Banners flying on a castle wall mark off the community within from the surrounding countryside. Inside, residents go about their appointed tasks for the good of the community. Commands passed along from royalty to knights to workers are obeyed by all. The almost impenetrable wall prevents the enemy without from entering and disturbing the peace within. Only certain small creatures can pass through the open slitlike windows, and the drawbridge must be lowered for most needed supplies.

The plasma membrane, which carries markers identifying it as belonging to the individual, can be likened to the castle wall. Under the command of the nucleus, the organelles carry out their specific functions and contribute to the working of the cell as a whole. Very few molecules can freely cross the membrane, and most nutrients must be transported across by special carriers. The cell uses these nutrients as a source of building blocks and energy to maintain the cell. The operations of the cell will continue only as long as the plasma membrane selectively permits specific materials to enter and leave and prevents the passage of others.

4.1 Plasma Membrane Structure and Function

The plasma membrane is a phospholipid bilayer in which protein molecules are either partially or wholly embedded (Fig. 4.1). The phospholipid bilayer has a *fluid* consistency, comparable to that of light oil. The proteins are scattered throughout the membrane; therefore they form a *mosaic* pattern. This description of the plasma membrane is called the **fluid-mosaic model** of membrane structure.

Phospholipids spontaneously arrange themselves into a bilayer. The hydrophilic (water loving) polar heads of the phospholipid molecules face the outside and inside of the cell where water is found, and the hydrophobic (water fearing) nonpolar tails face each other (Fig. 4.1). In addition to phospholipids, there are two other types of lipids in the plasma membrane. **Glycolipids** have a structure similar to phospholipids except that the hydrophilic head is a variety of sugars joined to form a straight or

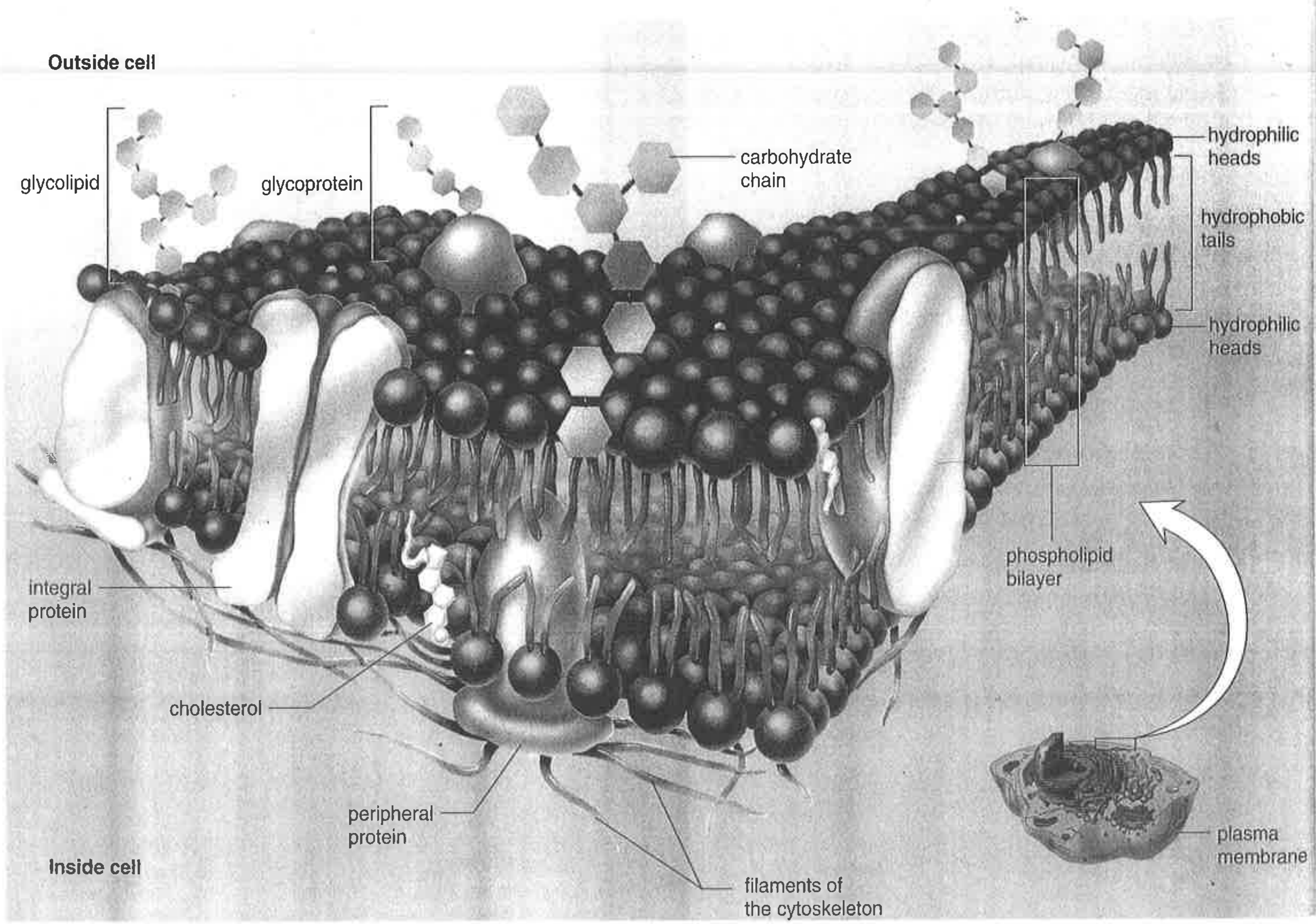
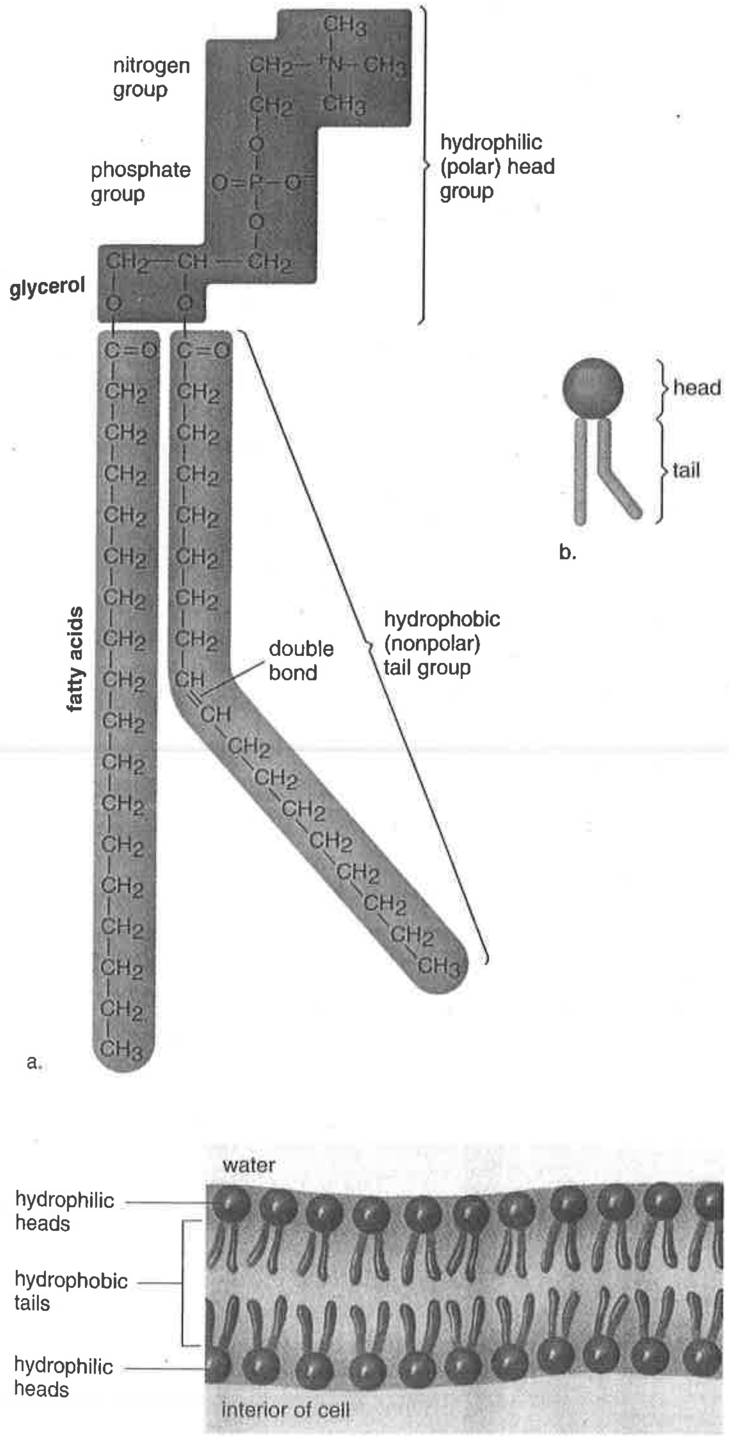


