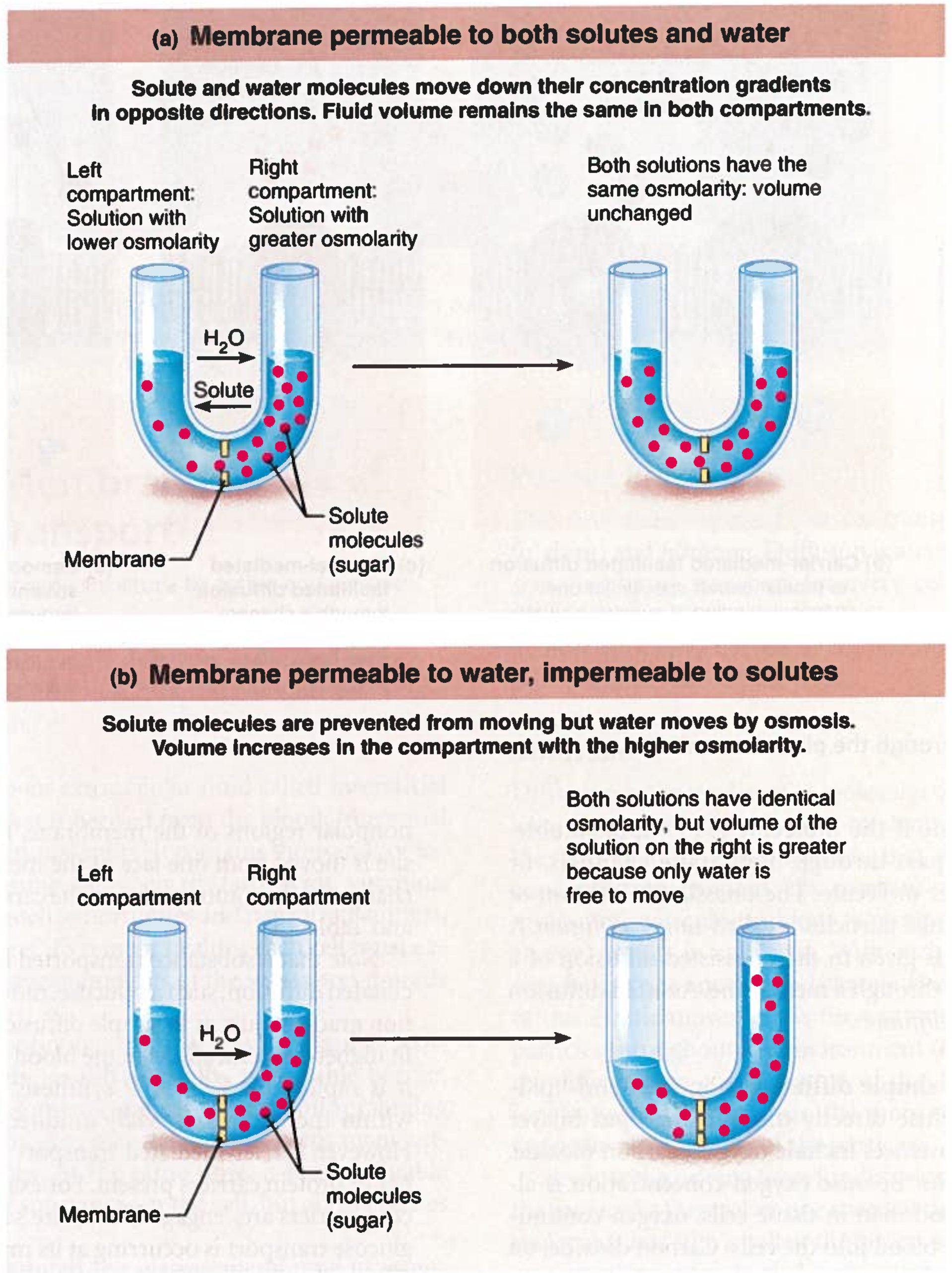


(a) Membrane permeable to both solutes and water

Solute and water molecules move down their concentration gradients in opposite directions. Fluid volume remains the same in both compartments.

(b) Membrane permeable to water, impermeable to solutes

Solute molecules are prevented from moving but water moves by osmosis. Volume increases in the compartment with the higher osmolarity.

