reagent</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Albumin, Pepsin, Water, Biuret reagent</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Albumin, Water, Biuret reagent</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Conclusions: Protein Digestion**

- Explain your results in Table 9.1 by reasoning why digestion did or did not occur. To be complete, consider all the requirements for an enzymatic reaction as listed in Table 9.4. Now show here that tube 1 met all the requirements for digestion:

  - Pepsin is the correct ____________.
  - Albumin is the correct ____________.
  - 37°C is the optimum ____________.
  - HCl provides the optimum ____________.
  - 1½ hours provides ____________ for the reaction to occur.

- Review “What Is a Control?” on page 106. Which tube was the negative control? ____________

  Explain why it was the negative control. ____________

- If this control tube had given a positive result for protein digestion, what could you conclude about this experiment? ____________
9.2 Fat Digestion by Pancreatic Lipase

Lipids include fats (e.g., butterfat) and oils (e.g., sunflower, corn, olive, and canola). Lipids are digested by pancreatic lipase in the small intestine (Fig. 9.3).

Figure 9.3 Emulsification and digestion of fat.
Bile from the liver (stored in the gallbladder) enters the small intestine, where lipase in pancreatic juice from the pancreas digests fat.

The following two reactions describe fat digestion:

1. \[ \text{fat} \xrightarrow{\text{bile (emulsifier)}} \text{fat droplets} \]

2. \[ \text{fat droplets + water} \xrightarrow{\text{lipase (enzyme)}} \text{glycerol + fatty acids} \]

With regard to the first step, consider that fat is not soluble in water; yet, lipase makes use of water when it digests fat. Therefore, bile is needed to emulsify fat—cause it to break up into fat droplets that disperse in water. The reason for dispersal is that bile contains molecules with two ends. One end is soluble in fat, and the other end is soluble in water. Bile can emulsify fat because of this.

With regard to the second step, would the pH of the solution be lower before or after the enzymatic reaction? (*Hint:* Remember that an acid decreases pH and a base increases pH.)
Test for Fat Digestion

In the test for fat digestion, you will be using a pH indicator, which changes color as the solution in the test tube goes from basic conditions to acidic conditions. Phenol red is a pH indicator that is red in basic solutions and yellow in acidic solutions.

Experimental Procedure: Fat Digestion

1. Label three clean test tubes (1 to 3). Using the designated graduated pipet, add 1 ml of vegetable oil to all tubes.
2. Add 2 ml of phenol red solution to each tube. What role does phenol red play?
3. Add 2 ml of pancreatic lipase (pancreatin) to tubes 1 and 2 and 2 ml of water to tube 3, as listed in Table 9.2. What role does lipase play?
4. Add a pinch of bile salts to tube 1.
5. Record the initial color of all tubes in Table 9.2.
6. Incubate all three tubes at 37°C and check every 20 minutes.
7. Record any color change and how long it took to see this color change in Table 9.2.

<table>
<thead>
<tr>
<th>Tube</th>
<th>Contents</th>
<th>Color</th>
<th>Time Taken</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Initial</td>
<td>Final</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Vegetable oil Phenol red Pancreatin Bile salts</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Vegetable oil Phenol red Pancreatin</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Vegetable oil Phenol red Water</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Conclusions: Fat Digestion

- Explain your results in Table 9.2 by reasoning why digestion did or did not occur.
- What role did bile salts play in this experiment?
- What role did phenol red play in this experiment?
- Review “What Is a Control?” on page 106. Which test tube in this experiment could be considered a negative control?
9.3 Starch Digestion by Pancreatic Amylase

Starch is present in bakery products and in potatoes, rice, and corn. Starch is digested by pancreatic amylase in the small intestine, a process described by the following reaction:

\[ \text{starch + water} \xrightarrow{\text{amylase (enzyme)}} \text{maltose} \]

1. If digestion does not occur, which will be present—starch or maltose?

2. If digestion does occur, which will be present—starch or maltose?

Tests for Starch Digestion

You will be using two tests for starch digestion:

1. If digestion has not taken place, the iodine test for starch will be positive (+). If digestion has occurred, the iodine test for starch will be negative (−).

2. If digestion of starch has taken place, the Benedict’s test for sugar (maltose) will be positive (+). If digestion has not taken place, the Benedict’s test for sugar will be negative (−).

To test for sugar, add five drops of Benedict’s reagent. Place the tube in a boiling water bath for a few minutes, and note any color changes (see Table 9.3 on page 112). Boiling the test tube is necessary for the Benedict’s reagent to react.

Experimental Procedure: Starch Digestion

1. Label six clean test tubes (1 to 6).
2. Using a transfer pipet, add 1 ml of pancreatic-amylase solution to tubes 1 to 4 and 1 ml of water to tubes 5 and 6.
3. Test tubes 1 and 2 immediately.
   - **Tube 1** Shake the starch solution and add 1 ml of starch solution. Immediately add five drops of iodine to test for starch. Put this tube in a test tube rack and record your results in Table 9.3.
   - **Tube 2** Shake the starch solution and add 1 ml of starch solution. Immediately add five drops of Benedict’s reagent, and place the tube in a boiling water bath to test for sugar. Put this tube in the test tube rack and record your results in Table 9.3.

4. Shake the starch suspension and add 1 ml of starch suspension to tubes 3 to 6. Allow the tubes to stand for 30 minutes.
   - **Tubes 3 and 5** After 30 minutes, test for starch using the iodine test. Place these tubes in the test tube rack and record your results in Table 9.3.
   - **Tubes 4 and 6** After 30 minutes, test for sugar using the Benedict’s test. Place these tubes in the test tube rack and record your results in Table 9.3.
5. Examine all your tubes in the test tube rack and decide whether digestion occurred (+) or did not occur (−). Complete Table 9.3.
Table 9.3  Starch Digestion by Amylase

<table>
<thead>
<tr>
<th>Tube</th>
<th>Contents</th>
<th>Time*</th>
<th>Type of Test</th>
<th>Test Results (+ or -)</th>
<th>Digestion (+ or -)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Pancreatic amylase</td>
<td>0</td>
<td>Iodine</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Starch</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Pancreatic amylase</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Starch</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Pancreatic amylase</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Starch</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Pancreatic amylase</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Starch</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Water</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Starch</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Water</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Starch</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Enter either 0 for immediately or T for after 30 minutes.

**Conclusions: Starch Digestion**

- Considering tubes 1 and 2, this experimental procedure showed that _________ must pass for digestion to occur.
- Considering tubes 5 and 6, this experimental procedure showed that an active _____________ must be present for digestion to occur.
- Why would you not recommend doing the test for starch and the test for sugar on the same tube? _____________  
- Which test tubes served as a negative control for this experiment? _____________
  Explain your answer. _____________

**Absorption of Sugars and Other Nutrients**

Figure 9.4 shows that the folded lining of the small intestine has many fingerlike projections called villi. The small intestine not only digests food; it also absorbs the products of digestion, such as sugars from carbohydrate digestion, amino acids from protein digestion, and glycerol and fatty acids from fat digestion at the villi.

**Figure 9.4  Anatomy of the small intestine.**

Nutrients enter the bloodstream across the much-convoluted walls of the small intestine.
9.4 Requirements for Digestion

Explain in Table 9.4 how each of the requirements listed influences effective digestion.

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific enzyme</td>
<td></td>
</tr>
<tr>
<td>Specific substrate</td>
<td></td>
</tr>
<tr>
<td>Warm temperature</td>
<td></td>
</tr>
<tr>
<td>Specific pH</td>
<td></td>
</tr>
<tr>
<td>Time</td>
<td></td>
</tr>
<tr>
<td>Fat emulsifier</td>
<td></td>
</tr>
</tbody>
</table>

To lose weight, some obese individuals undergo an operation in which (1) the stomach is reduced to the size of a golf ball, and (2) food bypasses the duodenum (first 2 feet) of the intestine. Answer these questions to explain how this operation would affect the requirements for digestion.

1. How is the amount of substrate reduced?  
2. How is the amount of digestive enzymes reduced?  
3. How is time reduced?  
4. What makes the pH of the small intestine higher than before?  
5. How is fat emulsification reduced?  
6. How does surgery to reduce obesity sometimes result in malnutrition?
Laboratory Review 9

1. When iodine (KI) solution turns blue-black, what substance is present?

2. What color is Benedict’s reagent originally?

3. What happens to an enzyme when it is boiled?

4. Saliva and pancreatic juice contain what type enzyme to digest starch?

5. As oil is digested, why does the solution turn from red to yellow, indicating an acid pH?

6. What temperature promotes enzymatic action?

7. What do you call a sample that goes through all the steps of an experiment but lacks the factor being tested?

8. What role do bile salts play in the digestion of fat?

9. What color does biuret reagent turn when peptides are present?

10. Is the optimal pH for pepsin acidic or basic?

11. Why would you predict that pepsin would not digest starch?

12. In addition to pepsin and water, what is needed to digest protein?

13. Name the enzyme responsible for the hydrolysis of starch.

Thought Questions

14. Which of the following two combinations is most likely to result in digestion?
   a. Pepsin, protein, water, body temperature
   b. Pepsin, protein, hydrochloric acid (HCl), body temperature
   Explain.

15. Which of the following two combinations is most likely to result in digestion?
   a. Amylase, starch, water, body temperature, testing immediately
   b. Amylase, starch, water, body temperature, waiting 30 minutes
   Explain.

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13
Nervous System and Senses

Learning Outcomes

13.1 Central Nervous System
- Identify the parts of the brain studied, and state the functions of each part.
- Give examples to show that the parts of the brain work together.
- Describe the anatomy of the spinal cord and tell how the cord functions as a relay station.
  Prelab Question: Distinguish between the cerebral cortex and the cerebrum.

13.2 Peripheral Nervous System
- Distinguish between cranial nerves and spinal nerves on the basis of location and function.
- Describe the anatomy and physiology of a spinal reflex arc.
  Prelab Question: How does the brain become aware that you have removed your hand from a hot stove?

13.3 The Human Eye
- Identify the parts of the eye and state a function for each part.
  Prelab Question: What part of the eye contains the sensory receptors for sight?

13.4 The Human Ear
- Identify the parts of the ear and state a function for each part.
  Prelab Question: What part of the ear contains the sensory receptors for hearing?

13.5 Sensory Receptors in Human Skin
- Describe the anatomy of the human skin and explain the distribution and function of sensory receptors.
- Relate the abundance of touch receptors to the ability to distinguish between two different touch points.
  Prelab Question: What part of the skin contains sensory receptors?

13.6 Human Chemoreceptors
- Relate the ability to distinguish foods to the senses of smell and taste.
  Prelab Question: Taste is dependent on what types of chemical stimuli?