Figure 4.1 Fluid-mosaic model of plasma membrane structure.
The membrane is composed of a phospholipid bilayer in which proteins are embedded. The hydrophilic heads of phospholipids are a part of the outside surface and the inside surface of the membrane. The hydrophobic tails make up the interior of the membrane. Note the plasma membrane's asymmetry—carbohydrate chains are attached to the outside surface and cytoskeleton filaments are attached to the inside surface.



c. Phospholipid molecules in plasma membrane

Figure 2.23 Phospholipid structure and shape.
a. Phospholipids are constructed like fats, except that they contain a phosphate group. This phospholipid also includes an organic group that contains nitrogen. **b.** The hydrophilic portion of the phospholipid molecule (head) is soluble in water, whereas the two hydrocarbon chains (tails) are not. **c.** This causes the molecule to arrange itself as shown when exposed to water.

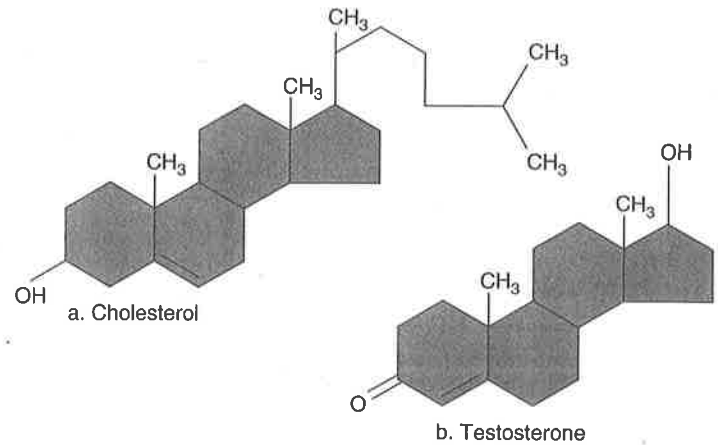


Figure 2.24 Steroid diversity.
a. Cholesterol, like all steroid molecules, has four adjacent rings, but the effects of steroids on the body largely depend on the attached groups indicated in red. **b.** Testosterone is the male sex hormone.

Phospholipids

Phospholipids, as their name implies, contain a phosphate group (Fig. 2.23). Essentially, they are constructed like fats, except that in place of the third fatty acid, there is a phosphate group or a grouping that contains both phosphate and nitrogen. These molecules are not electrically neutral as are fats because the phosphate and nitrogenous groups are ionized. It forms the so-called hydrophilic head of the molecule, while the rest of the molecule becomes the hydrophobic tails. The plasma membrane which surrounds cells is a phospholipid bilayer in which the heads face outward into a watery medium and the tails face each other because they are water repelling.

Steroids

Steroids are lipids having a structure that differs entirely from that of fats. Steroid molecules have a backbone of four fused carbon rings, but each one differs primarily by the arrangement of the atoms in the rings and the type of functional groups attached to them. Cholesterol is a component of an animal cell's plasma membrane and is the precursor of several other steroids, such as the sex hormones estrogen and testosterone (Fig. 2.24)

We know that a diet high in saturated fats and cholesterol can lead to circulatory disorders. This type of diet causes fatty material to accumulate inside the lining of blood vessels and blood flow is reduced. As discussed in the Science reading on page 36, nutrition labels are now required to list the calories from fat per serving and the percent daily value from saturated fat and cholesterol.

Lipids include fats and oils for long-term energy storage and steroids. Phospholipids, unlike other lipids, are soluble in water because they have a hydrophilic group.

Table 4.1 Passage of Molecules into and out of Cells

	Name	Direction	Requirement	Examples
Passive Transport Means	DIFFUSION	Toward lower concentration	Concentration gradient only	Lipid-soluble molecules, water, and gases
	FACILITATED TRANSPORT	Toward lower concentration	Carrier and concentration gradient	Some sugars and amino acids
Active Transport Means	ACTIVE TRANSPORT	Toward greater concentration	Carrier plus cellular energy	Other sugars, amino acids, and ions
	EXOCYTOSIS	Toward outside	Vesicle fuses with plasma membrane	Macromolecules
	ENDOCYTOSIS			
	Phagocytosis	Toward inside	Vacuole formation	Cells and subcellular material
	Pinocytosis (includes receptor-mediated endocytosis)	Toward inside	Vesicle formation	Macromolecules

4.2 The Permeability of the Plasma Membrane

The plasma membrane is **differentially** (selectively) **permeable.** Some substances can move across the membrane and some cannot (Fig. 4.4). Macromolecules cannot diffuse across the membrane because they are too large. Ions and charged molecules cannot cross the membrane because they are unable to enter the hydrophobic phase of the lipid bilayer.

Noncharged molecules such as alcohols and oxygen are lipid-soluble and therefore can cross the membrane with ease. They are able to slip between the hydrophilic heads of the phospholipids and pass through the hydrophobic tails of

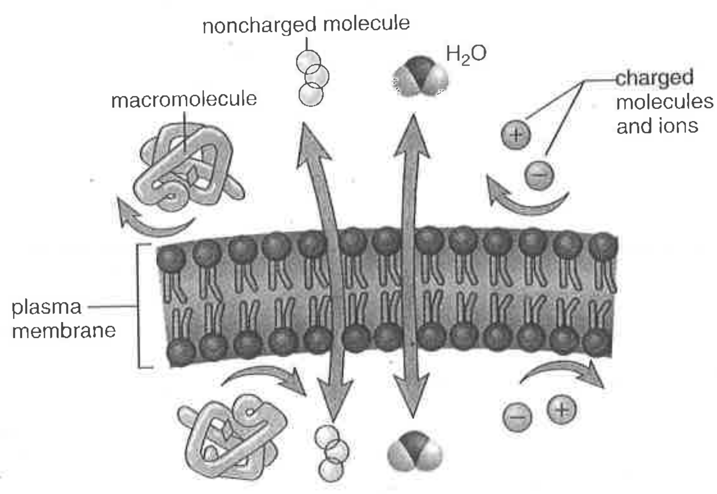


Figure 4.4 How molecules cross the plasma membrane. The curved arrows indicate that these substances cannot cross the plasma membrane and the back and forth arrows indicate that these substances can cross the plasma membrane.

the membrane. Small polar molecules such as carbon c ide and water also have no difficulty crossing througl membrane. These molecules follow their **concentra gradient** which is a gradual decrease in concentration distance. To take an example, oxygen is more concentr outside the cell than inside the cell because a cell oxygen during aerobic cellular respiration. Therefore gen follows its concentration gradient as it enters a cell. bon dioxide, on the other hand, which is produced wl cell carries on cellular respiration, is more concentr inside the cell than outside the cell, and therefore it m down its concentration gradient as it exits a cell.

