Once a particle is transported across the cell membrane, it is available for use by the cell. The particle then diffuses throughout the cytoplasm to reach the areas inside the cell where they are used. Diffusion occurs without any input of energy, but it has one major limitation: it takes time.

One factor that permits diffusion across cell membranes is a concentration gradient. In general, however, concentration gradients within the cell are not nearly as great as those across the cell membrane. Once molecules have diffused through the cell membrane, their rate of diffusion within the cell tends to slow abruptly. Diffusion over long distances inside the cell is slow and inefficient. For example, as shown in Figure 8.21, oxygen passing into a hypothetical cell with a diameter of about 1.65 m would take more than a week to reach a mitochondrion at the cell’s centre. A cell this large would die long before oxygen and nutrients could reach the organelles that need them.

To ensure access to oxygen and nutrients, cells must minimize the distance over which substances diffuse. As a result, there is an upper limit on cell size. The relative magnitude of a cell’s surface area to its volume is called its surface area-to-volume ratio. In this section you will see how cell surface area, volume, shape, and function are affected by size limitations. In the Find Out Activity on the next page you will see how surface area changes in relation to a cell’s volume.

Substances diffuse very slowly throughout the cell’s internal fluid (taking more than a week to reach the centre).

Figure 8.21 A human-sized amoeba? An amoeba could never be human-sized for two reasons: (1) It would take a very long time for molecules critical to its survival, such as oxygen, to reach its centre via diffusion. (2) Relative to its volume, an amoeba does not have much surface area (cell membrane) across which substances can move in and out.
Charting Cell Size

What is the relationship between cell surface area and volume? In this activity, you will calculate cell surface area and volume for cells of different sizes. You will then determine how the surface area-to-volume ratio changes as the cells grow.

Procedure  • Performing and Recording

1. Draw a table or set up a computer spreadsheet to calculate surface area and volume for cube-shaped cells. Your table or spreadsheet should have four columns: cell width, surface area, volume, and surface area-to-volume ratio.

2. In separate rows, calculate surface area and volume for cells 1 mm, 2 mm, 3 mm and 4 mm wide.

3. Using your results for surface area and volume, calculate the surface area-to-volume ratio for each cell.

4. Create line graphs to illustrate the data. There are several ways of plotting the data to investigate relationships between cell width,
surface area, volume, and surface area-to-volume ratios. Experiment with different ways of looking at these relationships. You may draw your graph by hand or use a computer.

The Importance of Surface Area-to-Volume Ratio

As a cell grows, its volume increases much faster than its surface area. How does the surface area-to-volume ratio affect cell function?

The 2 mm wide cell pictured in Figure 8.22 would require eight times more nutrients and would have eight times more waste to eliminate than the 1 mm wide cell. The surface area of the 2 mm cell, however, would increase only by a factor of four. Therefore, the cell membrane might not have enough surface area to transport oxygen, nutrients, and wastes.

A very large cell with a very low surface area-to-volume ratio could either starve to death or be poisoned from the buildup of its own wastes. Such a cell would not survive to reproduce.

Find Out

What Did You Find Out?  • Analyzing and Interpreting

1. Describe how surface area and volume change as cell width increases.

2. Describe how the surface area-to-volume ratio changes as cell width increases.

3. (a) What did you learn from each of the graphs?

(b) Which were most helpful for illustrating how changing cell size affects surface area-to-volume ratio? Explain your answer.
The relationships between variables are not always linear. Non-linear relationships occur when one of the variables changes by a factor that includes an exponent. For example, when the width \((W)\) of a square increases, the area of the square increases by a factor of \(W^2\). When the width of a cube increases, the area of the cube increases by a factor of \(W^3\). Brainstorm a list of other relationships that change by non-linear, or exponential, factors. Write the list, and any relevant mathematical formulas you know, in your notebook.

**Cell Shape and Surface Area**

Certain cell shapes boost surface area-to-volume ratios. Some bacteria are almost cube-shaped, much like the imaginary cell in Figure 8.22. However, cells come in an endless variety of shapes. Some shapes have a high surface area-to-volume ratio. For example, infoldings of the membrane and flattened cell shapes produce cells with large surface areas and relatively low volumes. The higher the surface area-to-volume ratio, the more transport is possible across the cell membrane. Cells specialized for transporting nutrients, such as those lining your digestive tract seen in Figure 8.23, have shapes that result in high surface area-to-volume ratios. Plant root hairs, such as those in Figure 8.24, also have a high surface area-to-volume ratio. This increases the absorption of nutrients across the root. In the next activity you will experiment with cell shape and size.

When a cell divides, it distributes its cytoplasm roughly equally between the two daughter cells. How is cell division important in keeping surface area-to-volume ratio from getting too low? Write an explanation in your notebook.