Application for Daily Living: LASIK Surgery

Introduction

The nervous system has two major divisions: the central nervous system (CNS) consisting of the brain and spinal cord and the peripheral nervous system (PNS), which contains cranial nerves and spinal nerves (Fig. 13.1). Sensory receptors detect changes in environmental stimuli, and nerve impulses move along sensory nerve fibers to the brain and the spinal cord. The brain and spinal cord sum up the data before sending impulses via motor nerve fibers to effectors (muscles and glands) so a response to stimuli is possible. Nervous tissue consists of neurons; whereas the brain and spinal cord contain all parts of neurons, nerves contain only axons.

Figure 13.1 The nervous system.
The central nervous system (CNS) is in the midline of the body, and the peripheral nervous system (PNS) is outside the CNS.
13.1 Central Nervous System

The brain is the enlarged anterior end of the spinal cord; it contains centers that receive input from and can command other regions of the nervous system.

Preserved Sheep Brain

The sheep brain (Fig. 13.2) is often used to study the brain. It is easily available and large enough that individual parts can be identified.

Observation: Preserved Sheep Brain

Examine the exterior and a midsaggital (longitudinal) section of a preserved sheep brain or a model of the human brain, and with the help of Figure 13.2, identify the following.

1. **Ventricles**: interconnecting spaces that produce and serve as a reservoir for cerebrospinal fluid, which cushions the brain. Toward the anterior, note the lateral ventricle (on one longitudinal section) and similarly a lateral ventricle (on the other longitudinal section). Trace the second ventricle to the third and then the fourth ventricles.

2. **Cerebrum**: most developed area of the brain; responsible for higher mental capabilities. The cerebrum is divided into the right and left cerebral hemispheres, joined by the corpus callosum, a broad sheet of white matter. The outer portion of the cerebrum is highly convoluted and divided into the following surface lobes (see Fig. 13.4):
   a. **Frontal lobe**: controls motor functions and permits voluntary muscle control; it also is responsible for abilities to think, problem solve, speak, and smell.
   b. **Parietal lobe**: receives information from sensory receptors located in the skin and also the taste receptors in the mouth. A groove called the central sulcus separates the frontal lobe from the parietal lobe.
   c. **Occipital lobe**: interprets visual input and combines visual images with other sensory experiences. The optic nerves split and enter opposite sides of the brain at the optic chiasma, located in the diencephalon.
   d. **Temporal lobe**: has sensory areas for hearing and smelling. The olfactory bulb contains nerve fibers that communicate with the olfactory cells in the nasal passages and take nerve impulses to the temporal lobe.

3. **Diencephalon**: portion of the brain where the third ventricle is located. The hypothalamus and thalamus are also located here.
   a. **Thalamus**: two connected lobes located in the roof of the third ventricle. The thalamus is the highest portion of the brain to receive sensory impulses before the cerebrum. It is believed to control which received impulses are passed on to the cerebrum. For this reason, the thalamus sometimes is called the "gatekeeper to the cerebrum."
   b. **Hypothalamus**: forms the floor of the third ventricle and contains control centers for appetite, body temperature, and water balance. Its primary function is homeostasis. The hypothalamus also has centers for pleasure, reproductive behavior, hostility, and pain.

4. **Cerebellum**: located just posterior to the cerebrum as you observe the brain dorsally, the cerebellum’s two lobes make it appear rather like a butterfly. In cross section, the cerebellum has an internal pattern that looks like a tree. The cerebellum coordinates equilibrium and motor activity to produce smooth movements.
Figure 13.2  The sheep brain.

a. Ventral view

b. Lateral view

c. Longitudinal section
5. **Brain stem**: Part of the brain that connects with the spinal cord. Because it includes the pons and medulla oblongata, it contains centers for the functioning of internal organs; because of its location, it serves as a relay station for nerve impulses passing from the cord to the brain. Therefore, it helps keep the rest of the brain alert and functioning.

   a. **Midbrain**: anterior to the pons, the midbrain serves as a relay station for sensory input and motor output. It also contains a reflex center for eye muscles.

   b. **Pons**: the ventral, bulblike enlargement on the brain stem. It serves as a passageway for nerve impulses running between the medulla and the higher brain regions.

   c. **Medulla oblongata** (or simply **medulla**): the most posterior portion of the brain stem. It controls internal organs; for example, cardiac and breathing control centers are present in the medulla. Nerve impulses pass from the spinal cord through the medulla to higher brain regions.

**The Human Brain**

*Label Figure 13.3 where indicated.* Based on your knowledge of the sheep brain, complete Table 13.1 by stating the major functions of each part of the brain listed.

<table>
<thead>
<tr>
<th>Table 13.1</th>
<th>Summary of Brain Functions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Part</strong></td>
<td><strong>Major Functions</strong></td>
</tr>
<tr>
<td>Cerebrum</td>
<td></td>
</tr>
<tr>
<td>Cerebellum</td>
<td></td>
</tr>
<tr>
<td><strong>Diencephalon</strong></td>
<td></td>
</tr>
<tr>
<td>Thalamus</td>
<td></td>
</tr>
<tr>
<td>Hypothalamus</td>
<td></td>
</tr>
<tr>
<td><strong>Brain stem</strong></td>
<td></td>
</tr>
<tr>
<td>Midbrain</td>
<td></td>
</tr>
<tr>
<td>Pons</td>
<td></td>
</tr>
<tr>
<td>Medulla oblongata</td>
<td></td>
</tr>
</tbody>
</table>

Which parts of the brain would work together to achieve the following?

1. Good eye–hand coordination ____________________________

2. Concentrating on homework when TV is playing ________________

3. Avoiding dark alleys while walking home at night ________________

4. Keeping the blood pressure constant ___________________________
Cerebral Lobes

As stated previously, the outer portion of the cerebrum is highly convoluted and divided into lobes as illustrated in Figure 13.4. The various sense organs send nerve impulses to a particular lobe where the nerve impulses are integrated to give us our senses of vision, hearing, smell, taste, and touch. Although not stated in Figure 13.4, the frontal lobe helps us remember smells of some significance to us. Write the name of a sense next to the appropriate lobe in Figure 13.4.

Figure 13.4 The cerebral lobes. Each lobe has centers for integrating nerve impulses received from a particular type of sense organ. Our five senses result from this activity of the brain.
The Spinal Cord

The spinal cord is a part of the central nervous system. It lies in the middorsal region of the body and is protected by the vertebral column.

Observation: The Spinal Cord

1. Examine a prepared slide of a cross section of the spinal cord under the lowest magnification possible.
2. Identify the following with the help of Figure 13.5:
   a. Gray matter: a central, butterfly-shaped area composed of masses of short nerve fibers, interneurons, and motor neuron cell bodies
   b. White matter: masses of long fibers that lie outside the gray matter and carry impulses up and down the spinal cord. In living animals, white matter appears white because an insulating myelin sheath surrounds long fibers.

13.2 Peripheral Nervous System

The peripheral nervous system contains the cranial nerves and the spinal nerves. Twelve pairs of cranial nerves project from the inferior surface of the brain. The cranial nerves are largely concerned with nervous communication between the head, neck, and facial regions of the body and the brain. The 31 pairs of spinal nerves emerge from either side of the spinal cord (Fig. 13.6).

Spinal Nerves

Each spinal nerve contains long fibers of sensory neurons and long fibers of motor neurons. In Figure 13.6, identify the following:

1. Sensory neuron: takes nerve impulses from a sensory receptor to the spinal cord. The cell body of a sensory neuron is in the dorsal root ganglion.
2. Interneuron: lies completely within the spinal cord. Some interneurons have long fibers and take nerve impulses to and from the brain. The neuron in Figure 13.6 transmits nerve impulses from the sensory neuron to the motor neuron.
3. Motor neuron: takes nerve impulses from the spinal cord to an effector—in this case, a muscle. Muscle contraction is one type of response to stimuli.

Suppose you were walking barefoot and stepped on a prickly sandbur. Describe the pathway of information, starting with the pain receptor in your foot, that would allow you to both feel and respond to this unwelcome stimulus.

Spinal Reflexes

A reflex is an involuntary and predictable response to a given stimulus that allows a quick response to environmental stimuli without communicating with the brain. In the spinal reflexes that follow, stretch receptors detect the tap, and sensory neurons conduct nerve impulses to interneurons in the spinal cord. The interneurons send a message via motor neurons to the effectors, muscles in the leg or foot. These reflexes are involuntary because the brain is not involved in formulating the response. Consciousness of the stimulus lags behind the response because information must be sent up the spinal cord to the brain before you can become aware of the tap.
**Figure 13.6  Spinal nerves and spinal cord.**
The arrows mark the path of nerve impulses from a sensory receptor to an effector. When a spinal reflex occurs, a sensory receptor is stimulated and generates nerve impulses that pass along the sensory neuron, the interneuron, and motor neuron causing the effector to respond.

**Experimental Procedure: Spinal Reflex**

One easily tested tendon reflex involves the **patellar tendon**. When this tendon is tapped with a reflex hammer (Fig. 13.7) or, in this experiment, with a meterstick, the attached muscle contracts and the leg rises. The stretch receptor generates nerve impulses which are transmitted along sensory neurons to the spinal cord. Nerve impulses from the cord then pass along motor neurons and stimulate the muscle, causing it to contract. Receptors in other tendons, such as the Achilles tendon, respond similarly.

**Knee-Jerk (Patellar) Reflex**

1. Have the subject sit on a table so that his or her legs hang freely.
2. Sharply tap one of the patellar tendons just below the patella (kneecap) with a meterstick.
3. In this relaxed state, does the leg flex (move toward the buttocks) or extend (move away from the buttocks)?
13.3 The Human Eye

First you will observe an eye model and then perform two experimental procedures to test your own eyes.

**Observation: The Human Eye**

The eye is a special sense organ for detecting light rays in the environment. Examine a human eye model, and identify the structures listed in Table 13.2 and depicted in Figure 13.8. As you identify the structures state their functions.

<table>
<thead>
<tr>
<th>Part</th>
<th>Location</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sclera</td>
<td>Outer layer of eye</td>
<td>Protects and supports eyeball</td>
</tr>
<tr>
<td>Cornea</td>
<td>Transparent portion of sclera</td>
<td>Refracts light rays</td>
</tr>
<tr>
<td>Choroid</td>
<td>Middle layer of eye</td>
<td>Absorbs stray light rays</td>
</tr>
<tr>
<td>Retina</td>
<td>Inner layer of eye</td>
<td>Contains receptors for sight</td>
</tr>
<tr>
<td>Rod cells (black and white vision)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cone cells (color vision)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fovea centralis</td>
<td>Special region of retina for cones</td>
<td>Makes acute vision possible</td>
</tr>
<tr>
<td>Lens</td>
<td>Between compartments</td>
<td>Refracts and focuses light rays</td>
</tr>
<tr>
<td>Ciliary body</td>
<td>Extension from choroid</td>
<td>Holds lens in place; functions in accommodation</td>
</tr>
<tr>
<td>Iris</td>
<td>Most anterior portion of choroid</td>
<td>Regulates light entrance</td>
</tr>
<tr>
<td>Pupil</td>
<td>Opening in middle of iris</td>
<td>Admits light</td>
</tr>
<tr>
<td>Aqueous and vitreous humors</td>
<td>Fluid media of eye</td>
<td>Transmits and refract light rays</td>
</tr>
<tr>
<td>Optic nerve</td>
<td>Extension from posterior of eye</td>
<td>Transmits impulses to occipital lobe of brain</td>
</tr>
</tbody>
</table>

Figure 13.8 Anatomy of the human eye.
The Blind Spot of the Eye
The blind spot occurs where the optic nerve fibers exit the retina. No vision is possible at this location because of the absence of rod cells and cone cells.