Special means are sometimes used to get ions charged molecules into and out of cells. Macromolecule cross a membrane when they are taken in or out by ve formation (Table 4.1). Ions and molecules like amino and sugars are assisted across by one of two classes of t port proteins. Carrier proteins combine with an ion or r cule before transporting it across the membrane. Ch proteins form a channel that allows an ion or charged r cule to pass through. Our discussion in this chapt largely restricted to carrier proteins. Carrier protein specific for the substances they transport across the pl membrane.

Ways of crossing a plasma membrane are classifi passive or active (Table 4.1). *Passive ways,* which do nc chemical energy, involve diffusion or facilitated trans These passive ways depend on the motion energy o and molecules. *Active ways,* which do require chemic ergy, include active transport, endocytosis, and exocyt

The plasma membrane is differentially permeable. Certain substances can freely pass through the membrane and others must be transported across either by carrier proteins or by vacuole formation.

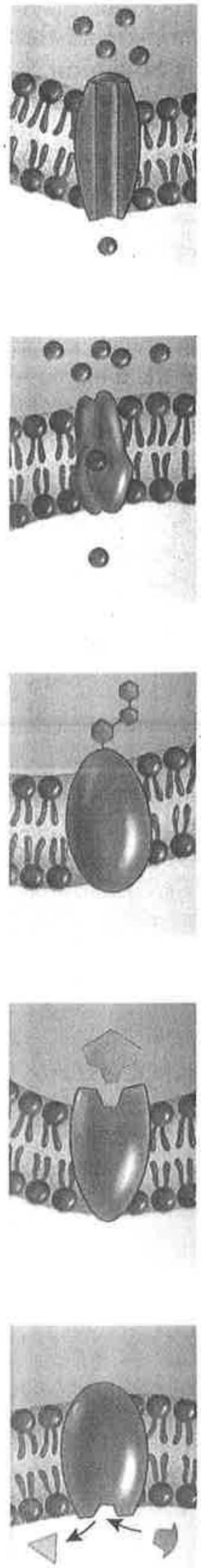
The Mosaic Quality of the Membrane

The plasma membranes of various cells and the membranes of various organelles each have their own unique collections of proteins. The proteins form different patterns according to the particular membrane and also within the same membrane at different times. When you consider that the plasma membrane of a red blood cell contains over 50 different types of proteins, you can see why the membrane is said to be a mosaic.

The integral proteins largely determine a membrane's specific functions. As we will discuss in more detail, certain plasma membrane proteins are involved in the passage of molecules through the membrane. Some of these are **channel proteins** through which a substance can simply move across the membrane; others are **carrier proteins** that combine with a substance and help it to move across the membrane. Still others are receptors; each type of **receptor protein** has a shape that allows a specific molecule to bind to it. The binding of a molecule, such as a hormone (or other signal molecule), can cause the protein to change its shape and bring about a cellular response. Some plasma membrane proteins are **enzymatic proteins** that carry out metabolic reactions directly. The peripheral proteins associated with the membrane often have a structural role in that they help stabilize and shape the plasma membrane.

Figure 4.3 depicts the various functions of membrane proteins.

The mosaic pattern of a membrane is dependent on the proteins, which vary in structure and function.



Channel Protein
Allows a particular molecule or ion to cross the plasma membrane freely. Cystic fibrosis, an inherited disorder, is caused by a faulty chloride (Cl^-) channel; a thick mucus collects in airways and in pancreatic and liver ducts.

Carrier Protein
Selectively interacts with a specific molecule or ion so that it can cross the plasma membrane. The inability of some persons to use energy for sodium-potassium (Na^+–K^+) transport has been suggested as the cause of their obesity.

Cell Recognition Protein
The MHC (major histocompatibility complex) glycoproteins are different for each person, so organ transplants are difficult to achieve. Cells with foreign MHC glycoproteins are attacked by blood cells responsible for immunity.

Receptor Protein
Is shaped in such a way that a specific molecule can bind to it. Pygmies are short, not because they do not produce enough growth hormone, but because their plasma membrane growth hormone receptors are faulty and cannot interact with growth hormone.

Enzymatic Protein
Catalyzes a specific reaction. The membrane protein, adenylate cyclase, is involved in ATP metabolism. Cholera bacteria release a toxin that interferes with the proper functioning of adenylate cyclase; sodium ions and water leave intestinal cells and the individual dies from severe diarrhea.

Figure 4.3 Membrane protein diversity.
These are some of the functions performed by proteins found in the plasma membrane.

Cell–Cell Recognition

The carbohydrate chains of glycolipids and glycoproteins serve as the "fingerprints" of the cell. The possible diversity of the chain is enormous; it can vary by the number of sugars (15 is usual, but there can be several hundred), by whether the chain is branched, and by the sequence of the particular sugars.

Glycolipids and glycoproteins vary from species to species, from individual to individual of the same species, and even from cell to cell in the same individual. Therefore, they make cell–cell recognition possible. Researchers working with mouse embryos have shown that as development proceeds, the different type cells of the embryo develop their own carbohydrate chains and that these chains allow the tissues and cells of the embryo to sort themselves out.

As you probably know, transplanted tissues are often rejected by the body. This is because the immune system is able to recognize that the foreign tissue's cells do not have the same glycolipids and glycoproteins as the rest of the body's cells. We also now know that a person's particular blood type is due to the presence of particular glycoproteins in the membrane of red blood cells.

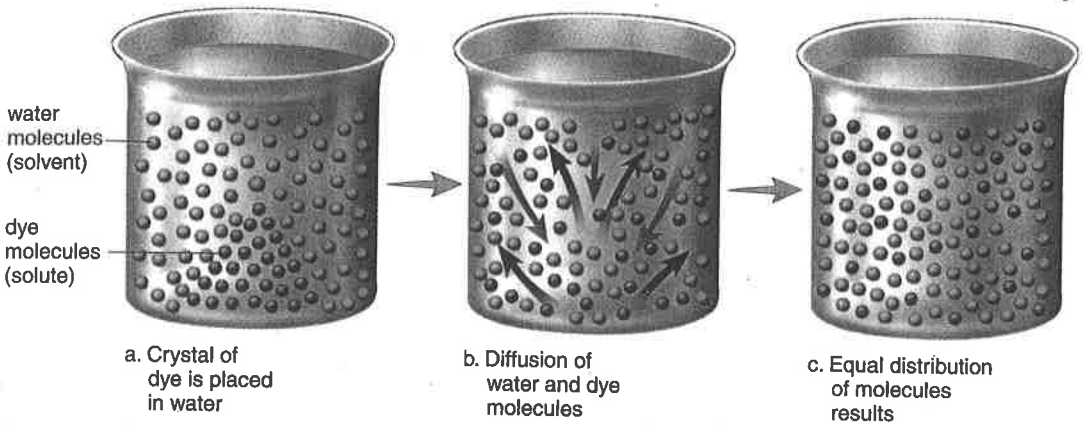


Figure 4.5 Process of diffusion.
Diffusion is spontaneous, and no chemical energy is required to bring it about. **a.** When dye crystals are placed in water, they are concentrated in one area. **b.** The dye dissolves in the water, and there is a net movement of dye molecules from higher to lower concentration. There is also a net movement of water molecules from a higher to a lower concentration. **c.** Eventually, the water and the dye molecules are equally distributed throughout the container.