**Pause & Reflect**

When a cell divides, it distributes its cytoplasm roughly equally between the two daughter cells. How is cell division important in keeping surface area-to-volume ratio from getting too low? Write an explanation in your notebook.
Exploring Surface Area-to-Volume Ratios in Model Cells

In this investigation, you will experiment with different cell shapes to see which shapes and sizes maximize or minimize the surface area-to-volume ratio.

**Challenge**
Create model cells with different shapes that produce very high or very low surface area-to-volume ratios.

**Apparatus**
- ruler
- table knife
- calculator (optional)

**Materials**
- modelling clay

**Design Specifications**
A. Your model cell will be built from modelling clay.
B. The amount of modelling clay you work with will remain constant; only the shape of your cell will change.
C. Identify shapes that give the highest and lowest surface area-to-volume ratios.

**Plan and Construct**
1. Create a model cell using the modelling clay. Make a cell that is cuboid (six-sided, but not necessarily square), spheroid, or a cylinder.
2. Sketch the shape of the cell in your notebook.
3. Use the formulas provided on this page to measure and record the volume and surface area of your cell in your notebook. If you make a sphere, use the table knife to carefully cut your sphere in half so that you can accurately measure the radius.

**Evaluate**
1. Using the surface area and the volume of each cell, determine the surface area-to-volume ratios. Record the values in your notebook.
2. Based on your results and those of your classmates, which shapes produced the highest and lowest surface area-to-volume ratios?

**Extension**
3. (a) Which cell shapes are most likely to be found in cells specialized for transporting materials across the cell membrane?
(b) Which cell shapes are most likely to restrict cells to very small sizes?
From One Cell to Many Cells

Although certain shapes allow some cells to be much larger than other cells, there is a limit to how large cells can be. How, then, do some organisms, such as the redwood tree shown in Figure 8.25, achieve such outstanding size? Multicellular organisms such as humans and trees, have millions of cells of many different types. Multicellular organisms grow by adding more cells instead of simply growing larger cells. Because the sizes of their individual cells are small, rapid diffusion within the cells of multicellular organisms is possible.

In single-celled organisms, one cell must perform all the functions of a living organism. Having many cells makes it possible for different groups of cells to become specialized. In multicellular organisms, cells are organized into tissues that do specific jobs. The cells within each tissue are specialized to carry out a subset of the organism's functions. For example, a redwood tree has cells in its roots that are specialized for absorbing water and minerals from the soil. Cells in the trunk are specialized for transporting water from the roots to the leaves. Cells in the leaves are specialized for absorbing the energy of sunlight to synthesize sugars. In the next investigation you will see how cell shape relates to its function.

Figure 8.25 Reaching heights over 90 m, redwood trees are thought to be the tallest trees in the world. These massive organisms depend on the functioning of individual specialized cells.

Pause & Reflect

Earlier in this chapter, you learned that placing cells in different kinds of solutions can cause them to swell or shrink. How would a human cheek cell's surface area-to-volume ratio change if it were placed in a strong salt solution? How would it change in a solution of pure water? Explain your response to this question in your notebook.

In some organisms, such as the aquatic alga Volvox, many individual cells live together in colonies. Each cell in the colony must perform nearly all the functions of a single-celled organism. However, the group of cells also functions together as one "organism." Each Volvox colony forms a hollow ball. Inside, a daughter colony will grow. When the daughter colony reaches maturity, it digests a passageway through the side of its parent colony and swims away.
Comparing Specialized Plant and Animal Cells

Earlier in this unit, you examined several different types of cells. You then made inferences about the relationship between a cell's function and its size and shape. In this investigation, you will examine several specialized plant and animal cells. You will then relate their specific shapes to the specialized function of transport across the cell membrane.

Question
How does a cell's shape relate to its specialized function?

Hypothesis
Formulate a hypothesis to explain how a cell's shape relates to the function of membrane transport.

Safety Precaution
- Handle microscope slides carefully to avoid breaking them and cutting yourself.

Apparatus
- compound light microscope
- prepared slides of intestinal villi, adipose tissue cells, root hair cells, and leaf spongy tissue cells

Procedure
1. Observe each of the slides under the microscope. Identify the following cells on the appropriate slides. Draw two or three of each kind of cell in your notebook.
   - cells of intestinal villi
   - adipose (fat) tissue cells
   - root hair cells
   - leaf spongy tissue cells

2. Based on your observations, predict what the specialized function of each cell might be. Explain your prediction.

Analyze
1. (a) How were you able to determine which of the cell types had the highest surface area-to-volume ratios?
   (b) What other information would you need to confirm your answer?