Experimental Procedure: Blind Spot of the Eye
This Experimental Procedure requires a laboratory partner. Figure 13.9 shows a small circle and a cross several centimeters apart.

Figure 13.9 Blind spot.
This dark circle (or cross) will disappear at one location because there are no rod cells or cone cells at each eye’s blind spot, where vision does not occur.

Left Eye
1. Hold Figure 13.9 approximately 30 cm from your eyes. The cross should be directly in front of your left eye. If you wear glasses, keep them on.
2. Close your right eye.
3. Stare only at the cross with your left eye. You should also be able to see the circle in the same field of vision. Slowly move the paper toward you until the circle disappears.
4. Repeat the procedure as many times as needed to find the blind spot.
5. Then slowly move the paper closer to your eyes until the circle reappears. Because only your left eye is open, you have found the blind spot of your left eye.
6. With your partner’s help, measure the distance from your eye to the paper when the circle first disappeared. Left eye: ________ cm

Right Eye
1. Hold Figure 13.9 approximately 30 cm from your eyes. The circle should be directly in front of your right eye. If you wear glasses, keep them on.
2. Close your left eye.
3. Stare only at the circle with your right eye. You should also be able to see the cross in the same field of vision. Slowly move the paper toward you until the cross disappears.
4. Repeat the procedure as many times as needed to find the blind spot.
5. Then slowly move the paper closer to your eyes until the cross reappears. Because only your right eye is open, you have found the blind spot of your right eye.
6. With your partner’s help, measure the distance from your eye to the paper when the cross first disappeared. Right eye: ________ cm

In this exercise, you created an artificial situation in which you became aware of how your perception of the world can be constrained by the eye’s anatomy. Although the eye detects patterns of light and color, it is the brain that determines what we visually perceive. The brain can fill in data that is missing based in part on past experiences.
**Accommodation of the Eye**

When the eye accommodates to see objects at different distances, the shape of the lens changes. The lens shape is controlled by the ciliary muscles attached to it. When you are looking at a distant object, the lens is in a flattened state. When you are looking at a closer object, the lens becomes more rounded. The elasticity of the lens determines how well the eye can accommodate. Lens elasticity decreases with increasing age, a condition called **presbyopia**. Presbyopia is the reason many older people need bifocals to see near objects.

**Experimental Procedure: Accommodation of the Eye**

This Experimental Procedure requires a laboratory partner. It tests accommodation of either your left or right eye.

1. Hold a pencil upright by the eraser and at arm’s length in front of whichever of your eyes you are testing (Fig. 13.10).
2. Close the opposite eye.
3. Move the pencil from arm’s length toward your eye.
4. Focus on the end of the pencil.
5. Move the pencil toward you until the end is out of focus. Measure the distance (in centimeters) between the pencil and your eye: _______ cm
6. At what distance can your eye no longer accommodate for distance? _______ cm
7. If you wear glasses, repeat this experiment without your glasses, and note the accommodation distance of your eye without glasses:
   _______ cm. (Contact lens wearers need not make these determinations, and they should write the words contact lens in this blank.)
8. The “younger” lens can easily accommodate for closer distances. The nearest point at which the end of the pencil can be clearly seen is called the **near point**. The more elastic the lens, the “younger” the eye (Table 13.3). How “old” is the eye you tested? _______

<table>
<thead>
<tr>
<th>Table 13.3 Near Point and Age Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
</tr>
<tr>
<td>Near point (cm)</td>
</tr>
</tbody>
</table>

**13.4 The Human Ear**

The human ear, whose parts are listed and depicted in Table 13.4 and Figure 13.11, serves two functions: hearing and balance.

**Observation: The Human Ear**

Examine a human ear model, and find the structures depicted in Figure 13.11 and listed in Table 13.4.
### Table 13.4 Parts of the Human Ear

<table>
<thead>
<tr>
<th>Part</th>
<th>Medium</th>
<th>Function</th>
<th>Mechanoreceptor</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Outer ear</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pinna</td>
<td>Air</td>
<td>Collects sound waves</td>
<td>—</td>
</tr>
<tr>
<td>Auditory canal</td>
<td></td>
<td>Filters air</td>
<td>—</td>
</tr>
<tr>
<td><strong>Middle ear</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tympanic membrane</td>
<td>Air</td>
<td>Amplify sound waves</td>
<td>—</td>
</tr>
<tr>
<td>and ossicles</td>
<td></td>
<td>Equalizes air pressure</td>
<td>—</td>
</tr>
<tr>
<td>Auditory tube</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Inner ear</strong></td>
<td>Fluid</td>
<td>Rotational equilibrium</td>
<td>Stereocilia embedded in cupula</td>
</tr>
<tr>
<td>Semicircular canals</td>
<td></td>
<td>Gravitational equilibrium</td>
<td>Stereocilia embedded in otolithic membrane</td>
</tr>
<tr>
<td>Vestibule (contains</td>
<td></td>
<td>Hearing</td>
<td>Stereocilia embedded in tectorial</td>
</tr>
<tr>
<td>utricle and saccule</td>
<td></td>
<td></td>
<td>membrane</td>
</tr>
<tr>
<td>Cochlea (spiral organ)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Figure 13.11 Anatomy of the human ear.
The outer ear extends from the pinna to the tympanic membrane. The middle ear extends from the tympanic membrane to the oval window. The inner ear encompasses the semicircular canals, the vestibule, and the cochlea.

### Physiology of the Human Ear
When you hear, sound waves are picked up by the tympanic membrane and amplified by the malleus, incus, and stapes. This creates pressure waves in the canals of the cochlea that lead to stimulation of hair cells, the receptors for hearing. Hair cells in the utricle and saccule of the vestibule and in semicircular canals are receptors for equilibrium (i.e., balance). Nerve impulses from the sensory receptors in the ears travel by way of the cochlear nerve and the vestibular nerve to the brain and eventually are interpreted by the ______ lobe of the brain.
**Experimental Procedure: Locating Sound**

Humans locate the direction of sound according to how fast it is detected by either or both ears. A difference in the hearing ability of the two ears can lead to a mistaken judgment about the direction of sound. You and a laboratory partner should perform this Experimental Procedure on each other. Enter the data for your ears, not your partner’s ears, in the spaces provided.

1. Ask the subject to be seated, with eyes closed. Then strike a tuning fork or rap two spoons together at the five locations listed in number 2. Use a random order.
2. Ask the subject to give the exact location of the sound in relation to his or her head. Record the subject’s perceptions when the sound is:
   a. Directly below and behind the head
   b. Directly behind the head
   c. Directly above the head
   d. Directly in front of the face
   e. To the side of the head
3. Is there an apparent difference in hearing between your two ears?

**13.5 Sensory Receptors in Human Skin**

The sensory receptors in human skin respond to touch, pain, temperature, and pressure (Fig. 13.12). There are individual sensory receptors for each of these stimuli, as well as free nerve endings able to respond to pressure, pain, and temperature.

**Figure 13.12  Sensory receptors in the skin.**
Each type of receptor shown responds primarily to a particular stimulus.
Sense of Touch

The dermis of the skin contains touch receptors, whose concentration differs in various parts of the body.

**Experimental Procedure: Sense of Touch**

You will need a laboratory partner to perform this Experimental Procedure. Enter your data, not the data of your partner, in the spaces provided.

1. Ask the subject to be seated, with eyes closed.
2. Then test the subject’s ability to discriminate between the two points of a hairpin or a pair of scissors at the four locations listed in number 5.
3. Hold the points of the hairpin or scissors on the given skin area, with both of the points simultaneously and gently touching the subject.
4. Ask the subject whether the experience involves one or two touch sensations.
5. Record the shortest distance between the hairpin or scissor points for a two-point discrimination.
   a. Forearm: _________ mm
   b. Back of the neck: _________ mm
   c. Index finger: _________ mm
   d. Back of the hand: _________ mm
6. Which of these areas apparently contains the greatest density of touch receptors? ___________________________
   Why is this useful? ___________________________
7. Do you have a sense of touch at every point in your skin? _________ Explain. ___________________________
8. What specific part of the brain processes nerve impulses from touch and pain receptors? See Figure 13.4.

---

Sense of Heat and Cold

Temperature receptors respond to a change in temperature.

**Experimental Procedure: Sense of Heat and Cold**

1. Obtain three 1,000 mL beakers, and fill one with ice water, one with tap water at room temperature, and one with warm water (45°–50°C).
2. Immerse your left hand in the ice-water beaker and your right hand in the warm-water beaker for 30 seconds.
3. Then place both hands in the beaker with room-temperature tap water.
4. Record the sensation in the right and left hands.
   a. Right hand: ___________________________
   b. Left hand: ___________________________
5. Explain your results. ___________________________
13.6 Human Chemoreceptors

The taste receptors, called ________________, located in the mouth, and the smell receptors, called ________________, located in the nasal cavities, are the chemoreceptors that respond to molecules in the air and water. Nerve impulses from taste receptors go to the ________________ lobe of the brain while those from smell receptors go to the ________________ lobe of the brain.

**Experimental Procedure: Sense of Taste and Smell**

You will need a laboratory partner to perform the following procedures. It will not be necessary for all tests to be performed on both partners. You should take turns being either the subject or the experimenter. Dispose of used cotton swabs in a hazardous waste container or as directed by your instructor.

1. Students work in groups. Each group has one experimenter and several subjects.
2. The experimenter should obtain a LifeSavers candy from the various flavors available, without letting the subject know what flavor it is.
3. The subject closes both eyes and holds his or her nose.
4. The experimenter gives the LifeSavers candy to the subject, who places it on his or her tongue.
5. The subject, while still holding his or her nose, guesses the flavor of the candy. The experimenter records the guess in Table 13.5.
6. The subject releases his or her nose and guesses the flavor again. The experimenter records the guess and the actual flavor in Table 13.5.

**Table 13.5 Taste and Smell Experiment**

<table>
<thead>
<tr>
<th>Subject</th>
<th>Actual Flavor</th>
<th>Flavor While Holding Nose</th>
<th>Flavor After Releasing Nose</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Conclusions: Sense of Taste and Smell**

- From your results, how would you say that smell affects the taste of LifeSavers candy?