4.3 Diffusion and Osmosis

Diffusion is the movement of molecules from a higher to a lower concentration—that is, down their concentration gradient—until equilibrium is achieved and they are distributed equally. Diffusion is a physical process that can be observed with any type of molecule. For example, when a crystal of dye is placed in water (Fig. 4.5), the dye and water molecules move in various directions, but their net movement, which is the sum of their motion, is toward the region of lower concentration. Therefore, the dye is eventually dissolved in the water, resulting in a colored solution. A solution contains both a solute, usually a solid, and a solvent, usually a liquid. In this case, the **solute** is the dye and the **solvent** is the water molecules. Once the solute and solvent are evenly distributed, they continue to move about, but there is no net movement of either one in any direction.

As discussed, the chemical and physical properties of the plasma membrane allow only a few types of molecules to enter and exit a cell simply by diffusion. Gases can diffuse through the lipid bilayer; this is the mechanism by which oxygen enters cells and carbon dioxide exits cells. Also, consider the movement of oxygen from the alveoli (air sacs) of the lungs to blood in the lung capillaries (Fig. 4.6). After inhalation (breathing in), the concentration of oxygen in the alveoli is higher than that in the blood; therefore, oxygen diffuses into the blood. The principle of diffusion can be employed in the treatment of certain human disorders, as is discussed in the Science Focus on page 71.

Molecules diffuse down their concentration gradients. A few types of small molecules can simply diffuse through the plasma membrane.

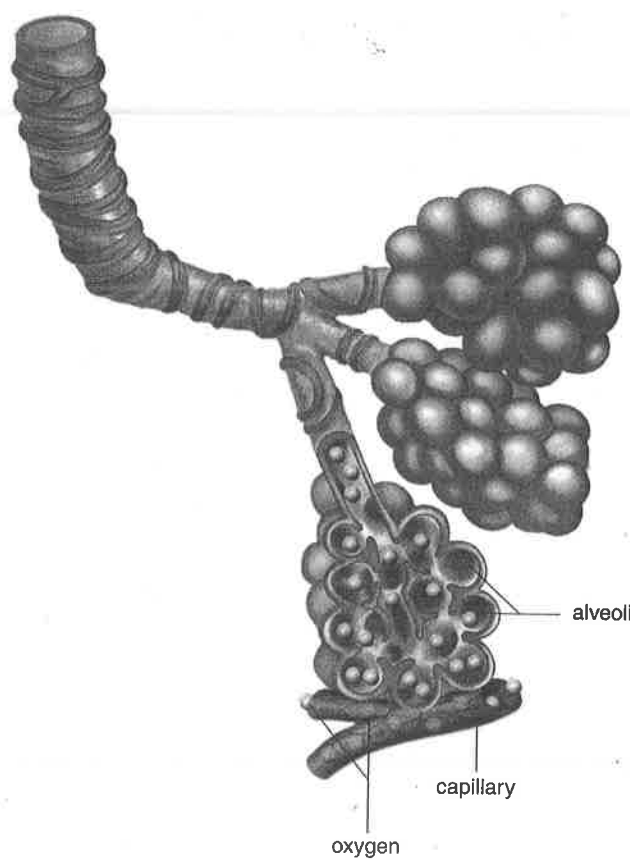


Figure 4.6 Gas exchange in lungs.
Oxygen (O_2) diffuses into the capillaries of the lungs because there is a higher concentration of oxygen in the alveoli (air sacs) than in the capillaries.

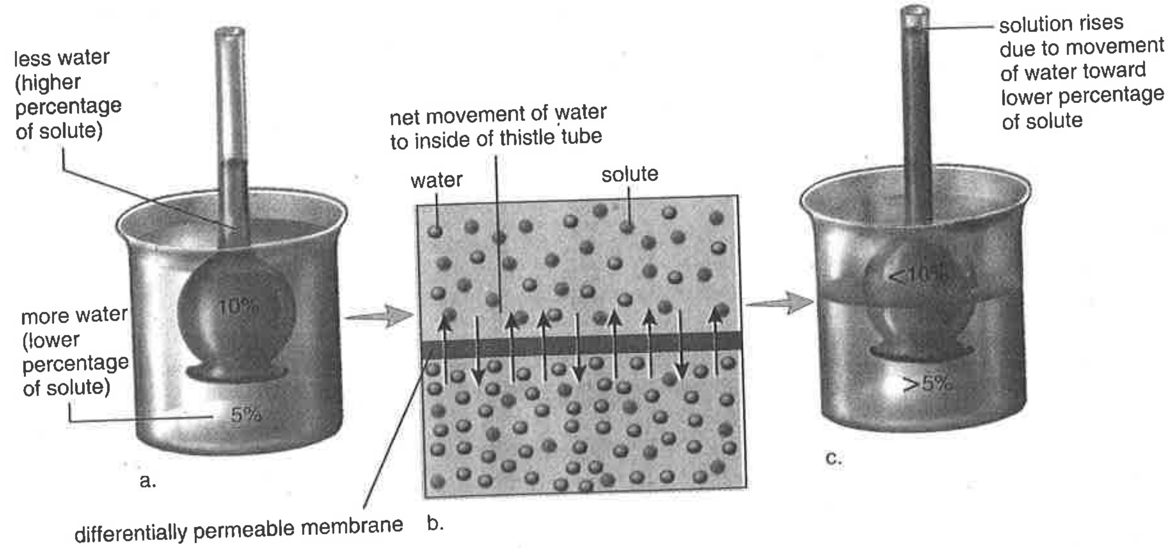


Figure 4.7 Osmosis demonstration.
(Far left) A thistle tube, covered at the broad end by a differentially permeable membrane, contains a 10% sugar solution. The beaker contains a 5% sugar solution. **(Middle)** The solute (green circles) is unable to pass through the membrane, but the water (blue circles) passes through in both directions. There is a net movement of water toward the inside of the thistle tube, where there is a lower percentage of water molecules. **(Far right)** Due to the incoming water molecules, the level of the solution rises in the thistle tube.

Osmosis

Osmosis is the diffusion of water into and out of cells. To illustrate osmosis, a thistle tube containing a 10% sugar solution[1] is covered at one end by a differentially permeable membrane and is then placed in a beaker containing a 5% sugar solution (Fig. 4.7). The beaker contains more water molecules (lower percentage of solute) per volume, and the thistle tube contains fewer water molecules (higher percentage of solute) per volume. Under these conditions, there is a net movement of water from the beaker to the inside of the thistle tube across the membrane. The solute is unable to pass through the membrane; therefore, the level of the solution within the thistle tube rises (Fig. 4.7*c*).

