2.1 The Cell Membrane: Gatekeeper of the Cell

At the border separating two nations, customs officers check the items that travellers are carrying. Some materials, such as firearms and plants, are not allowed to cross the border because of a country's laws. In a similar way, materials passing into and out of a cell are "checked" at the cell membrane. Like the customs checkpoint, a cell membrane allows some substances to enter or leave the cell, and it stops other substances. Because it allows only certain materials to cross it, the cell membrane is said to be **selectively permeable**. (A membrane that lets all materials cross it is **permeable**. A membrane that lets nothing cross it is **impermeable**.)

How does a cell membrane carry out this function? The answer is in the structure of the membrane. Imagine you have two small bags. One is made of plastic, the other of cheesecloth. Now imagine you pour water into both bags, as shown in Figures 2.1A and B. The plastic holds the water, but the cheesecloth lets the water run through. The plastic is impermeable to water, while the cheesecloth is permeable to water. This difference is due to differences in the structure of the materials from which the bags are made.

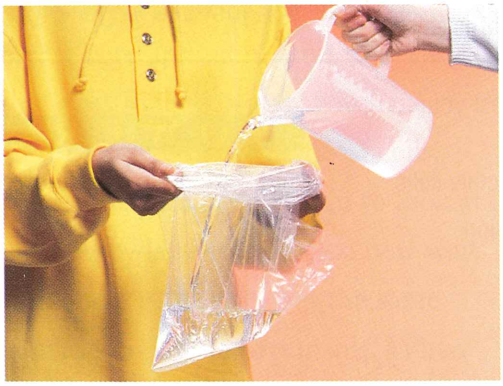


Figure 2.1A Plastic is impermeable to water.

Figure 2.1B Cheesecloth is permeable to water.

Now imagine you are pouring a mixture of water and sand into both bags. Is each bag permeable, impermeable, or selectively permeable to the mixture? (If you are not sure, you could try carrying out a demonstration like the one in Figure 2.1 and observing what happens.)

Diffusion

The structure of the cell membrane controls what can move into and out of a cell. What causes substances to move in the first place? One clue is shown in Figure 2.2. What makes the blob of ink move outwards through the water in the container?

Figure 2.2 In time, the ink particles will become evenly dispersed with the water particles, and the whole solution will appear ink-coloured.

According to the particle theory, the particles in all liquids and gases are constantly moving in every direction and bumping into each other. (For more information on the particle theory, see page 111.) These collisions explain why particles that are concentrated in one area, such as the ink blob, spread apart into areas where there are fewer ink particles, and thus fewer collisions. This spreading-out process is called **diffusion**. Eventually, the ink particles will become evenly distributed throughout the container of water. At this time, individual ink particles continue to move, but there is no further change in the overall distribution of the ink in the water. Just like the ink, food colouring and the colour from certain crystals would also diffuse throughout the water, if they were left undisturbed for several minutes.

Pause & Reflect

Here are some situations in which diffusion occurs: A sugar cube is left in a beaker of water for a while. Fumes of perfume rise from the bottle when the top is removed. Give some other examples of diffusion. Can solids diffuse? Why or why not? Write your responses in your Science Log.

Off the Wall

Recall that an average cell has a diameter of 20 to 30 μm. Suppose this cell were placed in a solution with a concentration of oxygen higher than in the cell's cytoplasm. The time required for diffusion to equalize the concentrations would be about 3 s at room temperature. If the cell were much larger — with a diameter of 20 cm, say — the same process would take about 11 years!

At Home ACTIVITY

Observing Diffusion

You can observe diffusion by means of your sense of sight. Is there another way to observe this process? Try this. Have a friend or a family member stand at one end of a room with an orange while you stand at the other end facing the wall. Ask your friend to peel the orange. How do you know that particles have diffused from the orange throughout the air in the room?

