Diffusion, Osmosis, and Active Transport

How Substances Move Across Cell Membranes

Introduction

Every living cell depends on the constant movement of substances in and out through the plasma membrane, which is a selectively permeable barrier controlling material exchange (Campbell, Urry, Cain, Wasserman, & Minorsky, 2020).

This regulation maintains homeostasis, ensuring optimal internal conditions for metabolism (Sherwood, 2012). The three key mechanisms enabling molecular transport are diffusion, osmosis, and active transport (Silverthorn, 2012). **Diffusion** refers to the passive movement of particles from areas of high concentration to areas of low concentration due to molecular motion (Kratz, 2010).

Osmosis is the diffusion of water molecules across a selectively permeable membrane.

Active transport, in contrast, requires cellular energy in the form of ATP to move substances against the gradient (Lodish et al., 2008). Together, these processes sustain vital biological functions in both plant and animal cells.

Diffusion

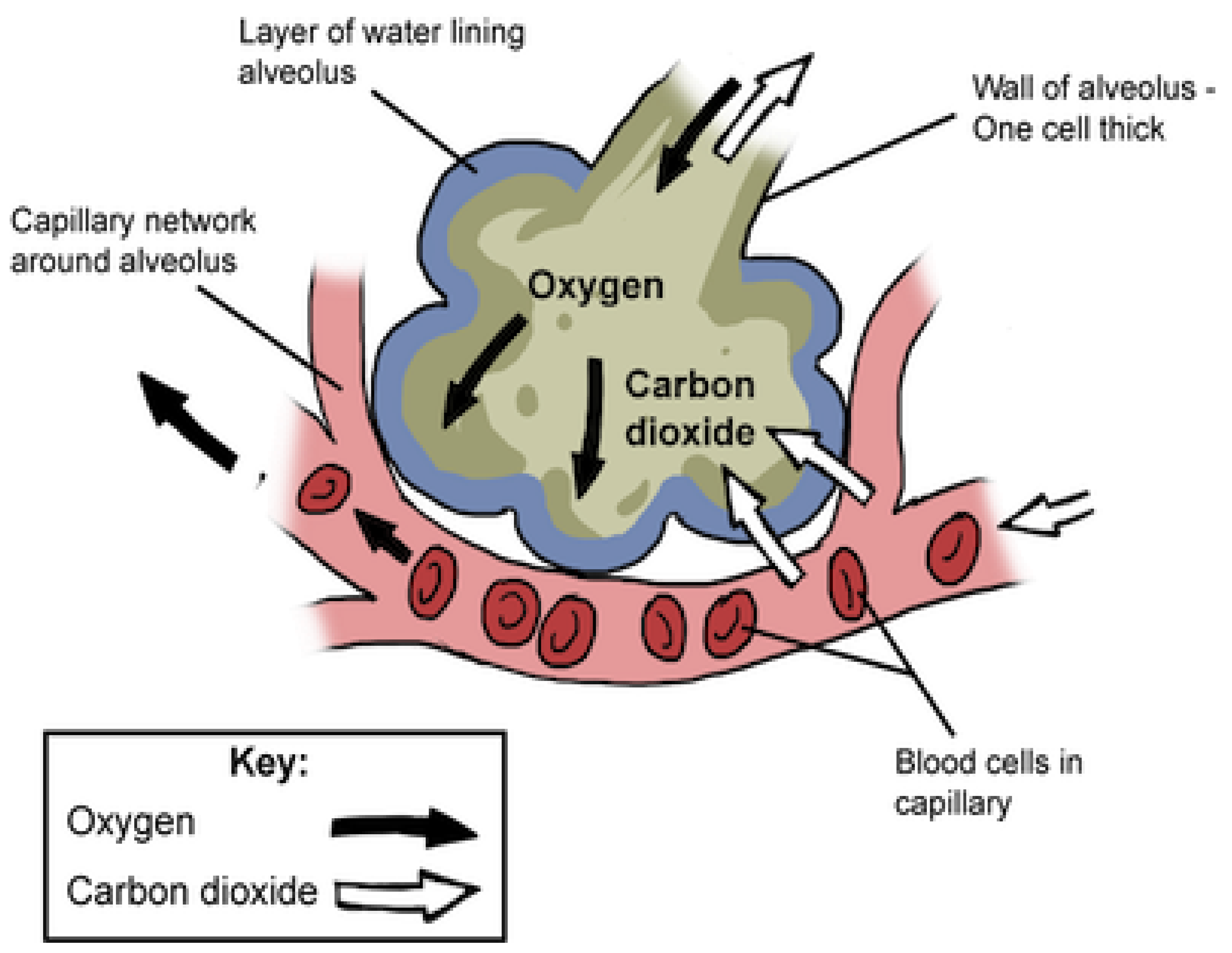

Figure 1. Diffusion of oxygen and carbon dioxide across the alveolar-capillary membrane.