Notice the following in this illustration of osmosis:

1. A differentially permeable membrane separates two solutions. The membrane does not permit passage of the solute.
2. The beaker has more water (lower percentage of solute), and the thistle tube has less water (higher percentage of solute).
3. The membrane permits passage of water, and there is a net movement of water from the beaker to the inside of the thistle tube.
4. In the end, the concentration of solute in the thistle tube is less than 10%. Why? Because there is now less solute per volume. And the concentration of solute in the beaker is greater than 5%. Why? Because there is now more solute per volume.

Water enters the thistle tube due to the osmotic pressure of the solution within the thistle tube. **Osmotic pressure** is the pressure that develops in a system due to osmosis[2]. In other words, the greater the possible osmotic pressure the more likely water will diffuse in that direction. Due to osmotic pressure, water is absorbed from the human large intestine, is retained by the kidneys, and is taken up by capillaries from tissue fluid.

Tonicity

Tonicity refers to the strength of a solution in relationship to osmosis. In the laboratory, cells are normally placed in **isotonic solutions;** that is, the solute concentration is the same on both sides of the membrane, and therefore there is no net gain or loss of water (Fig. 4.8). The prefix *iso* means the same as, and the term tonicity refers to the strength of the solution. A 0.9% solution of the salt sodium chloride (NaCl) is known to be isotonic to red blood cells. Therefore, intravenous solutions medically administered usually have this tonicity.

Solutions that cause cells to swell, or even to burst, due to an intake of water are said to be **hypotonic solutions.** The prefix *hypo* means less than, and refers to a solution with a lower percentage of solute (more water) than the cell. If a cell is placed in a hypotonic solution, water enters the cell; the net movement of water is from the outside to the inside of the cell.

Any concentration of a salt solution lower than 0.9% is hypotonic to red blood cells. Animal cells placed in such a solution expand and sometimes burst due to the buildup of pressure. The term *lysis* is used to refer to disrupted cells; hemolysis, then, is disrupted red blood cells.

[1]Percent 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.

[2]Osmotic pressure is measured by placing a solution in an osmometer and then immersing the osmometer in pure water. The pressure that develops is the osmotic pressure of a solution.

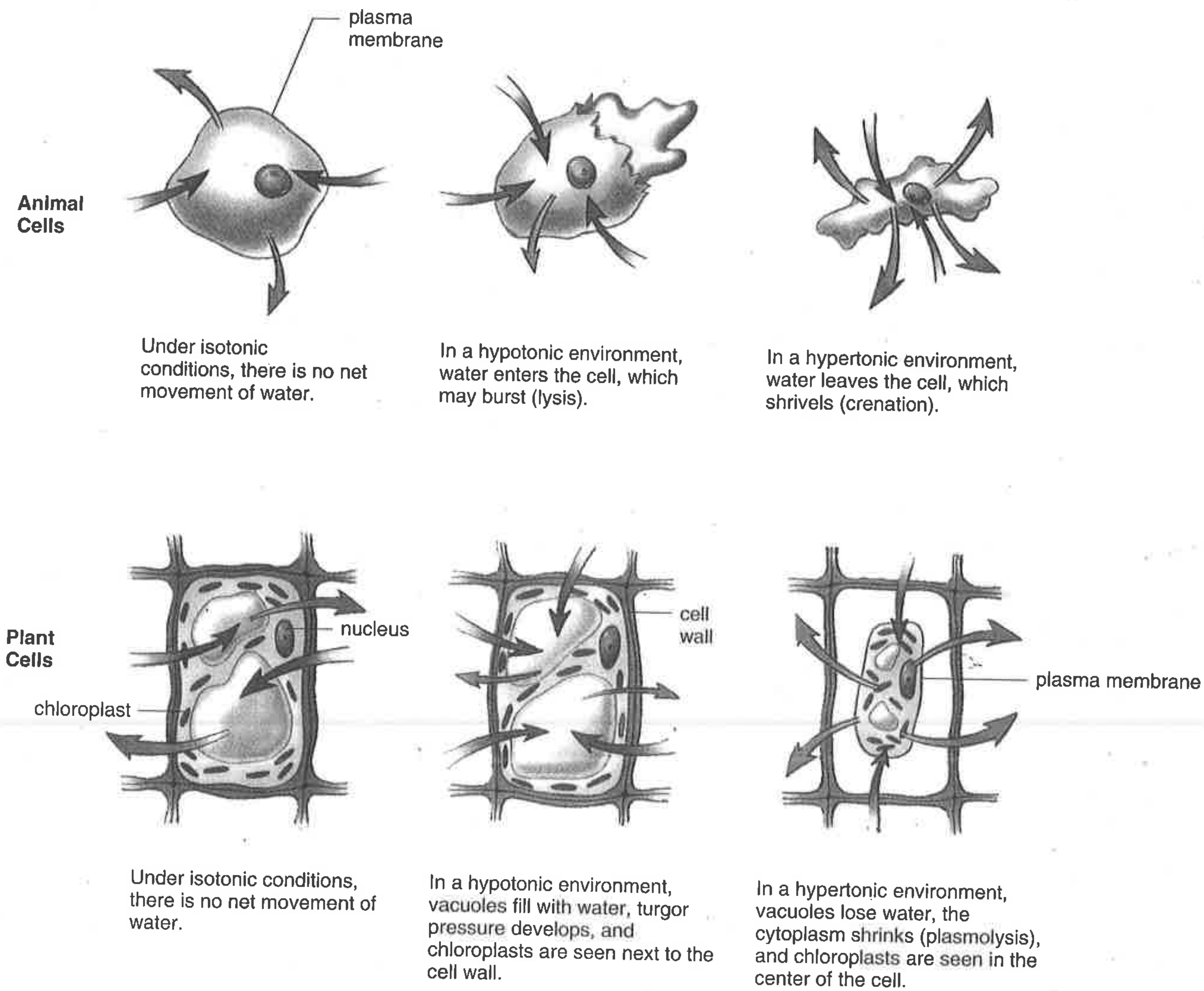


Figure 4.8 Osmosis in animal and plant cells.
The arrows indicate the net movement of water. In an isotonic solution, a cell neither gains nor loses water; in a hypotonic solution, a cell gains water; and in a hypertonic solution, a cell loses water.

The swelling of a plant cell in a hypotonic solution creates **turgor pressure.** When a plant cell is placed in a hypotonic solution, we observe expansion of the cytoplasm because the large central vacuole gains water and the plasma membrane pushes against the rigid cell wall. The plant cell does not burst because the cell wall does not give way. Turgor pressure in plant cells is extremely important to the maintenance of the plant's erect position. If you forget to water your plants they wilt due to decreased turgor pressure.

Solutions that cause cells to shrink or to shrivel due to a loss of water are said to be **hypertonic solutions.** The prefix *hyper* means more than, and refers to a solution with a higher percentage of solute (less water) than the cell. If a cell is placed in a hypertonic solution, water leaves the cell; the net movement of water is from the inside to the outside of the cell.

Any solution with a concentration higher than 0.9% sodium chloride is hypertonic to red blood cells. If animal cells are placed in this solution, they shrink. The term *crenation* refers to red blood cells in this condition. Meats are sometimes preserved by salting them. The bacteria are not killed by the salt but by the lack of water in the meat.

When a plant cell is placed in a hypertonic solution, the plasma membrane pulls away from the cell wall as the large central vacuole loses water. This is an example of **plasmolysis,** a shrinking of the cytoplasm due to osmosis. Dead plants you see along a salted roadside after the winter died because they were exposed to a hypertonic solution.