Diffusion also plays a part in moving substances into and out of cells. For example, imagine an amoeba living in water. The concentration of dissolved carbon dioxide gas in the water is the same as the concentration of dissolved carbon dioxide gas in the amoeba's cytoplasm. Carbon dioxide particles therefore move into and out of the cell at the same rate, passing through small openings in the amoeba's selectively permeable membrane (see Figure 2.3A).

Now imagine the amoeba has been producing carbon dioxide as a waste product inside its single cell. The concentration of dissolved carbon dioxide particles in the amoeba's cytoplasm is now greater than the concentration of carbon dioxide in the surrounding water. As a result, more carbon dioxide particles move out of the cell by diffusion during a given time than move into the cell (see Figure 2.3B). The diffusion process continues until the concentration of the dissolved carbon dioxide gas on both sides of the cell membrane is once again equal.

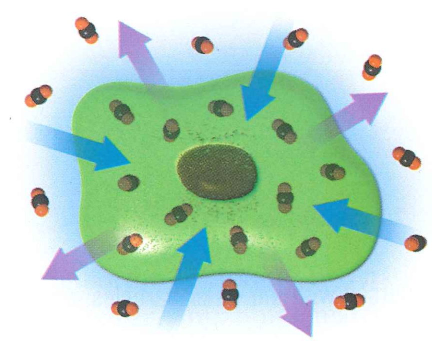


Figure 2.3A An equal concentration of carbon dioxide particles on both sides of the cell membrane. The particles move into and out of the cell at an equal rate.

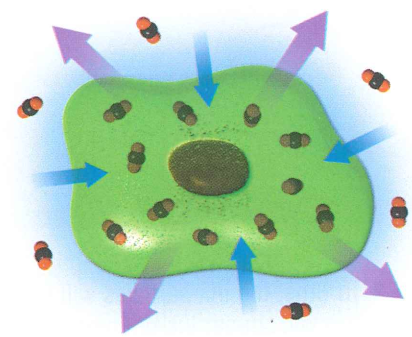


Figure 2.3B A greater concentration of carbon dioxide particles inside the cell. The particles move out of the cell at a greater rate than they move into the cell.

Figure 2.4A
Limp carrot sticks

Figure 2.4B
Carrot sticks 24 h later

Osmosis

The most common substance found inside and around cells is water. About 70 percent of a cell's content is water, and most cells die quickly without a supply of this liquid. Water particles are small and can easily move into and out of cells by diffusion. The diffusion of water through a selectively permeable membrane is called **osmosis**.

You have probably already seen osmosis at work. Have you ever cut carrot sticks from a fresh carrot? You may have left some extra sticks in the refrigerator. By the next day, they have lost some of their moisture and they have gone limp. Suppose you place the sticks in a glass of water. Several hours later they are crisp again. What has happened? Water particles have moved from the water in the glass into the carrot cells by osmosis. (See Figures 2.4A and B.)

Now recall the idea introduced at the beginning of this chapter. It suggested that you drink water to help your cells carry out their functions. When you are very active, you lose moisture from your body in your breath and in sweat. Water is drawn out of your cells by osmosis. You need a new supply of water to restore the cell water content in your body to its normal level.

Water is important to living things because it dissolves many of the substances involved in cell processes. For example, glucose (which cells use for energy) dissolves in water to form a glucose solution. When water moves out of a cell, the dissolved substances inside the cell become more concentrated. When water moves into a cell, the dissolved substances inside the cell become more diluted.

Water tends to move by osmosis from a dilute solution to a more concentrated solution (see Figure 2.5). In other words, water moves from a region where it is in high concentration to one where it is in lower concentration. That is why water moves from tap water in a glass into dehydrated carrot cells. What do you think would happen if you put a fresh carrot stick into a glass containing a concentrated salt solution? Why might this happen? The next investigation will help you answer this question.