- What do you conclude about the effect of smell on your sense of taste?
Application for Daily Living

LASIK Surgery
The focusing ability of the lens to place an image on the retina so we can see is assisted by the cornea. The cornea refracts or bends the light rays, and then the lens takes on the chore from then on. This accounts for why LASIK eye surgery, which reshapes the cornea, works. The traditional LASIK vision correction involves two steps: (1) First, the surgeon has to make a flap in the outer surface of the eye to expose the underlying cornea. (2) Then, the cornea is reshaped.

Anyone considering undergoing LASIK eye surgery should be aware that various side effects have been seen from dry eyes to severe glare when driving at night. Therefore, the procedure should be discussed with a physician or optician first. They can recommend a reliable clinic and surgeon and will also be able to advise whether there is any reason why LASIK eye surgery might not work for you.

Laboratory Review 13

1. What part of the brain is largest in humans?
2. What part of the brain controls muscular coordination?
3. What is the most inferior portion of the brain stem?
4. What structures protect the spinal cord?
5. Are motor neuron cell bodies located in the gray or white matter of the spinal cord?
6. What type of neuron is found completely within the central nervous system?
7. Which neuron's cell body is in the dorsal root ganglion?
8. What part of the eye contains the sensory receptors for sight?
9. Where on the retina is the blind spot located?
10. What do you call the outer layer of the eye?
11. What part of the ear contains the sensory receptors for hearing?
12. In which part of the ear are the malleus, incus, and stapes located?
13. What layer of the skin contains sensory receptors for touch?
14. Are touch receptors distributed evenly or unevenly in the skin?
15. What senses are dependent on chemoreceptors?
16. The four taste sensations are sour, salty, bitter, and ________.
17. What advantages are associated with the spinal cord and spinal nerves functioning below the level of consciousness?
18. Identify the type of neuron responsible for transmitting nerve impulses from the spinal cord to an effector.
Thought Questions

19. Trace the path of light in the human eye through each structure or compartment—from the exterior to the retina. How do nerve impulses from the retina reach the occipital lobe of the brain?

20. Trace the path of sound waves in the human ear—from the tympanic membrane to the sensory receptors for hearing.

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14
Reproduction and Development

Learning Outcomes

14.1 Male and Female Reproductive Systems
- Trace the path of sperm in the male and the egg in the female.
- Locate on a model and state a function for each major organ in the male and female reproductive systems.
- Identify a slide of the testis and the ovary and the major structures in these organs.
- Describe the specialization of a sperm and of an egg for their functions.

Prelab Question: What is the most significant biological contribution of a male and a female to an offspring?

14.2 Embryonic Development
- Identify the cellular stages of development with reference to slides of early sea star development.
- Identify the tissue stages of development with reference to slides of frog development.
- Associate the germ layers with the development of various organs.
- Identify which organs develop first in a vertebrate embryo (e.g., frog, chick, and human).
- When presented with a sequence of human embryos, point out and discuss aspects of their increasing complexity.

Prelab Question: Which human organs develop first during development?

14.3 Extraembryonic Membranes, the Placenta, and the Umbilical Cord
- Distinguish between and give a function for the extraembryonic membranes, the placenta, and the umbilical cord.
- Trace the development of the extraembryonic membranes during embryonic development, and state a function for each membrane.

Prelab Question: Which extraembryonic membrane becomes the placenta?

14.4 Fetal Development
- Trace the main events of human fetal development.

Prelab Question: Account for why the respiratory system is not functional until the sixth month or later.

Application for Daily Living: Cord Around Baby’s Neck

Introduction

The sperm and egg contribute chromosomes to the offspring. The testes in males and the ovaries in females produce the gametes and also the hormones that maintain the organs and the characteristics we associate with a male and female. In humans, embryonic development begins when the sperm fertilizes the egg and a zygote is formed. Cell division produces a ball of cells that arrange themselves into three layers, called the germ layers. It is possible to associate the development of particular organs with a specific germ layer. Embryonic development comes to a close when all the basic organs have formed. Refinements and an increase in size occur during fetal development.
14.1 Male and Female Reproductive Systems

Only the urinary and reproductive systems have a different anatomy and physiology in males and females.

Observation: Male Reproductive System Model

The functions of the male reproductive system are to (1) produce sperm and the male sex hormones within the testes, (2) transport the sperm in ducts until they exit through the penis, (3) nourish and provide a medium for sperm in which they can survive, and (4) deliver sperm to the vagina of the female. Identify the following organs in a model (Fig. 14.1):

1. Testes. The primary sex organs of males where the sperm and male sex hormones (e.g., testosterone) are produced. The testes fulfill the first function noted previously for the male reproductive system.
2. Epididymis. A tightly coiled, threadlike tube where sperm are stored until they are mature and capable of fertilizing an egg.
3. Vas deferens. A muscular tube that conducts sperm to the ejaculatory duct.
4. Ejaculatory duct. When the vas deferens and a duct from the seminal vesicle meet, they form a short ejaculatory duct, which passes through the prostate gland and empties into the urethra.
5. Urethra. The male urethra is located in the penis. The urethra either conducts semen or it conducts urine to the exterior and does not pass them both at the same time. What function of the male reproductive system previously listed is fulfilled by the ducts (2–5) just described?

6. Seminal vesicles, the prostate gland, and the bulbar urethral glands. These glands do not produce hormones, but they do produce secretions that account for why semen (the substance that exits the penis during ejaculation) is a thick fluid. The secretions of these glands are favorable to the health of the sperm. What function noted previously for the male reproductive system is fulfilled by these glands?

---

The prostate gland frequently enlarges in older men and blocks the urethra. Under these conditions, a male is apt to have difficulty urinating. Explain.
Observation: Microscopic Examination of the Testis and Sperm

**Testes**

1. Obtain a slide of the testis. As shown in Figure 14.2a, a testis (sing., testis) contains many seminiferous tubules where spermatogenesis (production of sperm) occurs. Note under low power the circular nature of a tubule.

2. Switch to high power, and observe one tubule in particular. Between the tubules, try to identify interstitial cells, which produce testosterone. Testosterone enters the body by way of the blood and not by way of ducts. Explain why a vasectomy, a cutting of the vas deferens, causes a male to be sterile but has no effect on his masculinity.

3. Spermatogenesis occurs in the seminiferous tubules (Fig. 14.2b). Identify:
   - Sertoli cells nuclei. The cytoplasm of a Sertoli cell surrounds a cell undergoing spermatogenesis.
   - Germ cells. First spermatogonia, next spermatocytes, and finally spermatids occur, but they are hard to identify. Males produce four viable spermatids for each spermatogenesis. Each spermatid becomes a sperm.
   - Sperm. Sperm tails look like thin, fine, dark lines in the lumen of the tubule. The sperm are fully developed but immature. They will complete their maturation in the epididymis. Why is it important for sperm cells to have a tail?

**Sperm**

Obtain a prepared slide of sperm and compare what you see to Figure 14.2c. An acrosome contains enzymes that digest a path through cells that surround an egg and the outer covering of an egg so that one sperm can enter.

State another way sperm are specialized.

The ejaculated semen of a normal male contains several hundred million sperm, each a product of spermatogenesis, but only one sperm normally enters an egg. Speculate why so many sperm are needed for fertilization to occur.

---

**Figure 14.2 Testis and sperm.**
Observation: Female Reproductive System Model

The function of the female reproductive system (Fig. 14.3) is to (1) produce eggs and sex hormones within the ovaries; (2) transport eggs from the ovaries to the uterus; (3) receive the sperm in the vagina, also the birth canal; and (4) protect the fertilized egg (zygote) until it matures and is born. Identify the following organs in a model (see Fig. 14.3):

1. **Ovaries.** The primary sex organs of females where eggs and female sex hormones (e.g., estrogen and progesterone) are produced.
2. **Oviducts.** At the end nearest the ovaries, the oviducts have fimbriae that sweep over an ovary so that a released egg enters the oviduct. Cilia that line the oviduct and muscular contraction of its walls propel the egg toward the uterus. Fertilization, if it occurs, happens in an oviduct.
3. **Uterus.** A thick-walled, muscular organ about the size and shape of an inverted pear, where development of the embryo and fetus occur. The cervix surrounds the opening to the uterus.
4. **Vagina.** The uterus empties into the vagina, which makes a 45° angle with the small of the back.

![Figure 14.3 The female reproductive system.](image)

Observation: Microscopic Examination of the Ovary

**Ovary**

1. Examine a prepared slide of an ovary, and refer to Figure 14.4 for help in identifying the structures.
2. Locate a primary follicle, which appears as a circle of small cells surrounding a somewhat larger cell, the primary oocyte.
3. Find a secondary follicle, and switch to high power. Note the secondary oocyte (egg), surrounded by numerous cells, to one side of the liquid-filled follicle. Why is it important for females to produce an egg that has plentiful cytoplasm?
4. Look for a large, fluid-filled vesicular (Graafian) follicle, which contains a mature secondary oocyte to one side. This follicle will be next to the outer surface of the ovary because it is the type of follicle that releases the egg during ovulation.

5. Look for the remains of the corpus luteum, which will look like scar tissue. The corpus luteum develops after the vesicular follicle has released its egg, and then later it deteriorates. Not all slides will contain a corpus luteum and a vesicular follicle because they may not have been present when the slide was made.

6. Oogenesis
   The primary follicle and the secondary follicle are the site of oogenesis (production of an egg). Each oogenesis event in females produces a single egg. In contrast to males, females produce one egg a month.

![Figure 14.4 Ovary and oocytes.](image)

**Summary of Reproductive Systems**
- Complete Table 14.1 to describe the differences between the male and female human reproductive systems. A gonad is an organ that produces gametes, the sperm and egg.

<table>
<thead>
<tr>
<th>Table 14.1: Comparison of Human Male and Female Reproductive Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Male</strong></td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td>Gonad</td>
</tr>
<tr>
<td>Duct from gonad</td>
</tr>
<tr>
<td>Duct from gonad leads to</td>
</tr>
<tr>
<td>Copulatory organ</td>
</tr>
</tbody>
</table>

---
14.2 Embryonic Development

We will divide embryonic development into three stages: cellular, tissue layer, and organ development. In human beings, it takes two months to complete embryonic development. It is impossible for us to view the stages of embryonic development in a human being, so we will use the sea star, frog, and chick as our observational material.

**Cellular Stages of Development**

The cellular stages of development include the following:

- **Zygote formation**: A single sperm fertilizes an egg and the result is a zygote, the first cell of the new individual.
- **Morula formation**: The zygote divides into a number of smaller cells until there is a cluster of 16–32 cells called a morula.
- **Blastula formation**: The morula becomes a blastula, a hollow ball of cells.