2. What was the reasoning behind your predictions about the cells' functions?

3. Compare the two plant cell types with the two animal cell types. Discuss any similarities and differences you saw between the two.

Conclude and Apply
4. Gather information about the cells you observed from your teacher, or search the library or Internet.
   (a) In your notebook, write a few sentences about the specialized function of each of the four cell types.
   (b) How are their sizes and shapes important to their functions?

5. Compare the cells' actual functions with your predictions. How did the two differ? How sound was your reasoning in formulating the predictions you made?
Dr. Pierre Côté is a civil engineer whose interest in environmental engineering, specifically water treatment, led to his development of a new “membrane.” ZeeWeed is a unique filtration membrane that represents a revolution in water treatment. Typical water treatment involves passing water through clean sand, followed by gel-like coagulants. Chlorine is then added to kill bacteria. Dr. Côté’s ZeeWeed can be used to treat ground water or surface water for drinking or to purify municipal and industrial waste water before discharge to the environment. ZeeWeed is composed of thin, hollow fibres. The membrane of the fibres has pores small enough to block the passage of viruses and micro-organisms. These fibres are mounted in an open frame that can be immersed directly in the water to be treated. The fibres float freely like seaweed. ZeeWeed requires little energy. A light stream of air bubbles keeps the ZeeWeed fibres moving, thereby exposing the fibre membranes to incoming water currents. A slight suction on the clean-water side draws water through the pores of the membranes into the hollow interior of the fibres, leaving the micro-organisms and viruses behind. ZeeWeed has won an innovation award for Dr. Côté and his team.

Section 8.3 Summary

Once molecules diffuse into the cell, their diffusion rate slows. Because of this, it is inefficient for cells to become too large — it would take too long for critical nutrients to reach cell organelles and the cell could die. As well, as cells grow, their volume increases much faster than their surface area. So, smaller cells, or cells with a high surface area such as the microvilli in the human intestine, have a higher surface area-to-volume ratio. Small cells are more efficient. Multicellular organisms grow so large by having thousands of small cells, rather than fewer very large cells.

Check Your Understanding

1. Which cell has a higher surface area-to-volume ratio: a spherical cell with a diameter of 10 nm, or a spherical cell with a diameter of 15 nm? Explain your answer.

2. Describe two features of multicellular organisms not seen in single-celled organisms.

3. Thinking Critically To keep warm on a cold day, dogs often lie down curled up in a round ball. To cool off on a hot day, they stretch flat on the floor, bellies exposed. Why would this behaviour help dogs to regulate their body temperature?

4. Thinking Critically Explain why cells the size of basketballs do not exist.

5. Apply As blood circulates through your arteries and veins, it exchanges material with the surrounding tissues. When blood vessels enter a tissue, they branch from one wide vessel into many smaller vessels. How does this branching influence the delivery of nutrients and removal of wastes to and from the tissues?

6. Apply The ZeeWeed water filtration system described above filters water through many thin tubes. Suppose an engineer wishes to redesign the ZeeWeed system with fewer and wider tubes. Will the design improve the efficiency of the filter? Explain your reasoning.

7. Thinking Critically In terms of minimizing the surface area-to-volume ratio, there are clear benefits to a cell if it is small. Why then are all organisms not microscopic single-celled organisms?
Now that you have completed this chapter, try to do the following. If you cannot, go back to the sections indicated in parentheses after each part.

(i) Explain how a cell's shape influences its surface area-to-volume ratio. (8.3)

(j) Explain why large organisms must be multicellular rather than single-celled. (8.3)

(a) Describe the structure of a cell membrane. (8.1)

(b) What is a semi-permeable membrane? (8.1)

(c) Explain why semi-permeability is important to the function of cell membranes. (8.1)

(d) Describe some of the functions of membrane proteins. (8.1, 8.2)

(e) Describe the distribution and behaviour of particles that are in equilibrium. (8.2)

(f) Describe how materials move across a cell membrane against a concentration gradient. (8.2)

(g) Explain how the concentration of solutes in solutions affects the direction of osmosis. (8.2)

(h) Describe the function and mechanisms of endocytosis and exocytosis. (8.2)

Prepare Your Own Summary

Summarize this chapter by doing one of the following. Use a graphic organizer (such as a concept map), produce a poster, or write the summary to include the key chapter concepts. Here are a few ideas to use as a guide:

• Write a letter to a classmate who has been away, explaining how cell membranes control the internal environment of cells. Explain why you think this is important for cell survival.
• Create a chart that lists the ways in which types of materials are transported in and out of cells. Describe how each method of transporting materials works, and what factors influence the direction of transport.
• Write a short poem or rap song to help you remember some of the new terms you learned in this chapter.
Key Terms

- macrophage
- phospholipid
- hydrophilic
- hydrophobic
- bilayer
- fluid-mosaic model
- semi-permeable
- selective transport
- Brownian motion
- concentration gradient
- equilibrium
- passive transport
- channel protein
- active transport
- membrane transport protein
- endocytosis
- vesicle
- vacuole
- phagocytosis
- pinocytosis
- receptor-mediated endocytosis
- exocytosis
- reverse osmosis
- kidney dialysis
- dialysis tubing
- transdermal patch
- liposomes
- surface area-to-volume ratio
- multicellular organisms

Understanding Key Concepts

If you need to check an item, section numbers are provided in brackets below.