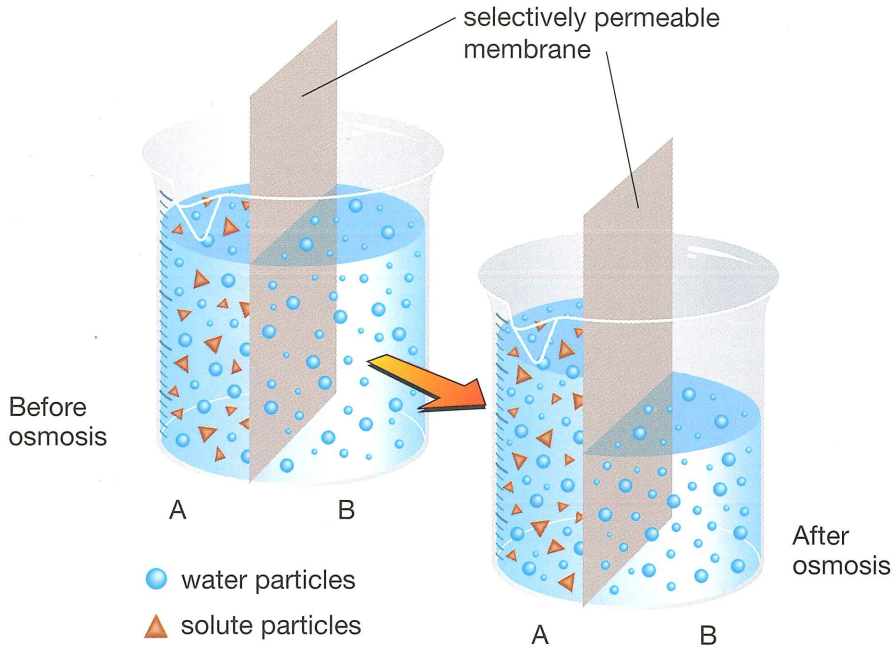


Figure 2.5 Water moves by osmosis from side B to side A inside the beaker. In this simplified diagram, which side represents a carrot stick and which side represents a glass of water?

Pause & Reflect

What is the *solvent* in a salt solution? What is the *solute* in a salt solution? For that matter, what is a *solution*? If you remember these terms from your earlier studies, you are ready to do Conduct an Investigation 2-A. If you need review, look up the three terms in the Glossary at the back of this book. Write the definitions in your Science Log.

Did You Know?

Can your doctor give you medicine without using pills, syrups, or needles? Yes, by using diffusion. Drugs can be put into a patch similar to a Band-Aid™ that is stuck onto the skin. There is a high concentration of drugs in the patch but a low concentration in the body. Therefore, the drug particles diffuse through the skin into the bloodstream.

Off the Wall

Imagine you have a box of marbles. The box is divided in half by a strip of cardboard with an opening. All of the marbles are packed very tightly on one side of the cardboard strip. Some of the marbles roll to the other side of the box through the opening in the cardboard strip. The marbles keep rolling until each side of the box has about equal numbers of marbles. This is another example of osmosis.

Active Transport

Small particles — such as water, carbon dioxide, and oxygen — diffuse freely into and out of cells through small openings in the cell membrane. This process depends only on the concentrations of the particles. It occurs without any use of energy by the cells.

However, cells also require certain substances in greater concentrations or in lower concentrations than can be obtained by diffusion alone. For example, cells need large amounts of glucose, which supplies them with energy. To meet this need, glucose particles must move from an area of low concentration (outside the cell) to an area of higher concentration (inside the cell). This process reverses the usual movement caused by diffusion. Unlike diffusion, this process requires the use of energy by the cells — like pushing a car uphill instead of letting it roll down to the bottom as it normally would.

The controlled movement of substances through the cell membrane is carried out by the membrane itself. To understand how it does this, scientists have studied the membrane structure in great detail (see Figures 2.6A and B). With the help of more powerful microscopes, they discovered large particles called **carrier proteins** embedded in the membrane. Like gates in a wall, carrier proteins control substances entering or leaving the cell. Each carrier protein attracts particles of a particular substance. The protein attaches to the substance, moves it through the membrane, and releases it on the opposite side, as shown in Figure 2.7. This energy-using process is called **active transport**.