**Observation: Cellular Stages of Development in the Sea Star**

The cellular stages of development are remarkably similar in all animals. Therefore, we can view slides of sea star development to study the cellular stages of human development (Fig. 14.5). A sea star is an invertebrate that develops in the ocean and, therefore, will develop easily in the laboratory where it can be observed.

Obtain slides or view a model of sea star development and note the following:

1. **Zygote.** Both plants and animals begin life as a single cell, a zygote. A zygote contains chromosomes from each parent. Explain.

2. **Cleavage.** View slides showing various numbers of cells due to the process of cleavage, cell division without growth until the morula stage. Is the morula about the same size as the zygote? Explain.

3. **Blastula.** The cavity of a blastula is called the blastocoel. Label blastocoel in Figure 14.5. The formation of a hollow cavity is important to the next stage of development.

**Figure 14.5 Starfish development.**

All animals, including starfish and humans, go through the same cellular stages from cleavage to blastula.
Observation: Cellular Stages of Development in Humans

In Figure 14.6, or in a model of human development, observe the same stages of development already observed in sea star slides. Also, observe that fertilization in humans occurs in an oviduct following ovulation. As the embryo undergoes cleavage, it travels in the oviduct to the uterus.

If the embryo splits at the 2-cell stage, the result is identical twins. (Fraternal twins arise when two separate eggs are fertilized.) How might you account for the development of identical triplets?

The blastula in humans is called a blastocyst. The blastocyst contains an inner cell mass that becomes the embryo, and the outer group of cells (the trophoblast) will become membranes that nourish and protect it. At about day 6, the blastocyst has reached the uterus and implants into the uterine wall, where it will receive nourishment from the mother’s bloodstream.

What’s the main difference between the cellular stages in a sea star and in a human?

---

Figure 14.6  Human development before implantation.

Structures and events proceed clockwise. At ovulation, an egg leaves the ovary. A single sperm penetrates the egg, and fertilization occurs in the oviduct. As the zygote moves along the oviduct, it undergoes cleavage to produce an embryo that implants in the uterine lining.
**Tissue Stages of Development**

The tissue stages of development include the following:

- **Early gastrula stage.** This stage begins when certain cells begin to push or invaginate into the blastocoel, creating a double layer of cells. The outer layer is called the ectoderm, and the inner layer is called the endoderm.

- **Late gastrula stage.** Gastrulation is not complete until there are three layers of cells. The third layer called mesoderm occurs between the other two layers already mentioned.

**Observation: Tissue Stages of Development in a Frog**

It is traditional to view frog gastrulation. A frog is a vertebrate, and so its development is expected to be closer to that of a human than is a sea star. In Figure 14.7, note that the yellow (vegetal pole) cells are heavily laden with yolk, and the blue (animal pole) cells are the ones that invaginate into the blastocoel forming the early gastrula.

1. **Early gastrula stage.** Obtain a cross section of a frog gastrula. Most likely, your slide is the equivalent of Figure 14.7b, number 3, in which case you will see two cavities, the old blastocoel and newly forming archenteron, which forms once the animal pole cells have invaginated. The archenteron will become the digestive tract.

2. **Late gastrula stage.** In Figure 14.7, note that a third layer of cells, the mesoderm, is colored red and that it develops between the ectoderm and endoderm.

**Figure 14.7 Drawings of frog developmental stages.**

* a. During cleavage, the number of cells increases but overall size remains the same.
* b. During gastrulation, three tissue layers form.
* c. During neurulation, the notochord and neural tube form.
Observation: Tissue Stages of Development in a Human

In a model of human development, observe the same stages of development already observed in frog slides. After implantation, gastrulation in humans turns the inner cell mass into the embryonic disk. Figure 14.8 shows the embryonic disk, which has the three layers of cells we have been discussing: the ectoderm, mesoderm, and endoderm. Figure 14.8 also shows the significance of these layers, often called the germ layers. The future organs of an individual can be traced back to one of the germ layers.

<table>
<thead>
<tr>
<th>Primary Germ Layer</th>
<th>Human Adult Structures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ectoderm (outer layer)</td>
<td>Epidermis of skin; epithelial lining of oral cavity and rectum; nervous system</td>
</tr>
<tr>
<td>Mesoderm (middle layer)</td>
<td>Skeletal; muscular system; dermis of skin; cardiovascular system; urinary system; reproductive system; outer layers of respiratory and digestive systems</td>
</tr>
<tr>
<td>Endoderm (inner layer)</td>
<td>Epithelial lining of digestive tract and respiratory tract; associated glands of these systems; epithelial lining of urinary bladder</td>
</tr>
</tbody>
</table>

Figure 14.8 An embryo has three primary germ layers. The three germ layers are ectoderm, mesoderm, and endoderm. Organs and tissues can be traced back to a particular germ layer as indicated in this illustration.
Organ Stages of Development

As soon as all three embryonic tissue layers (ectoderm, endoderm and mesoderm) are established, the organ level of development begins. It continues until development is complete. The first organs to develop are the

- Digestive tract. You have already observed the start of the archenteron during gastrulation.
- Spinal cord and brain
- Heart

Observation: Development of the Spinal Cord and Brain

One of the first systems to form is the nervous system. Why might it be beneficial for the nervous system to begin development first?

1. Obtain a cross section of a frog neurula stage, and match it to one of the drawings in Figure 14.7c.
   Which drawing seems to best match your slide? __________________________________________________________________________
   Your instructor will confirm your match for you.

2. A neural tube develops from ectoderm (Fig. 14.7c). Can you see how? __________________________________________________________________
   When neural folds rise up and fuse, the neural tube has formed. The neural tube, which runs the length of
   the embryo, is the first sign of the central nervous system. The nerve cord, also called the spinal cord, and
   the brain both develop from the neural tube.

   Notice how the neural tube develops above the notochord, a dorsal supporting rod that later becomes the
   vertebral column. Why would you expect the neural tube, which becomes the spinal cord, to develop in the same
   vicinity as the notochord, which becomes the vertebral column? _____________________________________________________________________

Observation: Development of the Heart

A chick embryo offers an opportunity to view a beating heart in an embryo. Your instructor may show you various stages. In particular you will want to observe the 48-hour chick embryo.

Observing Live Chick Embryos

Use the following procedure for selecting and opening the eggs of live chick embryos:

1. Choose an egg of the proper age to remove from the incubator, and put a penciled × on the uppermost side. The embryo is just below the shell.

2. Add warmed chicken Ringer solution to a finger bowl until the bowl is about half full. (Chicken Ringer solution is an isotonic salt solution for chick tissue that maintains the living state.) The chicken Ringer solution should not cover the yolk of the egg.

3. On the edge of the dish, gently crack the egg on the side opposite the ×.

4. With your thumbs placed over the ×, hold the egg in the chicken Ringer solution while you pry it open from below and allow its contents to enter the solution. If you open the egg too slowly or too quickly, the shell may damage the delicate membranes surrounding the embryo.
Observation: Forty-Eight-Hour Chick Embryo

1. Follow the standard procedure (see page 192) for selecting and opening an egg containing a 48-hour chick embryo.

2. The embryo has turned so that the head region is lying on its side. Refer to Figure 14.9, and identify the following:
   a. **Shape of the embryo**, which has started to bend. The head is now almost touching the heart.
   b. **Heart**, contracting and circulating blood. Can you make out a ventricle, an atrium, and the aortic arches in the region below the head? Later, only one aortic arch will remain.
   c. **Vitelline arteries and veins**, which extend over the yolk. The vitelline veins carry nutrients from the yolk sac to the embryo.
   d. **Brain** with several distinct regions.
   e. **Eye**, which has a developing lens.
   f. **Margin (edge) of the amnion**, which can be seen above the vitelline arteries (see next section for amnion).
   g. **Somites**, blocks of developing muscle tissue that differentiate from mesoderm, which now number 24 pairs.
   h. **Caudal fold** of the amnion. The embryo will be completely enveloped when the head fold and caudal fold meet the margin of the amnion.
   i. **Neural tube**, which runs the length of the embryo, is the first sign of the central nervous system.

![Figure 14.9  Forty-eight-hour chick embryo.](image)
The most prominent organs are labeled.
Observation: Development of Human Organs

Study models or other study aids available that show the development of the nervous system and the heart in human beings and/or show models of human embryos of different ages. Also view Figure 14.10, which depicts the external appearance of the embryo from the fourth to the seventh week of development.

During the embryonic period of development, the growing baby is susceptible to environmental influences, including the following:

- Drugs, such as alcohol; certain prescriptions; and recreational drugs. These can cause birth defects.
- Infections such as rubella, also called German measles, and other viral infections.
- Nutritional deficiencies.
- X-rays or radiation therapy.

Figure 14.10 External appearance of the embryo.

a. Weeks 4 to 5
b. Weeks 6 to 7
14.3 Extraembryonic Membranes, the Placenta, and the Umbilical Cord

- The extraembryonic membranes take their name from the observation that they are not part of the embryo proper. They are outside the embryo, and therefore they are “extra.”
- The placenta is the structure that provides the embryo with nutrient molecules and oxygen and takes away its waste molecules, such as carbon dioxide. The fetal half of the placenta is the chorionic villi, which contain fetal capillaries. The maternal half of the placenta is capillaries in the uterine wall.
- The umbilical cord is a tubular structure that contains two of the extraembryonic membranes (the allantois and the yolk sac) and also the umbilical blood vessels. The umbilical blood vessels bring fetal blood to and from the placenta. When a baby is born and begins to breathe on its own, the umbilical cord is cut and the remnants become the navel.

In this drawing, label the umbilical cord, which contains the umbilical blood vessels. Also label the placenta, which contains the maternal blood vessels.

**Observation: The Extraembryonic Membranes**

In a model, and in Figure 14.11, trace the development of the extraembryonic membranes. Also, note the development of the placenta and the umbilical cord. The extraembryonic membranes are the

- **Chorion.** The chorion begins to form at the blastocyst stage of development. The outer layer of cells surrounding the inner cell mass of the blastocyst becomes the chorion. Notice in Figures 14.8 and 14.11, the treelike chorionic villi are a part of the chorion that will become the placenta.
- **Amnion.** Forms the amniotic cavity, which envelopes the fetus and contains the amniotic fluid that cushions and protects the fetus (Fig. 14.12). All animals, whether the sea star, the frog, the chick, or a human, develop in an aqueous environment. Birth of a human is imminent when “the water breaks,” the loss of the amniotic fluid.
- **Allantois.** The allantois extends into the umbilical cord. It accumulates the small amount of urine produced by the fetal kidneys and later gives rise to the urinary bladder. Its blood vessels become the umbilical blood vessels.
- **Yolk sac.** The yolk sac is the first embryonic membrane to appear. In the chick, the yolk sac does contain yolk, food for the developing embryo. In humans, the yolk sac contains plentiful blood vessels and is the first site of blood cell formation.
Figure 14.11 Development of extraembryonic membranes.

a. At first, no organs are present in the embryo, only tissues. The amniotic cavity is above the embryonic disk, and the yolk sac is below. The chorionic villi are present. b. c. The allantois and yolk sac, two more extraembryonic membranes, are positioned inside the body stalk as it becomes the umbilical cord. d. At 35+ days, all membranes are present, and the umbilical cord takes blood vessels between the embryo and the chorion (placenta).