In an isotonic solution, a cell neither gains nor loses water. In a hypotonic solution, a cell gains water. In a hypertonic solution, a cell loses water and the cytoplasm shrinks.

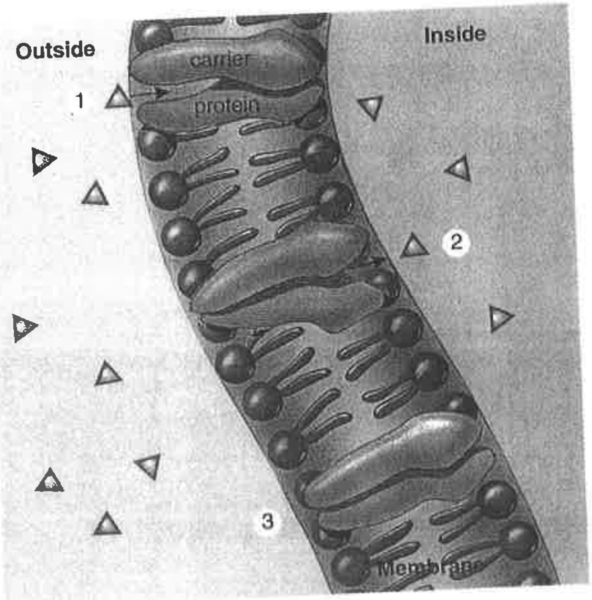


Figure 4.9 **Facilitated transport.**
A carrier protein speeds the rate at which a solute crosses a membrane from higher solute concentration to lower solute concentration. (1) Molecule enters carrier. (2) Molecule is transported across the membrane and exits on inside. (3) Carrier returns to its former state.

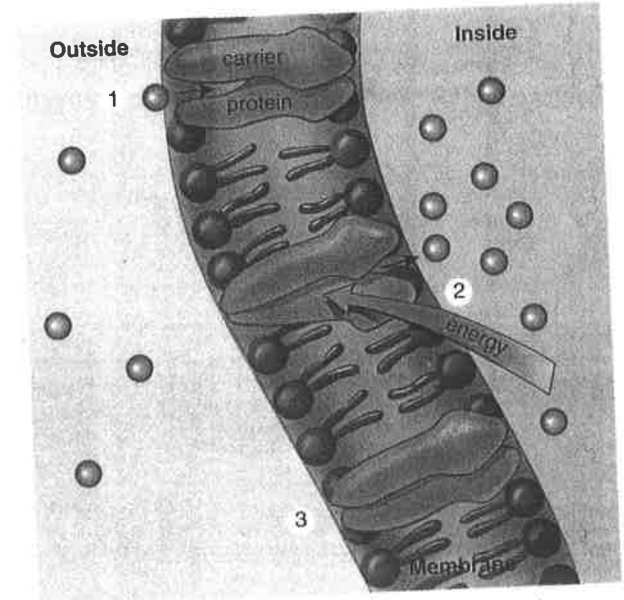


Figure 4.10 **Active transport.**
Active transport allows a solute to cross the membrane from lower solute concentration to higher solute-concentration. (1) Molecule enters carrier. (2) Chemical energy of ATP is needed to transport the molecule which exits inside of cell. (3) Carrier returns to its former state.

4.4 Transport by Carrier Proteins

The plasma membrane impedes the passage of all but a few substances. Yet, biologically useful molecules do enter and exit the cell at a rapid rate because there are carrier proteins in the membrane. **Carrier proteins** are specific; each can combine with only a certain type of molecule, which is then transported through the membrane. It is not completely understood how carrier proteins function; but after a carrier combines with a molecule, the carrier is believed to undergo a change in shape that moves the molecule across the membrane. Carrier proteins are required for facilitated and active transport (see Table 4.1).

Some of the proteins in the plasma membrane are carriers; they transport biologically useful molecules into and out of the cell.

Facilitated Transport

Facilitated transport explains the passage of such molecules as glucose and amino acids across the plasma membrane, even though they are not lipid soluble. The passage of glucose and amino acids is facilitated by their reversible combination with carrier proteins, which in some manner transport them through the plasma membrane. These carrier proteins are specific. For example, various sugar molecules of identical size might be present inside or outside the cell, but glucose can cross the membrane hundreds of times faster than the other sugars. This is a good example of the differential permeability of the membrane.

The carrier for glucose has been isolated and a model has been developed to explain how it works (Fig. 4.9). It seems likely that the carrier has two conformations and that it switches back and forth between the two states. After glucose binds to the open end of a carrier, it closes behind the glucose molecule. As glucose moves along, the constricted end of the carrier opens in front of the molecule. After glucose is released into the cytoplasm of the cell, the carrier changes its conformation so that the binding site for glucose is again open. This process can occur as often as 100 times per second. Apparently, the cell has a pool of extra glucose carriers. When the hormone insulin binds to a plasma membrane receptor, more glucose carriers ordinarily appear in the plasma membrane. Some forms of diabetes are caused by insulin insensitivity; that is, the binding of insulin does not result in extra glucose carriers in the membrane.

The model shows that after a carrier has assisted th movement of a molecule to the other side of the membrane it is free to assist the passage of other similar molecules. Nei ther diffusion, explained previously, nor facilitated trans port requires an expenditure of chemical energy because th molecules are moving down their concentration gradient i the same direction they tend to move anyway.

Active Transport

During **active transport,** ions or molecules move through the plasma membrane, accumulating either inside or outside the cell. For example, iodine collects in the cells of the thyroid gland; nutrients are completely absorbed from the gut by the cells lining the digestive tract, and sodium ions (Na^+) can be almost completely withdrawn from urine by cells lining the kidney tubules. In these instances, substances have moved to the region of higher concentration, exactly opposite to the process of diffusion. It has been estimated that up to 40% of a cell's energy supply may be used for active transport of solute across its membrane.

Both carrier proteins and an expenditure of energy are needed to transport molecules against their concentration gradient (Fig. 4.10). In this case, energy (ATP molecules) is required for the carrier to combine with the substance to be transported. Therefore, it is not surprising that cells involved primarily in active transport, such as kidney cells, have a large number of mitochondria near the membrane through which active transport is occurring.

Proteins involved in active transport often are called *pumps,* because just as a water pump uses energy to move water against the force of gravity, proteins use energy to move a substance against its concentration gradient. One type of pump that is active in all cells, but is especially associated with nerve and muscle cells, moves sodium ions (Na^+) to the outside of the cell and potassium ions (K^+) to the inside of the cell. These two events are presumed to be linked, and the carrier protein is called a **sodium-potassium pump.** A change in carrier shape after the attachment, and again after the detachment, of a phosphate group allows the carrier to combine alternately with sodium ions and potassium ions (Fig. 4.11). The phosphate group is donated by ATP, which is broken down enzymatically by the carrier.

The passage of salt (NaCl) across a plasma membrane is of primary importance in cells. The chloride ion (Cl^-) usually crosses the plasma membrane because it is attracted by positively charged sodium ions (Na^+). First, sodium ions are pumped across a membrane, and then chloride ions simply diffuse through channels that allow their passage. As noted in Figure 4.3, the chloride ion channels malfunction in persons with cystic fibrosis, and this leads to the symptoms of this inherited (genetic) disorder.

During facilitated transport, substances follow their concentration gradient. During active transport, substances are moved against their concentration gradient.