Off the Wall

Can cells break sidewalks? With the help of osmosis, they can! When cells take in water by osmosis, they tend to swell. The increasing pressure from the added volume of water may burst open animal cells. Plant cells, however, can withstand much greater pressure because they are surrounded by rigid cell walls. This pressure is called *osmotic pressure*. Have you ever seen weeds breaking through a paved sidewalk? They force their way through asphalt by osmotic pressure, generated by water in the cells of the shoot tip.

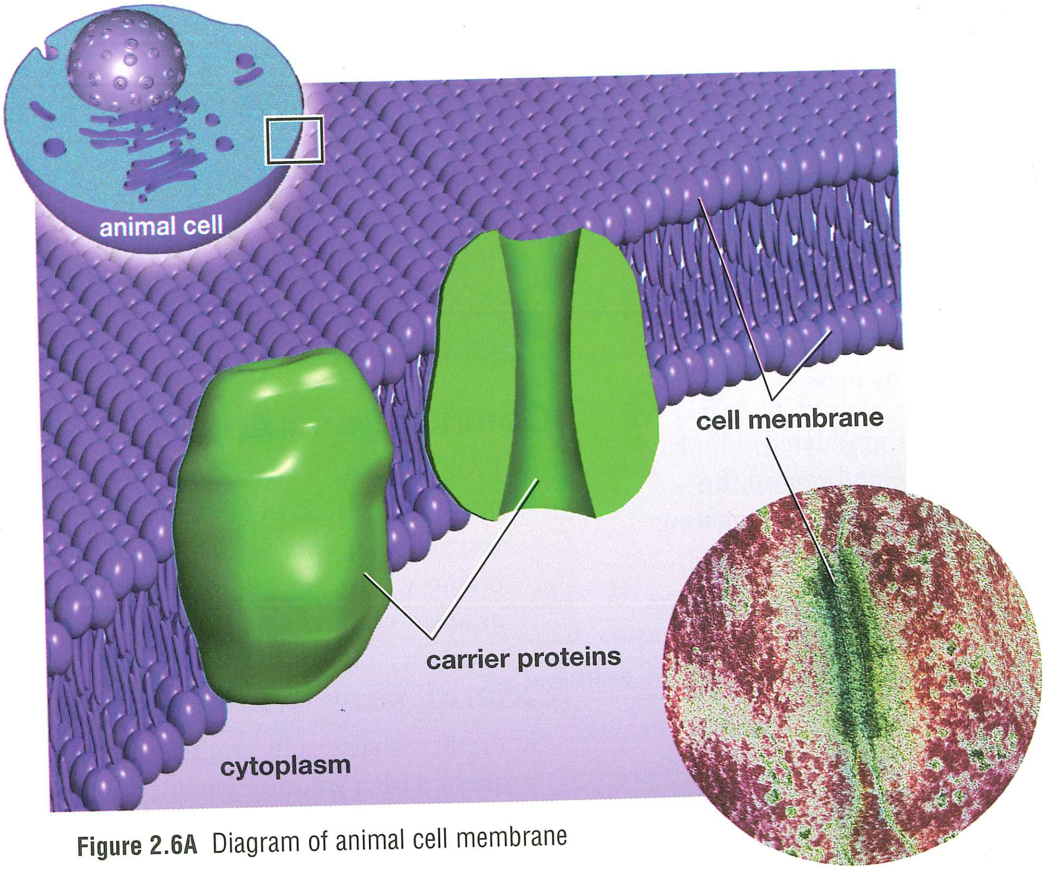


Figure 2.6A Diagram of animal cell membrane

Figure 2.6B Transmission electron microscope view of animal cell membrane (190 920×)