Figure 3.8 **Influence of membrane permeability on diffusion and osmosis.**

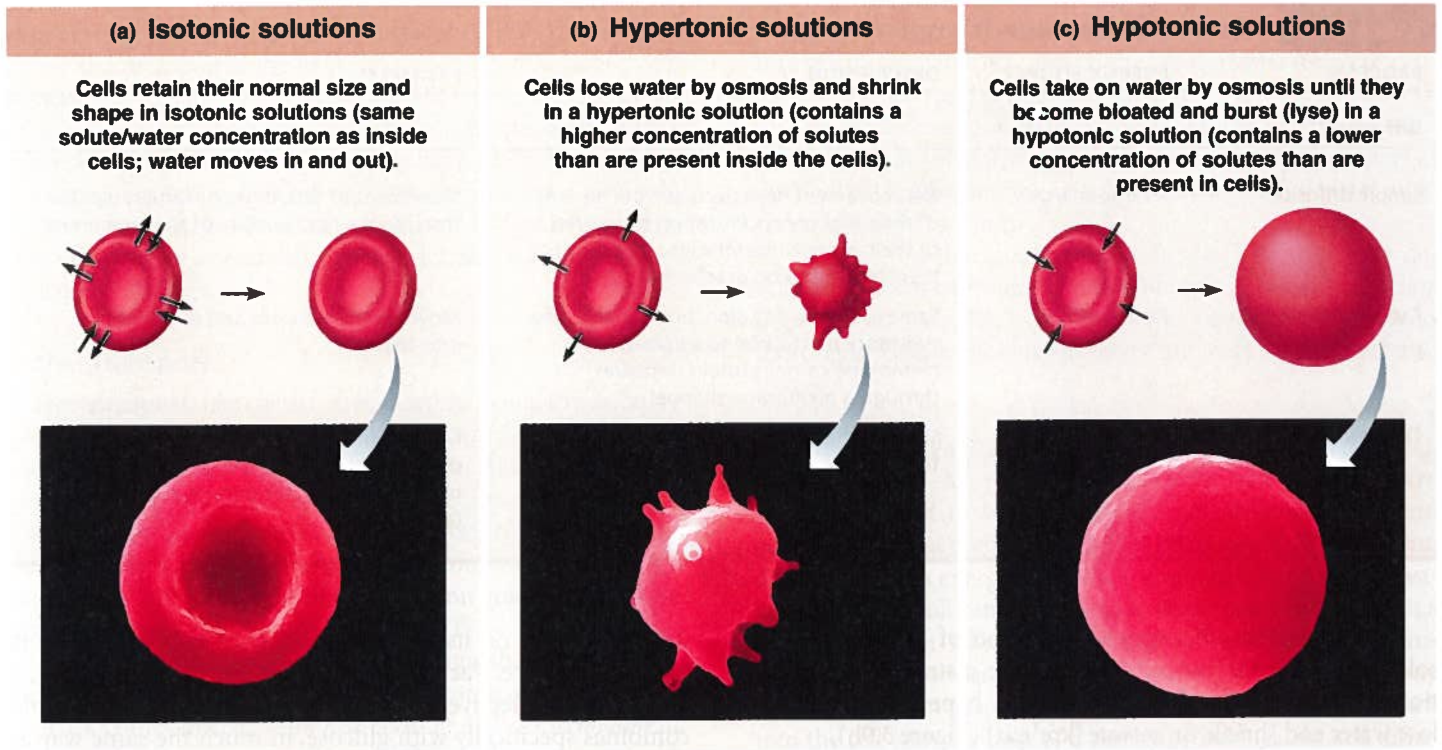
permeability of the membrane can be altered by regulating the activity or number of individual carriers or channels.

Oxygen, water, glucose, and various ions are vitally important to cellular homeostasis. Their passive transport by diffusion (either simple or facilitated) represents a tremendous saving of cellular energy. Indeed, if these substances had to be transported actively, cell expenditures of ATP would increase exponentially!