Figure 14.12 Fetus and amnion.
Photograph of a human fetus at 8 weeks. The scale bar is 3 cm.
14.4 Fetal Development

During fetal development (last seven months), the skeleton becomes ossified (bony), reproductive organs form, arms and legs develop fully, and the fetus enlarges in size and gains weight.

**Observation: Fetal Development**

1. Using Table 14.2 as a guide, examine models of fetal development.

2. In Table 14.2, note the following.
   a. **External genitals**: About the third month, it is possible to tell male from female if an ultrasound is done.
   b. **Quickening**: Fetal movement is felt during the fourth or fifth months.
   c. **Vernix caseosa**: Beginning with the fifth month, the skin is covered with a cheesy coating called vernix caseosa.
   d. **Lanugo**: During the sixth and seventh months, the body is covered with fine, downy hair termed lanugo.

3. All organ systems become fully functional during fetal development.

### Table 14.2: Fetal Development

<table>
<thead>
<tr>
<th>Month</th>
<th>Events for Mother</th>
<th>Events for Baby</th>
</tr>
</thead>
<tbody>
<tr>
<td>Third month</td>
<td>Uterus is the size of a grapefruit.</td>
<td>Possible to distinguish sex. Fingernails appear.</td>
</tr>
<tr>
<td>Fourth month</td>
<td>Fetal movement is felt by those who have been previously pregnant. Heartbeat is heard by stethoscope.</td>
<td>Bony skeleton visible. Hair begins to appear. 150 mm (6 in.), 170 g (6 oz.).</td>
</tr>
<tr>
<td>Fifth month</td>
<td>Fetal movement is felt by those who have not been previously pregnant. Uterus reaches up to level of umbilicus and pregnancy is obvious.</td>
<td>Protective cheesy coating, called vernix caseosa, begins to be deposited. Heartbeat can be heard.</td>
</tr>
<tr>
<td>Sixth month</td>
<td>Doctor can tell where baby’s head, back, and limbs are. Breasts have enlarged, nipples and areolae are darkly pigmented, and colostrum is produced.</td>
<td>Body is covered with fine hair called lanugo. Skin is wrinkled and reddish.</td>
</tr>
<tr>
<td>Seventh month</td>
<td>Uterus reaches halfway between umbilicus and rib cage.</td>
<td>Testes descend into scrotum. Eyes are open. 300 mm (12 in.), 1,350 g (3 lb).</td>
</tr>
<tr>
<td>Eighth month</td>
<td>Weight gain is averaging about a pound a week. Difficulty in standing and walking because center of gravity is thrown forward.</td>
<td>Body hair begins to disappear. Subcutaneous fat begins to be deposited.</td>
</tr>
<tr>
<td>Ninth month</td>
<td>Uterus is up to rib cage, causing shortness of breath and heartburn. Sleeping becomes difficult.</td>
<td>Ready for birth. 530 mm (20½ in.), 3,400 g (7½ lb).</td>
</tr>
</tbody>
</table>
Application for Daily Living

Cord Around Baby’s Neck

Babies are sometimes born with the umbilical cord wrapped around the neck. There isn’t much room in the uterus, and this is a common place for the cord to be located. The umbilical cord around the neck is not as dangerous as it sounds because the baby gets its oxygen by way of the placenta and the umbilical blood vessels and not the lungs. If the umbilical chord becomes overly stretched, oxygen may not be delivered as it should. This causes the fetal heart to slow down. First, the mother can change her position and/or be given oxygen but if the baby’s heart slows to below 100 beats for any length of time, then a cesarean delivery may be in order.

Laboratory Review 14

1. Where are the testes located in human males?
2. What is the function of the vas deferens?
3. What is the function of the prostate gland?
4. Where are the ovaries located?
5. What is the function of the uterus?
6. Where are sperm produced in the testes?
7. What structure in the ovary contains the developing oocyte (egg)?
8. Name the stage at which the embryo is a ball of cells.
9. Which extraembryonic membrane participates in the formation of the placenta?
10. What process directly follows the zygote stage?
11. What overall change in the skeleton occurs during fetal development?
12. Do the lungs function during fetal development?
13. What is the function of the placenta?

Thought Questions
14. A vasectomy is a procedure in which both of the vas deferens are severed. Why would such a procedure cause sterility?

15. List the three stages of embryonic development (p. 188, top), and explain.
16
Patterns of Genetic Inheritance

Learning Outcomes

16.1 Determining the Genotype
- Determine the genotype by observation of the person and their relatives.
Prelab Question: Both Nancy and Jim are homozygous for freckles, a dominant trait. Using letters, what is their genotype?

16.2 Determining Inheritance
- Do genetics problems involving autosomal dominant, autosomal recessive, and X-linked recessive alleles.
- Do genetic problems involving multiple allele inheritance and use blood type to help determine paternity.
Prelab Question: What are the chances that Nancy and Jim will have children with freckles?

16.3 Genetic Counseling
- Determine whether a karyotype contains a chromosome anomaly.
- Determine whether a pedigree represents a pattern of autosomal dominant, autosomal recessive, or X-linked recessive inheritance.
- Construct a pedigree to determine the chances of inheriting a particular phenotype when provided with generational information.
Prelab Question: In the pedigree of Nancy’s family and Jim’s family, would you expect to find few or many people with freckles? Explain.

Application for Daily Living: Choosing the Gender of Your Child

Introduction
Particulate genetics, which views the genes as particles located on the chromosomes, is no longer supported by molecular genetics. Still, its principles can be used to understand patterns of inheritance. First, a gene has two alternate forms called alleles for any trait such as hair line, finger length, and so on. One possible allele designated by a capital letter is dominant over the recessive allele, designated by a lowercase letter. An individual can be homozygous dominant (two dominant alleles, EE), homozygous recessive (two recessive alleles, ee) or heterozygous (one dominant and one recessive allele, Ee). Genotype refers to an individual’s alleles, and phenotype refers to an individual’s appearance (Fig. 16.1). Homozygous dominant and also heterozygous individuals show the dominant phenotype; homozygous recessive individuals show the recessive phenotype.

Figure 16.1 Genotype versus phenotype. Unattached earlobes (E) are dominant over attached earlobes (e). a. Homozygous dominant individuals have unattached earlobes. b. Homozygous recessive individuals have attached earlobes. c. Heterozygous individuals have unattached earlobes.

a. Unattached earlobe  b. Attached earlobe  c. Unattached earlobe
16.1 Determining the Genotype

Autosomal traits are determined by alleles on the autosomal chromosomes, all chromosomes except the sex chromosomes.

**Autosomal Dominant and Recessive Traits**

Figure 16.2 shows a few human traits.

1. What is the homozygous dominant genotype for type of hairline? __________ What is the phenotype?

2. What is the homozygous recessive genotype for finger length? What is the phenotype?

---

**Figure 16.2 Commonly inherited traits in human beings.**
The alleles indicate which traits are dominant and which are recessive.

- a. Widow’s peak: WW or Ww
- b. Straight hairline: ww
- c. Unattached earlobes: EE or Ee
- d. Attached earlobes: ee
- e. Short fingers: SS or Ss
- f. Long fingers: ss
- g. Freckles: FF or Ff
- h. No freckles: ff

3. Why does the heterozygous individual Ff have freckles?

These genetic problems use the alleles from Figure 16.2 and Table 16.1.

4. Victoria and the members of her immediate family have attached earlobes. What is Victoria’s genotype? __________ Her maternal grandfather has unattached earlobes. Deduce the genotype of her maternal grandfather. __________ Explain. __________

5. Lucas does not have a bent little finger, but his parents do. Deduce the genotype of his parents. __________ Of Lucas. __________ Explain. __________

6. Axel is adopted. He has hair on the back of his hand. Could both of his parents have had hair on the back of the hand? __________ Could both of his parents have had no hair on the back of the hand? __________ Explain. __________
Experimental Procedure: Human Traits

1. For this Experimental Procedure, you will need a lab partner to help you determine your phenotype for the traits listed in the first column of Table 16.1.
2. Determine your probable genotype. If you have the recessive phenotype, you know your genotype. If you have the dominant phenotype, you may be able to decide whether you are homozygous dominant or heterozygous by recalling the phenotype of your parents, siblings, or children. Circle your probable genotype in the second column of Table 16.1.
3. Your instructor will tally the class’s phenotypes for each trait so that you can complete the third column of Table 16.1.
4. Complete Table 16.1 by calculating the percentage of the class with each trait. Are dominant phenotypes always the most common in a population? Explain.

<table>
<thead>
<tr>
<th>Table 16.1</th>
<th>Autosomal Human Traits</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Trait:</strong> d = Dominant r = Recessive</td>
<td>Possible Genotypes</td>
</tr>
<tr>
<td><strong>Hairline:</strong></td>
<td>WW or Ww</td>
</tr>
<tr>
<td>Widow’s peak (d)</td>
<td>WW or Ww</td>
</tr>
<tr>
<td>Straight hairline (r)</td>
<td>Ww</td>
</tr>
<tr>
<td><strong>Earlobes:</strong></td>
<td>UU or Uu</td>
</tr>
<tr>
<td>Unattached (d)</td>
<td>uU or Uu</td>
</tr>
<tr>
<td>Attached (r)</td>
<td>uu</td>
</tr>
<tr>
<td><strong>Skin pigmentation:</strong></td>
<td>FF or Ff</td>
</tr>
<tr>
<td>Freckles (d)</td>
<td>FF or Ff</td>
</tr>
<tr>
<td>No freckles (r)</td>
<td>ff</td>
</tr>
<tr>
<td><strong>Hair on back of hand:</strong></td>
<td>HH or Hh</td>
</tr>
<tr>
<td>Present (d)</td>
<td>HH or Hh</td>
</tr>
<tr>
<td>Absent (r)</td>
<td>hh</td>
</tr>
<tr>
<td><strong>Thumb hyperextension—“hitchhiker’s thumb”:</strong></td>
<td>TT or Tt</td>
</tr>
<tr>
<td>Last segment cannot be bent backward (d).</td>
<td>TT or Tt</td>
</tr>
<tr>
<td>Last segment can be bent back to 60° (r).</td>
<td>tt</td>
</tr>
<tr>
<td><strong>Bent little finger:</strong></td>
<td>LL or Ll</td>
</tr>
<tr>
<td>Little finger bends toward ring finger (d).</td>
<td>LL or Ll</td>
</tr>
<tr>
<td>Straight little finger (r)</td>
<td>ll</td>
</tr>
<tr>
<td><strong>Interlacing of fingers:</strong></td>
<td>II or Ii</td>
</tr>
<tr>
<td>Left thumb over right (d)</td>
<td>II or Ii</td>
</tr>
<tr>
<td>Right thumb over left (r)</td>
<td>ii</td>
</tr>
</tbody>
</table>
**Experimental Procedure: Human Traits**

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---

**Table 16.1: Autosomal Human Traits**

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<thead>
<tr>
<th>Trait: <strong>d</strong> = Dominant</th>
<th>Possible Genotypes</th>
<th>Number In(^{(*)}) Class</th>
<th>Percentage of Class with Trait</th>
</tr>
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<tbody>
<tr>
<td><strong>r</strong> = Recessive</td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left thumb over right (d)</td>
<td>ll or lI</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right thumb over left (r)</td>
<td>ll</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Laboratory 16  Patterns of Genetic Inheritance  219
16.2 Determining Inheritance

A Punnett square is a means to determine the genetic inheritance of offspring if the genotypes of both parents are known. Figure 16.3 shows how to construct a Punnett square when autosomal alleles are involved. In a Punnett square, all possible types of sperm are lined up vertically, and all possible types of eggs are lined up horizontally, or vice versa, so that every possible combination of gametes occurs within the squares.