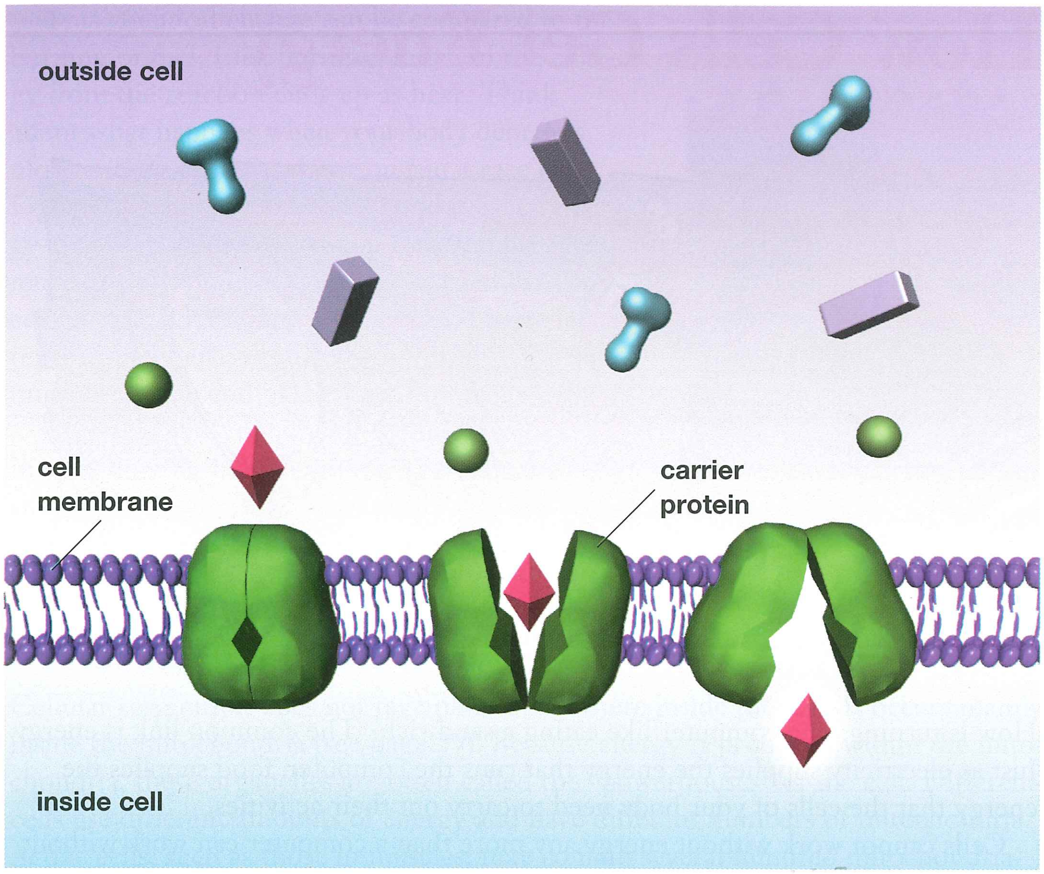


Figure 2.7 In active transport, carrier proteins in the cell membranes attract particles of particular substances, bind onto them, and release them on the opposite side of the membrane. These "gates" in the cell boundary can move particles either into or out of the cell.

In the Starting Point Activity on page 39, you were asked how cells might "breathe" and "eat." To carry out these activities, cells control the entrance and exit of key substances such as food particles. Active transport is one way this occurs. In the next section of this chapter, you will see how the food that you eat eventually gets turned into energy by your cells.

Check Your Understanding

1. What process causes water to enter or leave a cell?
2. How are osmosis and diffusion alike? How are they different?
3. How does active transport differ from diffusion? Give an example of each.
4. If your teacher opens a bottle of ammonia at the front of the classroom, you will smell ammonia at the back of the room a short time later. Explain what has occurred.
5. **Apply** Why do grocery stores spray their fresh vegetables with water?
6. **Thinking Critically** Why will a goldfish die if it is placed in salt water?