Osmosis The diffusion of a solvent, such as water, through a selectively permeable membrane is **osmosis** (oz-mo′sis; *osmos* = pushing). Even though water is highly polar, it passes via osmosis through the lipid bilayer (Figure 3.7d). This is surprising because you'd expect water to be repelled by the hydrophobic lipid tails. Although still hypothetical, one explanation is that random movements of the membrane lipids open small gaps between their wiggling tails, allowing water to slip and slide its way through the membrane by moving from gap to gap.

Water also moves freely and reversibly through water-specific channels constructed by transmembrane proteins called **aquaporins** (AQPs). Although aquaporins are believed to be present in all cell types, they are particularly abundant in red blood cells and in cells involved in water balance such as kidney tubule cells.

Osmosis occurs whenever the water concentration differs on the two sides of a membrane. If distilled water is present on both sides of a selectively permeable membrane, no *net* osmosis occurs, even though water molecules move in both directions through the membrane. If the solute concentration on the two sides of



(a) Isotonic solutions

Cells retain their normal size and shape in isotonic solutions (same solute/water concentration as inside cells; water moves in and out).

(b) Hypertonic solutions

Cells lose water by osmosis and shrink in a hypertonic solution (contains a higher concentration of solutes than are present inside the cells).

(c) Hypotonic solutions

Cells take on water by osmosis until they become bloated and burst (lyse) in a hypotonic solution (contains a lower concentration of solutes than are present in cells).

Figure 3.9 **The effect of solutions of varying tonicities on living red blood cells.**

the membrane differs, water concentration differs as well (as solute concentration increases, water concentration decreases).

The extent to which water's concentration is decreased by solutes depends on the *number*, not the *type*, of solute particles, because one molecule or one ion of solute (theoretically) displaces one water molecule. The total concentration of all solute particles in a solution is referred to as the solution's **osmolarity** (oz″mo-lar′ĭ-te). When equal volumes of aqueous solutions of different osmolarity are separated by a membrane that is *permeable to all molecules* in the system, net diffusion of both solute and water occurs, each moving down its own concentration gradient. Eventually, equilibrium is reached when the water concentration on the left equals that on the right, and the solute concentration on both sides is the same (Figure 3.8a).

If we consider the same system, but make the membrane *impermeable to solute molecules*, we see quite a different result (Figure 3.8b). Water quickly diffuses from the left to the right compartment and continues to do so until its concentration is the same on the two sides of the membrane. Notice that in this case equilibrium results from the movement of water alone (the solutes are prevented from moving). Notice also that the movement of water leads to dramatic changes in the volumes of the two compartments.

The last example mimics osmosis across plasma membranes of living cells, with one major difference. In our examples, the volumes of the compartments are infinitely expandable and the effect of pressure exerted by the added weight of the higher fluid column is not considered. In living plant cells, which have rigid cell walls external to their plasma membranes, this is not the case. As water diffuses into the cell, the point is finally reached where the **hydrostatic pressure** (the back pressure exerted by water against the membrane) within the cell is equal to its **osmotic pressure** (the tendency of water to move into the cell by osmosis). At this point, there is no further (net) water entry. As a rule, the higher the amount of nondiffusible, or *nonpenetrating*, solutes in a cell, the higher the osmotic pressure and the greater the hydrostatic pressure that must be developed to resist further net water entry.

However, such major changes in hydrostatic (and osmotic) pressures do not occur in living animal cells, which lack rigid cell walls. Osmotic imbalances cause animal cells to swell or shrink (due to net water gain or loss) until either the solute concentration is the same on both sides of the plasma membrane, or the membrane is stretched to its breaking point.

Such changes in animal cells lead us to the important concept of *tonicity* (to-nis′ĭ-te). As noted, many molecules, particularly intracellular proteins and selected ions, are prevented from diffusing through the plasma membrane. Consequently, any change in their concentration alters the water concentration on the two sides of the membrane and results in a net loss or gain of water by the cell.

The ability of a solution to change the shape or tone of cells by altering their internal water volume is called **tonicity** (*tono* = tension). Solutions with the same concentrations of nonpenetrating solutes as those found in cells (0.9% saline or 5% glucose) are **isotonic** ("the same tonicity"). Cells exposed to such solutions retain their normal shape, and exhibit no net loss or gain of water (Figure 3.9a). As you might expect, the body's extracellular fluids and most intravenous solutions (solutions infused into the body via a vein) are isotonic.