![Punnett square diagram](image)

**Results of Cross**
Phenotypic ratio 1:1

- Chance of widow's peak \( \frac{3}{4} = 50\% \)
- Chance of straight hairline \( \frac{1}{4} = 50\% \)

Figure 16.3 Punnett square.

**Calculating the Chances of a Phenotype**

Same as in Figure 16.3, learn to calculate the chances that an offspring will have a certain phenotype.

If in a Punnett Square, \( \frac{1}{4} \) of the offspring have the phenotype = ______% chance.

If in a Punnett Square, \( \frac{3}{4} \) of the offspring have the phenotype = ______% chance.

If in a Punnett Square, \( \frac{1}{2} \) of the offspring have the phenotype = ______% chance.

In these genetics problems, use letters to fill in the parentheses with the genotype of the parents.

1. **a.** With reference to Figure 16.4a, if a genetic disorder is recessive and both parents are heterozygous (_______), what are the chances that an offspring will have the disorder? ______

   **b.** With reference to Figure 16.4a, if a genetic disorder is dominant and both parents are heterozygous (_______), what are the chances that an offspring will have the disorder? ______
Figure 16.4  Two common patterns of autosomal inheritance in humans.
a. Both parents are heterozygous. b. One parent is heterozygous and the other is homozygous recessive. The letter $A$ stands for any trait that is dominant and the letter $a$ stands for any trait that is recessive. Substitute in the correct alleles for the problem you are working on. For example C = normal; c = cystic fibrosis.

2. a. With reference to Figure 16.4b, if the parents are heterozygous (__________) by homozygous recessive (__________), and the genetic disorder is recessive, what are the chances that the offspring will have the disorder? ________

b. With reference to Figure 16.4b, if the parents are heterozygous (__________) by homozygous recessive (__________), and the genetic disorder is dominant, what are the chances that an offspring will have the disorder? ________

Autosomal Disorders

1. Neurofibromatosis (NF), sometimes called von Recklinghausen disease, is one of the most common genetic disorders. It affects roughly 1 in 3,000 people. It is seen equally in every racial and ethnic group throughout the world. At birth or later, the affected individual may have six or more large tan spots on the skin. Such spots may increase in size and number and become darker. Small benign tumors (lumps) called neurofibromas may occur under the skin or in the muscles. Neurofibromas are made up of nerve cells and other cell types.

   Neurofibromatosis is a dominant disorder. If a heterozygous woman reproduces with a homozygous normal man, what are the chances a child will have neurofibromatosis? ________

2. Cystic fibrosis is due to abnormal mucus-secreting tissues. At first, the newborn infant may have difficulty regaining the birth weight despite good appetite and vigor. A cough associated with a rapid respiratory rate but no fever indicates lung involvement. Large, frequent, and foul-smelling stools are due to abnormal pancreatic secretions. Whereas children previously died in infancy due to infections, they now often survive because of antibiotic therapy.

   Cystic fibrosis is a recessive disorder. A carrier is an individual that appears to be normal but carries a recessive allele for a genetic disorder. A man and a woman are both carriers (__________) for cystic fibrosis. What are the chances their child will have cystic fibrosis? ________

3. Huntington disease does not appear until the 30s or early 40s. There is a progressive deterioration of the individual’s nervous system that eventually leads to constant thrashing and writhing movements until insanity precedes death. Studies suggest that Huntington disease is due to a single faulty gene that has multiple effects, in which case there is no hope for a cure.
People with Huntington disease seem to be more fertile than others. It is amazing that more than 1,000 of the cases in the United States in the past century can be traced to one man born in 1831. Huntington disease is a dominant disorder. Sophia is 25 years old and as yet has no signs of Huntington disease. Her mother does have Huntington disease (_______), but her father is free (_______) of the disorder. What are the chances that Sophia will develop Huntington disease?

4. Phenylketonuria (PKU) is characterized by severe mental retardation due to an abnormal accumulation of the common amino acid phenylalanine within cells, including neurons. The disorder takes its name from the presence of a breakdown product, phenylketone, in the urine and blood. Newborn babies are routinely tested at the hospital and, if necessary, are placed on a diet low in phenylalanine. Phenylketonuria (PKU) is a recessive disorder. Mr. and Mrs. Rodriguez appear to be normal, but they have a child with PKU. What are the genotypes of Mr. and Mrs. Rodriguez?

5. Tay–Sachs disease is caused by the inability to break down a certain type of fat molecule that accumulates around nerve cells until they are destroyed. Afflicted newborns appear normal and healthy at birth, but they do not develop normally. At first, they may learn to sit up and stand, but later they regress and become mentally retarded, blind, and paralyzed. Death usually occurs between ages three and four. Tay–Sachs is an autosomal recessive disorder. Is it possible for two individuals who do not have Tay–Sachs to have a child with the disorder? Explain.

X-Linked Inheritance and Disorders

The sex chromosomes designated X and Y carry genes just like the autosomal chromosomes. Genes particularly on the X chromosome that have nothing to do with gender inheritance are said to be X-linked. X-linked recessive disorders are due to recessive genes carried on the X chromosomes. Males are more likely to have an X-linked recessive disorder than females because the Y chromosome is blank for this trait. Does a color-blind male give his son a recessive-bearing X or a Y that is blank for the recessive allele?

The possible genotypes and phenotypes for an X-linked color blindness are as follows:

<table>
<thead>
<tr>
<th>Females</th>
<th>Males</th>
</tr>
</thead>
<tbody>
<tr>
<td>(X^bX^b)</td>
<td>(X^bY)</td>
</tr>
<tr>
<td>normal vision</td>
<td>normal vision</td>
</tr>
<tr>
<td>(X^bX^B)</td>
<td>(X^bY)</td>
</tr>
<tr>
<td>normal vision (carrier)</td>
<td>color blindness</td>
</tr>
<tr>
<td>(X^BX^B)</td>
<td></td>
</tr>
<tr>
<td>color blindness</td>
<td></td>
</tr>
</tbody>
</table>

An X-linked recessive disorder in males is always inherited from his mother. Most likely, his mother is heterozygous and therefore does not show the disorder. She is designated a carrier for the disorder. Figure 16.5 shows how females can become carriers.

1. a. What is the genotype for a color-blind female? _______ How many recessive alleles does a female inherit to be color-blind? _______

b. What is the genotype for a color-blind male? _______ How many recessive alleles does a male inherit to be color-blind? _______
In these questions, calculate the chances for males and females separately.

2. a. With reference to Figure 16.5a, if the mother is a carrier (_______) and the father has normal vision (_______), what are the chances that a daughter will be color-blind? _________
   b. A daughter will be a carrier? _________ c. A son will be color-blind? _________

3. a. With reference to Figure 16.5b, if the mother has normal vision (_______) and the father is color-blind (_______), what are the chances that a daughter will be color-blind? _________
   b. A daughter will be a carrier? _________ c. A son will be color-blind? _________

**X-Linked Genetics Problems**

For **color blindness**, there are two possible X-linked alleles involved. One affects the green-sensitive cones, whereas the other affects the red-sensitive cones. Overall about 7–10% of males have red-green color blindness, meaning that both alleles are affected.

1. A woman with normal color vision (_______), whose father was color-blind (_______), marries a man with normal color vision (_______). What genotypes could occur among their offspring? _________

What genotypes could occur if it was the normal-visioned man’s father who was color-blind?

2. John’s father is color-blind (_______) but his mother is not color-blind (_______).
   Is John necessarily color-blind? _________ Explain. _________
   Could he be color-blind? _________ Explain. _________

**Hemophilia** is called the bleeder’s disease because the affected person’s blood is unable to clot. Although hemophiliacs do bleed externally after an injury, they also suffer from internal bleeding, particularly around joints. Hemorrhages can be checked with transfusions of fresh blood (or plasma) or concentrates of the clotting protein. The most common type of hemophilia is hemophilia A, due to absence or minimal presence of a particular clotting factor called factor VIII.
Inheritance of Multiple Alleles

When a trait is controlled by multiple alleles, the gene has more than two possible alleles. But each person has only two of the possible alleles. For example, ABO blood type is determined by multiple alleles: \( I^A \), \( I^B \), and \( i \). Red blood cells have surface molecules called antigens that indicate they belong to the person. The \( I^A \) allele causes red blood cells to carry an \( A \) antigen, the \( I^B \) allele causes red blood cells to carry a \( B \) antigen, and the \( i \) allele causes the red blood cells to have neither of these antigens. \( I^A \) and \( I^B \) are dominant to \( i \). Remembering that each person can have any two of the possible alleles, these are possible genotypes and phenotypes for blood types.

<table>
<thead>
<tr>
<th>Genotypes</th>
<th>Antigens on Red Cells</th>
<th>Blood Types</th>
</tr>
</thead>
<tbody>
<tr>
<td>( I^A I^A ), ( I^A i )</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>( I^B I^B ), ( i i )</td>
<td>B</td>
<td>B</td>
</tr>
<tr>
<td>( I^A i )</td>
<td>A and B</td>
<td>AB</td>
</tr>
<tr>
<td>( i i )</td>
<td>none</td>
<td>O</td>
</tr>
</tbody>
</table>

Blood type also indicates whether the person is Rh positive or Rh negative. If the genotype is \( DD \) or \( Dd \), the person is Rh positive and if the genotype is \( dd \), the person is Rh negative. It is customary to simply attach a + or − superscript to the ABO blood type, as in \( A^+ \).

Experimental Procedure: Using Blood Type to Help Determine Paternity

In this experimental procedure a mother, Wanda, is seeking support for her child, Sophia. We will use blood typing to decide which of three men could possibly be the father.