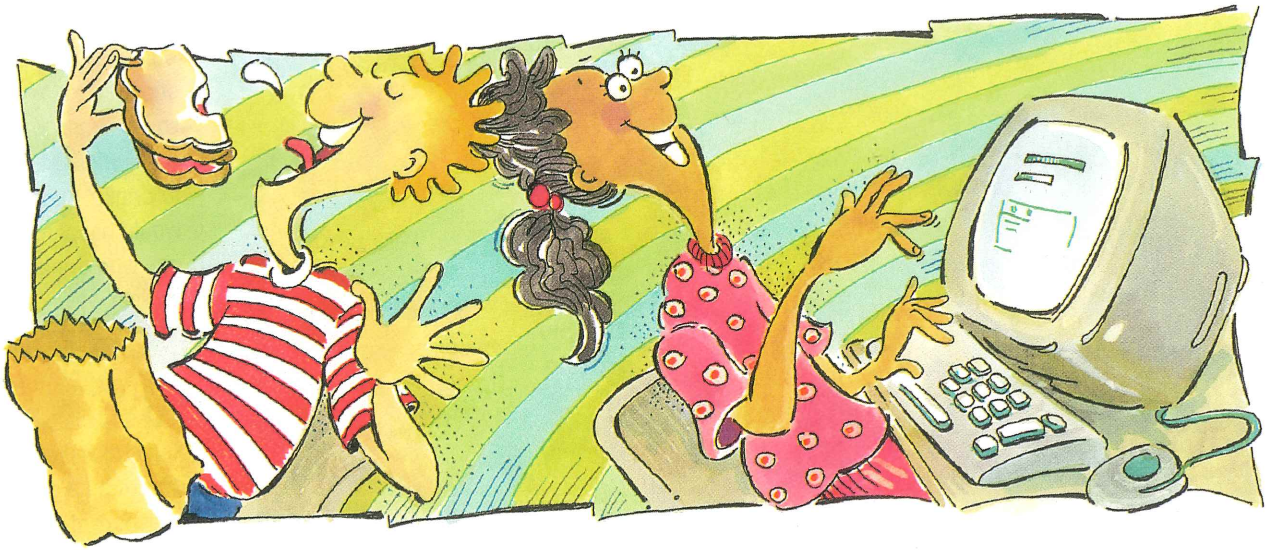
Word CONNECT

In the poem "The Rime of the Ancient Mariner" by Samuel Taylor Coleridge, a sailor stranded on a calm ocean says: "Water, water, everywhere, nor any drop to drink." Suggest what would happen to someone who drinks seawater. Explain why.

Did You Know?

Some diseases are caused by a defect in the transport of chemicals across the cell membrane. For example, kidney stones are produced by the buildup of crystals in kidney cells. Normally, the chemicals that form these crystals are transported across the cell membranes from kidney cells into the blood vessels and carried to other parts of the body.

2.2 How Cells Get Energy



How is turning on a computer like eating a sandwich? The common link is energy. Just as electricity supplies the energy that runs the computer, food supplies the energy that the cells of your body need to carry out their activities.

Cells cannot work without energy any more than a computer can work without being plugged in and turned on. The energy that cells use comes from food. What is food? For animals, food may be a sandwich, a mouse, or a blade of grass. For plants, food is carbohydrates made in their leaves by the process of photosynthesis. What all foods have in common, however, is particles that contain chemical energy.

The energy in food can only be released after food particles have entered the cells and have been broken down by a chemical reaction. The process that releases food energy is called **cellular respiration**.

You probably think of respiration as breathing in and out. That is what you and all other air-breathing animals do to obtain oxygen from the air and to get rid of carbon dioxide. Recall that cells carry out all the functions of living things. Your cells use the oxygen that you breathe in for cellular respiration, and they produce the carbon dioxide that you breathe out. Cellular respiration occurs in nearly all living cells of every organism — in plants and micro-organisms, as well as in animals.

Inside cells, oxygen combines with food particles (such as carbohydrates) in cellular respiration. The word equation for this chemical reaction is:

carbohydrates + oxygen → carbon dioxide + water + energy

DidYouKnow?