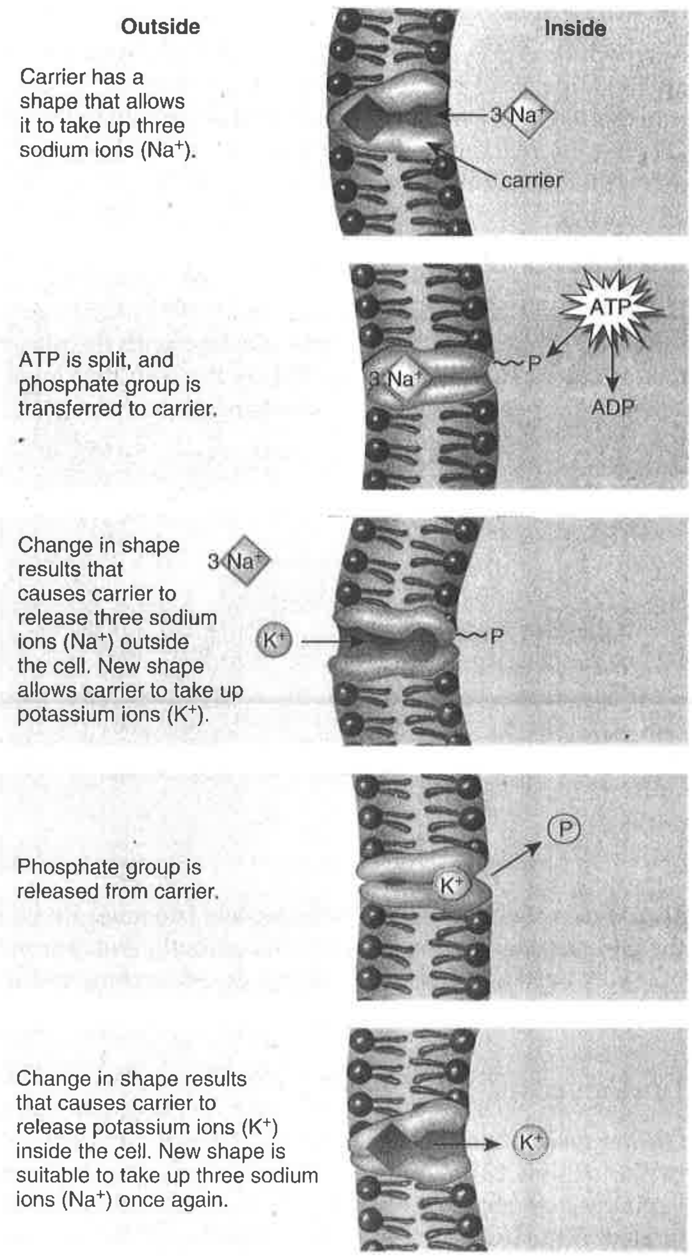


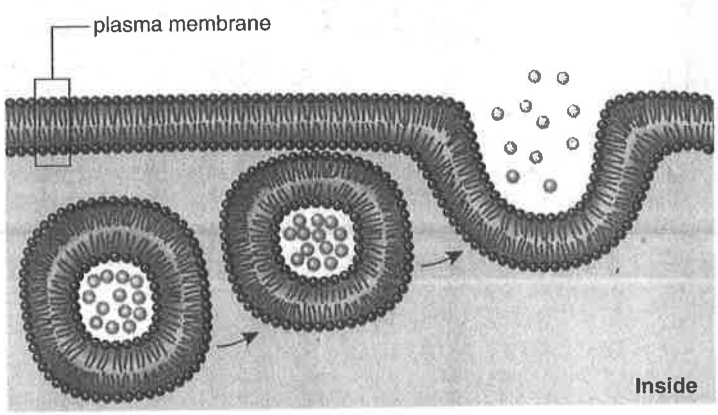
Figure 4.11 **The sodium-potassium pump.**
A carrier protein actively moves three sodium ions (Na^+) to the outside of the cell for every potassium ion (K^+) pumped to the inside of the cell. Note that chemical energy of ATP is required.

4.5 Exocytosis and Endocytosis

What about the transport of macromolecules such as polypeptides, polysaccharides, or polynucleotides, which are too large to be transported by carrier proteins? They are transported in or out of the cell by vesicle formation, thereby keeping the macromolecules contained so that they do not mix with those in the cytoplasm.

Exocytosis

During **exocytosis,** vesicles often formed by the Golgi apparatus and carrying a specific molecule, fuse with the plasma membrane as secretion occurs. This is the way that insulin leaves insulin-secreting cells, for instance.



Notice that the membrane of the vesicle becomes a part of the plasma membrane. During cell growth, exocytosis is probably used as a means to enlarge the plasma membrane, whether or not secretion is also taking place.

Endocytosis

During **endocytosis,** cells take in substances by vesicle formation (Fig. 4.12). A portion of the plasma membrane invaginates to envelop the substance, and then the membrane pinches off to form an intracellular vesicle.

When the material taken in by endocytosis is large, such as a food particle or another cell, the process is called phagocytosis. **Phagocytosis** is common in unicellular organisms like amoebas and in amoeboid cells like macrophages, which are large cells that engulf bacteria and worn-out red blood cells in mammals. When the endocytic vesicle fuses with a lysosome, digestion occurs.

Pinocytosis occurs when vesicles form around a liquid or very small particles. Blood cells, cells that line the kidney tubules or intestinal wall, and plant root cells all use this method of ingesting substances. Whereas phagocytosis can be seen with the light microscope, the electron microscope must be used to observe pinocytic vesicles, which are no larger than 1–2 μm.