1. Explain why a cell membrane is called a bilayer. (8.1)

2. Which of the following are open systems? (8.1)
   - (a) a school cafeteria
   - (b) a sealed glass jar
   - (c) a cell
   - (d) a plant vacuole
   - (e) a closed metal box

3. (a) In the diagram below a protein in the cell membrane recognizes a glucose molecule and changes its shape to receive it. Which type of cell transport is being represented?
   (b) Redraw the diagram in your notebook and label the components of the cell membrane. (8.1, 8.2)

4. Name the type of transport and cell structures that would most likely be used to move the following materials into or out of a cell. (8.2)
   - (a) bacterial cell
   - (b) carbon dioxide
   - (c) water
   - (d) sodium ion

5. How does the particle model of matter help to explain the process of diffusion? (8.1)

6. List three types of membrane proteins and their roles. (8.2)

7. Explain why the structure of phospholipid molecules causes them to spontaneously form membrane bilayers. (8.1)

8. Explain how a dialysis membrane is used to filter the blood of patients with kidney failure. (8.2)

9. What limits cell size and why? (8.3)

10. Compare and contrast receptor-mediated endocytosis and active transport. Discuss at least one similarity and one difference between the two. (8.2)

Developing Skills

11. Three cubes of potato are placed in beakers containing solutions of different concentrations. Compared with the fluid in the potato cells, the solutions are hypertonic, isotonic, and hypotonic.
   (a) Make diagrams to illustrate the movement of water across the cell membranes of the potato cells.
15. Imagine that you have been given two solutions of unknown concentrations and a piece of dialysis tubing. Devise a way to experimentally determine which solution has the higher solute concentration.

16. A bird’s egg is surrounded by a thin biological membrane and enclosed by a shell. Both the membrane and the shell are semi-permeable. If the shell is carefully removed from an egg, the membrane underneath is left intact. Design a lab to explore osmosis with this living membrane.

17. Some organisms live in shallow ponds that dry up after a few weeks of hot, dry weather. This means that the concentration of solutes in the water will change. How will this affect the cells of organisms living in the ponds?

12. Make a model cell membrane that shows its different components. Include a legend that makes your model easy to understand. Use modelling clay or make a computer model.

13. Beet root cells can be used to study the effects of different solvents on membrane permeability. As each solvent dissolves the cell membrane, coloured pigments inside the cells leak out, tinting the solution. Slices of beet root were placed in three different solutions for 10 min. A special device was then used to measure the absorbance (measure of pigment concentration) in each solution, as shown below.

<table>
<thead>
<tr>
<th>Alcohol concentration (%)</th>
<th>Absorbance for each alcohol</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Methanol</td>
</tr>
<tr>
<td>0</td>
<td>250</td>
</tr>
<tr>
<td>20</td>
<td>300</td>
</tr>
<tr>
<td>40</td>
<td>500</td>
</tr>
<tr>
<td>60</td>
<td>625</td>
</tr>
<tr>
<td>80</td>
<td>625</td>
</tr>
<tr>
<td>100</td>
<td>628</td>
</tr>
</tbody>
</table>

(a) Make a line graph of the data. Identify the manipulated and responding variables.

(b) At lower concentrations, which alcohol was most damaging to beet cell membranes?

(c) Which alcohol appears to affect beet cell membranes the most? Explain how you arrived at your conclusion.

Problem Solving/Applying

14. List three common household items that contain or have features of a semi-permeable membrane. Explain how the semi-permeability of each item relates to its function.

19. What would happen to a cell if its cell membrane were permeable rather than semi-permeable?

20. Your lungs are made up of millions of tiny sacs that fill with air when you breathe in. Among the air sacs are many blood vessels that pick up oxygen to be carried throughout the body. The cells making up the air sacs are very flat and are only one cell layer thick. Using your knowledge of the influence of cell shape on diffusion, infer why this cell shape is beneficial.

21. Give two reasons why scientists believe that cell membranes have a fluid structure.

Critical Thinking

18. Explain why a cell can be considered an open system even though a membrane barrier surrounds it.