1. Obtain three testing plates, each of which contains three depressions; vials of blood from possible fathers 1, 2, and 3, respectively; vials of anti-A serum, anti-B serum, and anti-Rh serum. (All of these are synthetic.)
2. Using a wax pencil, number the plates so you know which plate is for possible father 1, 2, or 3. Look carefully at a plate and notice the wells are designated as A, B, or Rh.
3. Being sure to close the cap to each vial in turn, do the following using plate #1:
   - Add a drop of father 1 blood to all three wells—close the cap.
   - Add a drop of anti-A (blue) to the well designated A—close the cap.
   - Add a drop of anti-B (yellow) to the well designated B—close the cap.
   - Add a drop of anti-Rh (clear) to the well designated Rh—close the cap.
4. Stir the contents of each well with a mixing stick of the correct color. After a few minutes, examine the wells for agglutination (i.e., granular appearances that indicate the blood type). (Rh\(^+\) takes the longest to react.) If a person had AB\(^+\) blood, which wells would show agglutination?

5. Repeat steps 3 and 4 for plates 2 and 3.
6. Record the blood type results for each of the men in Table 16.2.

<table>
<thead>
<tr>
<th>Table 16.2 Blood Types of Involved Persons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mother*</td>
</tr>
<tr>
<td>---------</td>
</tr>
<tr>
<td>Wanda</td>
</tr>
<tr>
<td>Blood type</td>
</tr>
</tbody>
</table>

*Your instructor may have you confirm these results.
Conclusion

1. Noting that only father 3 could have given Sophia the Rh antigen, from whom did she receive the
   \( I^B \) allele? ________ From which parent did she receive the \( I^A \) allele? ________ Is there any other
   possible interpretation to the results of blood typing? ________

Blood Typing Problems

1. A man with type A blood reproduces with a woman who has type B blood. Their child has blood type O.
   Using \( I^A \), \( I^B \), and \( i \), give the genotype of all persons involved.
   man ________ woman ________ child ________

2. If a child has type AB blood and the father has type B blood, what could the genotype of the mother be?
   ________ or ________

3. If both mother and father have type AB blood, they cannot be the parents of a child who has what blood
   type? ________

4. What blood types are possible among the children if the parents are \( I^A i \times I^B i \)? (Hint: Do a Punnett square
   using the possible gametes for each parent.)

Punnett Square:

16.3 Genetic Counseling

Potential parents are becoming aware that many illnesses are caused by
abnormal chromosomal inheritance or by gene mutations. Therefore, they
are seeking genetic counseling, which is available in many major hospitals.
The counselor helps the couple understand the mode of inheritance for a
condition of concern so that the couple can make an informed decision
about how to proceed.

Determining Chromosomal Inheritance

If a genetic counselor suspects that a condition is due to a chromosome
anomaly, he or she may suggest that the chromosomal inheritance be
examined. It is possible to view the chromosomes of an individual because
cells can be microscopically examined and photographed just before cell
division occurs. A computer is then used to arrange the chromosomes by
pairs. The resulting pattern of chromosomes is called a karyotype.

A trisomy occurs when the individual has three chromosomes instead
of two chromosomes at one karyotype location. Trisomy 21 (Down
syndrome) is the most common autosomal trisomy in humans. Survival to
adulthood is common. Characteristic facial features include an eyelid fold, a
flat face, and a large fissured tongue. Some degree of intellectual impairment
is common, as is early-onset Alzheimer disease. Sterility due to sexual
underdevelopment may be present.
Observation: Sex Chromosome Anomalies

A female with Turner syndrome (XO) has only one sex chromosome, an X chromosome; the O signifies the absence of the second sex chromosome. Because the ovaries never become functional, these females do not undergo puberty or menstruation, and their breasts do not develop. Generally, females with Turner syndrome have a short build, folds of skin on the back of the neck, difficulty recognizing various spatial patterns, and normal intelligence. With hormone supplements, they can lead fairly normal lives.

When an egg having two X chromosomes is fertilized by an X-bearing sperm, an individual with poly-X syndrome results. The body cells have three X chromosomes and therefore 47 chromosomes. Although they tend to have learning disabilities, poly-X females have no apparent physical anomalies, and many are fertile and have children with a normal chromosome count.

When an egg having two X chromosomes is fertilized by a Y-bearing sperm, a male with Klinefelter syndrome results. This individual is male in general appearance, but the testes are underdeveloped, and the breasts may be enlarged. The limbs of XXY males tend to be longer than average, muscular development is poor, body hair is sparse, and many XXY males have learning disabilities.

Jacob syndrome occurs in males who are usually taller than average, suffer from persistent acne, and tend to have speech and reading problems. At one time, it was suggested that XYY males were likely to be criminally aggressive, but the incidence of such behavior has been shown to be no greater than that among normal XY males.

Label each karyotype in Figure 16.6 and indicate the sex chromosomes for that syndrome. Explain your answers on the lines provided.
Determining the Pedigree

A pedigree shows the inheritance of a genetic disorder within a family. A pedigree can help determine the inheritance pattern and whether any particular individual has an allele for that disorder. Then a Punnett square can be done to determine the chances of a couple producing an affected child.

In a pedigree, roman numerals indicate the generation, and arabic numerals indicate particular individuals in that generation. The symbols used to indicate normal and affected males and females, reproductive partners, and siblings are shown in Figure 16.7.

Pedigree Analyses

For each of the following pedigrees, determine how a genetic disorder is inherited. Is the inheritance pattern autosomal dominant, autosomal recessive, or X-linked recessive? Also, decide the genotype of particular individuals in the pedigree. A pedigree indicates the phenotype, and you can reason out the genotype.

1. Study the following pedigree:

   a. What is the inheritance pattern for this genetic disorder?

   b. What is the genotype of the following individuals? Use A for the dominant allele and a for the recessive allele.

   Generation I, individual 1:

   Generation II, individual 1:

   Generation III, individual 8:

2. Study the following pedigree:
a. What is the inheritance pattern for this genetic disorder?

b. What is the genotype of the following individuals?
   Generation I, individual 1: ________________________________
   Generation II, individual 8: ______________________________
   Generation III, individual 1: ______________________________

3. Study the following pedigree:

   ![Pedigree Diagram]

   a. What is the inheritance pattern for this genetic disorder?

   b. What is the genotype of the following individuals?
      Generation I, individual 1: ________________________________
      Generation II, individual 7: ______________________________
      Generation III, individual 11: ______________________________

   **Construction of a Pedigree**

   You are a genetic counselor who has been given the following information from which you will construct a pedigree.

   Your data: Henry's maternal grandfather and his mother have double eyelashes. Their spouses do not. Henry who has double eyelashes is married to Isabella who has normal eyelashes, and their first child Polly has normal eyelashes. The couple wants to know the chances of any child having a double row of eyelashes.

   1. **Using pedigree symbols only, construct two pedigrees.** Begin with the maternal grandfather and grandmother, and end with Polly. Place it on both the left and right.

   **Pedigree 1**

   ![Pedigree 1 Diagram]

   **Pedigree 2**

   ![Pedigree 2 Diagram]
2. What is your key for this trait?
   Key:
   __________________ normal eyelashes
   __________________ double row of eyelashes

3. Try out a pattern of autosomal dominant inheritance by assigning appropriate genotypes for the dominant pattern of inheritance to each person in pedigree 1. Then try out a pattern of X-linked dominant inheritance by assigning appropriate genotypes for the x-linked pattern of inheritance to each person in pedigree 2. Which pattern is correct?

4. Use correct genotypes to show the cross between Henry and Isabella and perform a Punnett square for this cross.

   Henry   Isabella
   _______  X  _______

5. What are the chances that a child of Henry and Isabella will have double eyelashes? __________________

---

**Application for Daily Living**

**Choosing the Gender of Your Child**

The gender of a child depends upon whether an X-bearing sperm or a Y-bearing sperm enters the egg. A new technology that can separate X-bearing and Y-bearing sperm offers prospective parents the opportunity to choose the sex of their child. The results are not perfect. Following artificial insemination, there's about an 85% success rate for a girl and about a 65% success rate for a boy.

Proponents of sex-selection technology argue that there are many instances in which the ability to choose the sex of a child may benefit society. For example, if a mother is a carrier of an X-linked genetic disorder, such as hemophilia or Duchenne muscular dystrophy, this would be the simplest way to ensure a healthy child. Previously, a pregnant woman with these concerns had to wait for the results of an amniocentesis test and then decide whether to abort the pregnancy if it was a boy. In such cases, is it better to ensure that the child will not have a specific genetic disorder than to take the risk?

Also, it's possible for parents to use this technology simply because they choose to have a child of one particular gender. Do you think it is acceptable to select the sex of your child? Some are concerned that allowing parents to select the sex of their children could lead to selecting specific traits for their children. Should this be a concern?
1. Mary’s father does not have freckles but Mary does. What genotypes could Mary’s mother have?

2. What is the genotype of a man who has unattached earlobes but whose mother has attached earlobes?

3. A cross gives a 3:1 phenotypic ratio. What are the genotypes of the parents?

4. What does a geneticist construct to show the inheritance pattern of a genetic disorder within a family?

5. The alleles of which parent, regardless of the phenotype, determine color blindness in a son?

6. If only males are affected in a pedigree chart, what is the likely inheritance pattern for the trait?

7. Which cross gives the better chance of an offspring with the recessive phenotype $Aa \times Aa$ or $Aa \times aa$?

8. Mary has a widow’s peak but her sister has a smooth hairline. Is either one of Mary’s parents homozygous dominant or recessive?

9. Both parents have attached earlobes (recessive). What percentage of children will have unattached earlobes?

10. Mary (blood type A) has a child who is blood type O. What is Mary’s genotype?

11. A woman is a carrier for hemophilia. What are the chances for sons with hemophilia if the father does not have hemophilia?

12. If the parents are not affected and a child is affected, what is the inheritance pattern?

13. How do you recognize a karyotype of a person with Klinefelter syndrome?

14. A man has Huntington disease (autosomal dominant). He cannot assume his mother passed him the gene. Why not?

15. A boy is a hemophiliac but his mother is not. What is her genotype?

16. The trait is autosomal recessive and the results of a cross are 1:1. Using $A =$ dominant and $a =$ recessive, give the genotypes of the parents.

17. Give the genotype of a girl that is a hemophiliac.

**Thought Questions**

18. What would be the genotype of a man who is homozygous dominant for widow’s peak and is color blind. *(Hint: First do the genotype for widow’s peak, and then do the genotype for color blindness.)*

19. What is the probability a woman heterozygous for an X-linked trait will have a son with a genetic disorder if the genetic disorder is recessive? If the genetic disorder is dominant? Explain.

20. If a pedigree shows that the daughters of affected fathers (the mother is homozygous normal) are affected, what could be the pattern of inheritance if the offending allele is on the X chromosome?
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