The word *photosynthesis* comes from two Greek words. *Photo* means "light." *Synthesis* means "putting together." Recall that in the process of photosynthesis, carbon dioxide and water are put together to make carbohydrates. The energy for this chemical reaction comes from sunlight. The word equation for photosynthesis is:

carbon dioxide + water + light energy → carbohydrates + oxygen

This chemical change can be compared to the burning of fuel. Like burning, much of the energy from the reaction ends up as heat. Think about what happens when your body demands more energy, such as when you run a race (see Figure 2.8). First, you need a good meal of energy-rich carbohydrates. As you run, you breathe more quickly, pumping in more oxygen for your cells to use. The oxygen and the food particles react inside your cells, producing energy for your muscles. At the end of the race, you feel warm.

No wonder! Every one of the millions of cells in your muscles has been burning food particles at a higher rate, not to mention the trillions of other cells in your body all working to carry out the respiration reaction.

Figure 2.8 Cellular respiration provides the energy to run a race.

Powerhouses of the Cell

Cellular respiration does not take place everywhere inside the cell. It occurs mainly inside the mitochondria (see page 29). Because energy is produced within the mitochondria, these organelles are often called the "powerhouses" of the cell. Different cells use different amounts of energy and have different numbers of mitochondria. Active cells, such as those in muscles, may contain several hundred mitochondria. The energy produced inside the mitochondria can be used by other parts of the cell (see Figure 2.9).

Why do cells need energy? Cell membranes need energy to move materials into and out of cells by active transport. Muscle cells need energy to contract. Sperm cells use energy to swim. Nerve cells use energy to send signals. Most cells also use energy to grow and reproduce. You will study cell reproduction in the next section.

DidYouKnow?

Have you ever felt stiff and sore after working your muscles harder than usual? This happens because your muscle cells cannot get oxygen fast enough to meet their demand for energy. So, instead of using cellular respiration to release energy from glucose, the muscle cells use a chemical reaction called fermentation. A product of this reaction is a chemical called lactic acid. It is this chemical that makes your muscles feel stiff. However, regular exercise strengthens your muscles and improves the efficiency of your heart and lungs. This helps get more oxygen to your cells faster and reduces the risk of soreness after exercise.

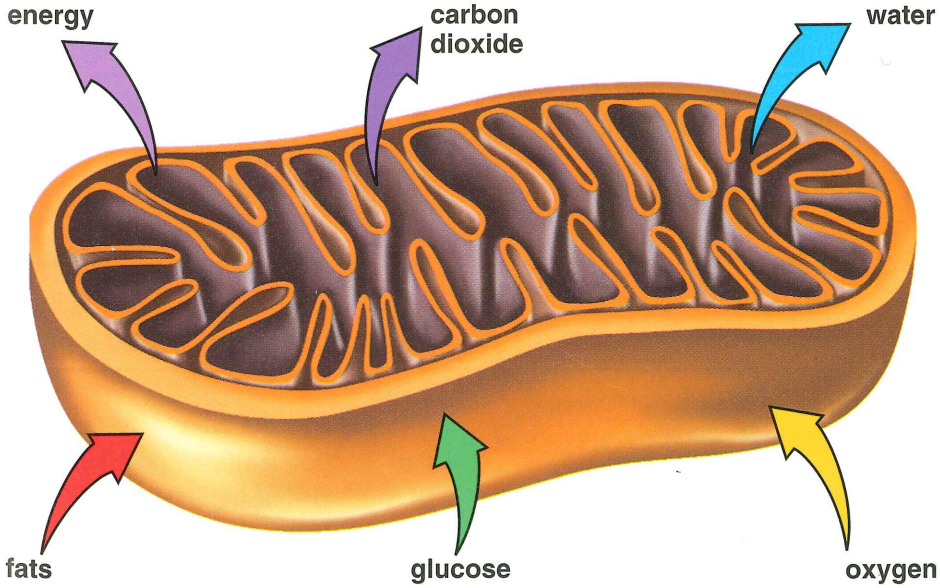


Figure 2.9 Cutaway diagram of a mitochondrion. Fats and glucose are broken down into smaller particles before entering the mitochondria, where cellular respiration occurs.