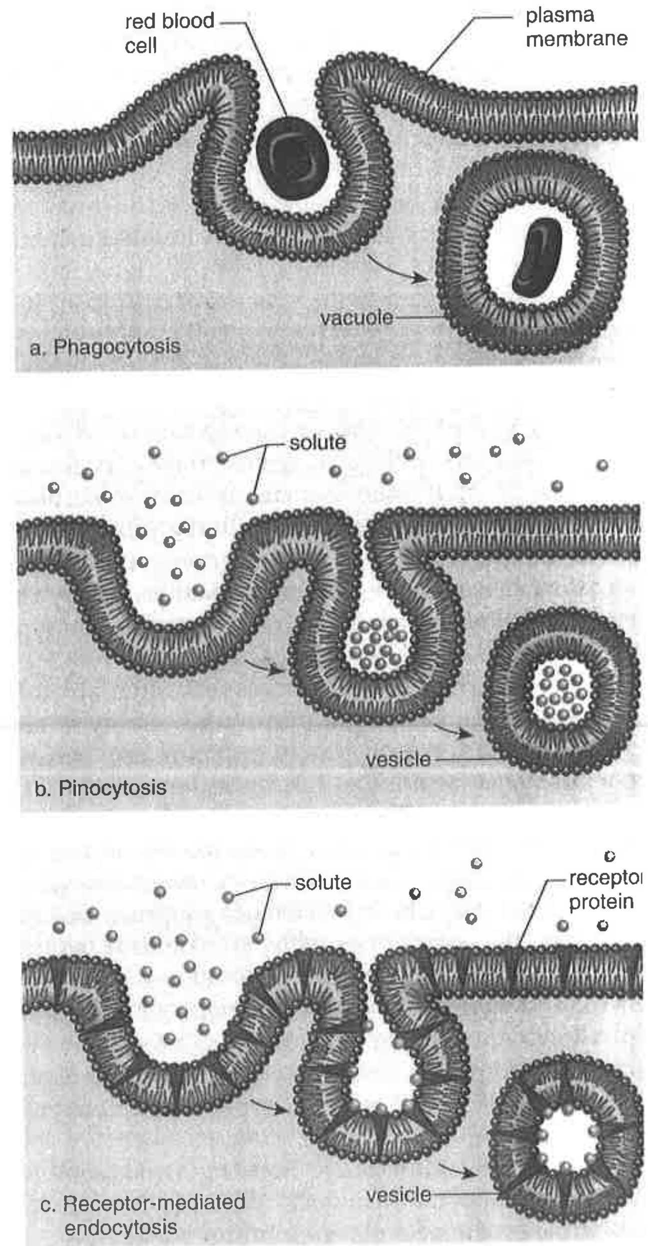
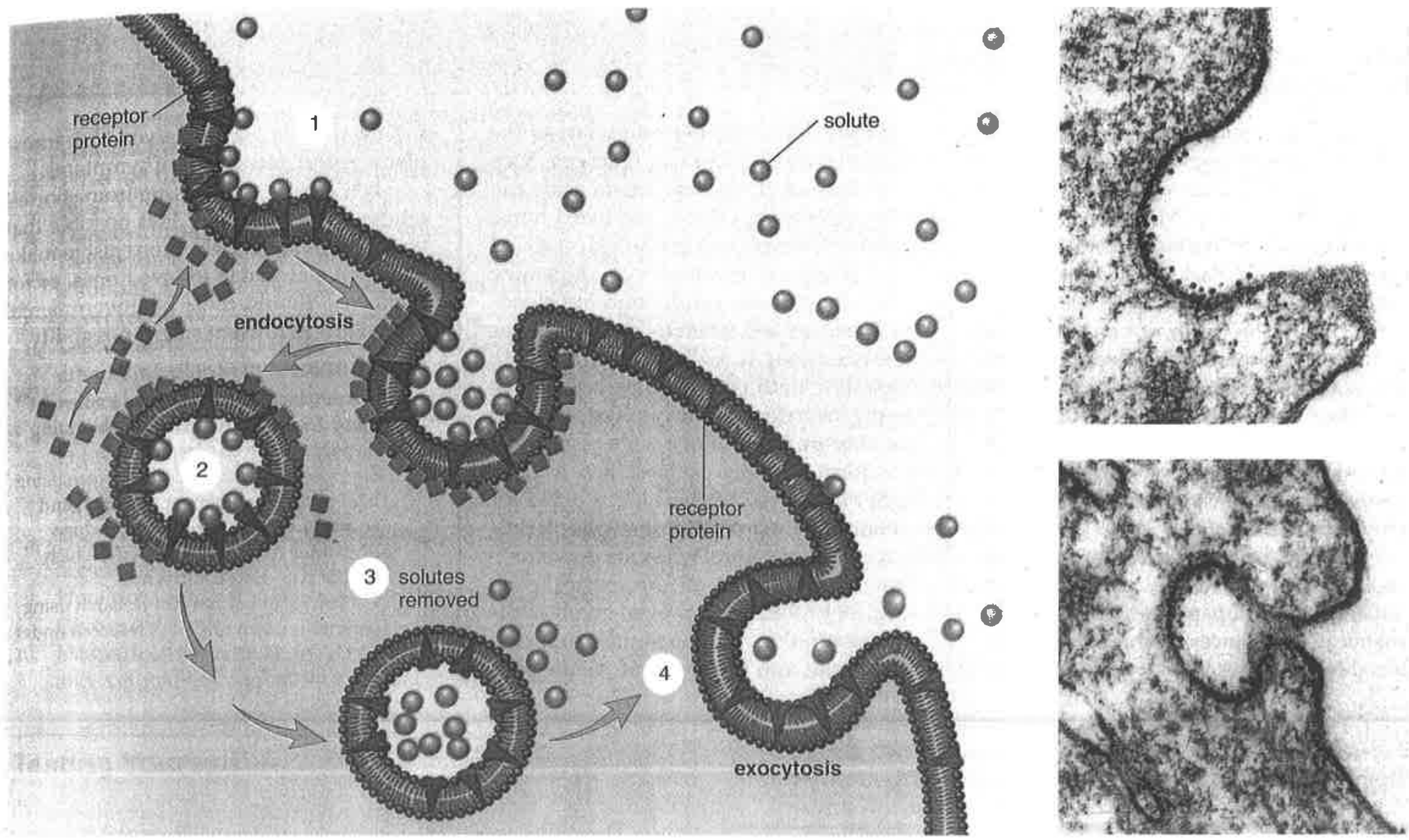


Figure 4.12 Three methods of endocytosis.
a. Phagocytosis occurs when the substance to be transported ir the cell is large; certain specialized cells in the body can engulf v out red blood cells by phagocytosis. Digestion occurs when the resulting vacuole fuses with a lysosome. **b.** Pinocytosis occurs v a macromolecule such as a polypeptide is to be transported intc cell. The result is a small vacuole or vesicle. **c.** Receptor-mediat endocytosis is a form of pinocytosis. The substance to be taken ligand) first binds to a specific receptor protein which migrates t pit or is already in a pit. The vesicle that forms contains the ligan and its receptor. Sometimes the receptor is recycled, as shown i Figure 4.13.



a. b.

Figure 4.13 Receptor-mediated endocytosis.
a. (1) The receptors in the coated pits combine only with a solute. (2) The vesicle that forms is at first coated with a fibrous protein (blue squares), but soon the vesicle loses its coat. (3) Solutes leave the vesicle. (4) When exocytosis occurs, membrane and therefore receptors are returned to the plasma membrane. **b.** Electron micrographs of a coated pit in the process of forming a vesicle.

Receptor-mediated endocytosis is a form of pinocytosis that is quite specific because it involves the use of a receptor protein shaped in such a way that a specific molecule such as vitamins, peptide hormones, and lipoproteins can bind to it. The binding of a solute to the receptors causes the receptors to gather at one location. This location is called a coated pit because there is a layer of fibrous protein on the cytoplasmic side (see step 1, Fig. 4.13). Once the vesicle is formed, the fibrous coat is released and the vesicle appears uncoated (see step 2). The fate of the vesicle and its contents depends on the kind of solute it contains. Sometimes the solute simply enters the cytoplasm (step 3). A spent hormone, on the other hand, may be digested when the vesicle fuses with a lysosome. The membrane of the vesicle and, therefore, the receptors are returned to the plasma membrane (step 4), or the vesicle can go to other membranous locations.

Aside from simply allowing substances to enter cells selectively from an extracellular fluid, coated pits are also involved in the transfer and exchange of substances between cells. Such exchanges take place when the substances move from maternal blood into fetal blood at the placenta, for example.

The importance of receptor-mediated endocytosis is demonstrated by a genetic disorder called familial hypercholesterolemia. Cholesterol is transported in blood by a complex of lipids and proteins called low-density lipoprotein (LDL). These individuals have inherited a gene that causes them to have a reduced number and/or defective receptors for LDL in their plasma membranes. Instead of cholesterol entering cells, it accumulates in the walls of arterial blood vessels, leading to high blood pressure, occluded (blocked) arteries, and heart attacks.

Substances are secreted from a cell by exocytosis. Substances enter a cell by endocytosis. Receptor-mediated endocytosis allows cells to take up specific kinds of molecules and then sort them within the cell.