Adapted from Gilam (2015)

Diffusion operates without energy expenditure and continues until equilibrium is reached (Campbell et al., 2020). Factors such as temperature, membrane surface area, and concentration gradient influence diffusion rate (Silverthorn, 2012). A classic example is the exchange of oxygen and carbon dioxide between alveoli and blood capillaries, which occurs entirely by diffusion (Sherwood, 2012).

Osmosis

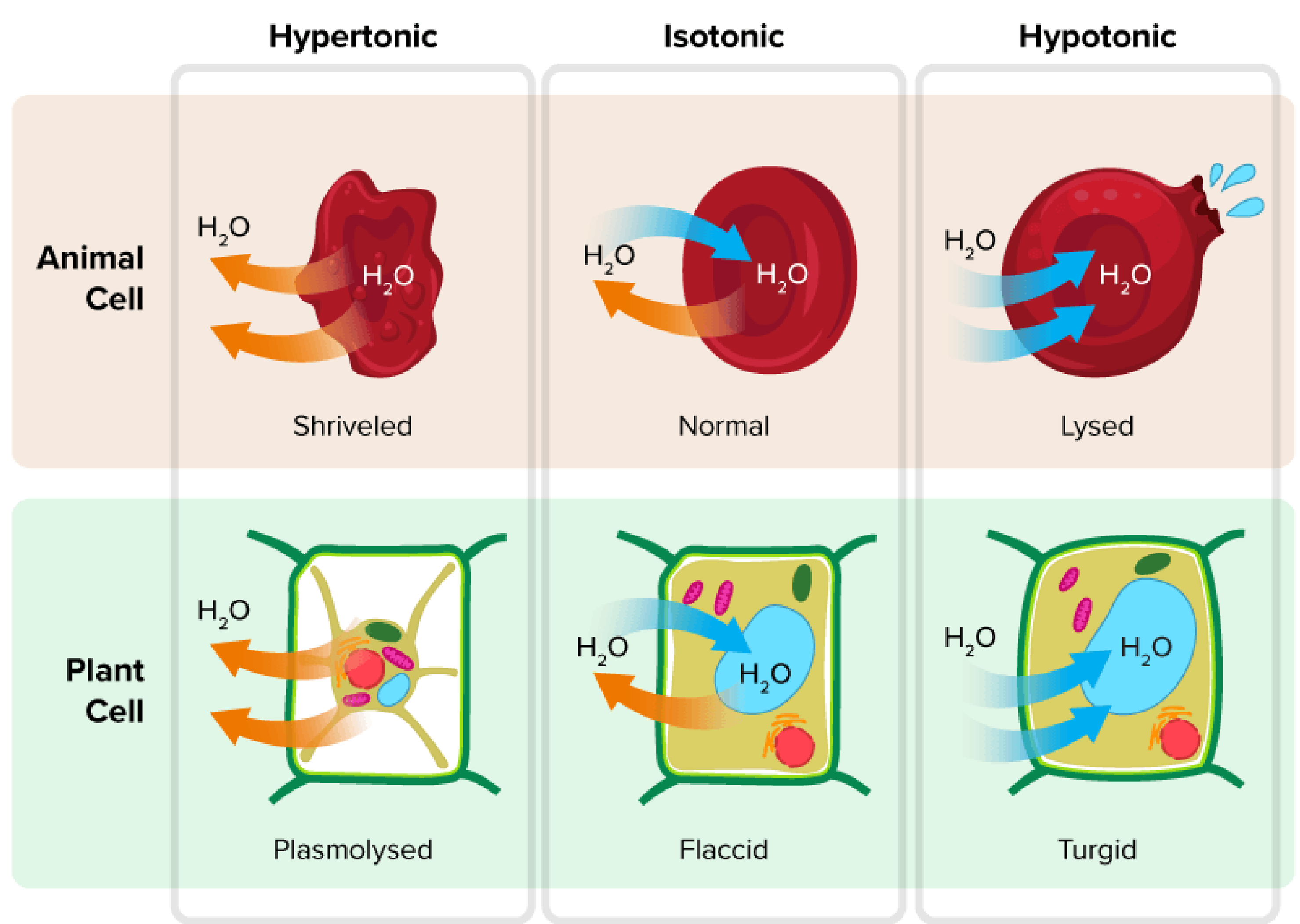

Figure 2. Osmosis in animal and plant cells under different solute conditions.

Adapted from Wilkin and Brainard (2021)

Osmosis involves water movement from regions of low solute concentration to high solute concentration through a partially permeable membrane (Kratz, 2010). In plant cells, water uptake maintains turgor pressure, essential for structural support, while loss of water causes plasmolysis (Campbell et al., 2020). In animal cells, excessive water inflow may lead to lysis, whereas hypertonic conditions result in crenation

Active Transport

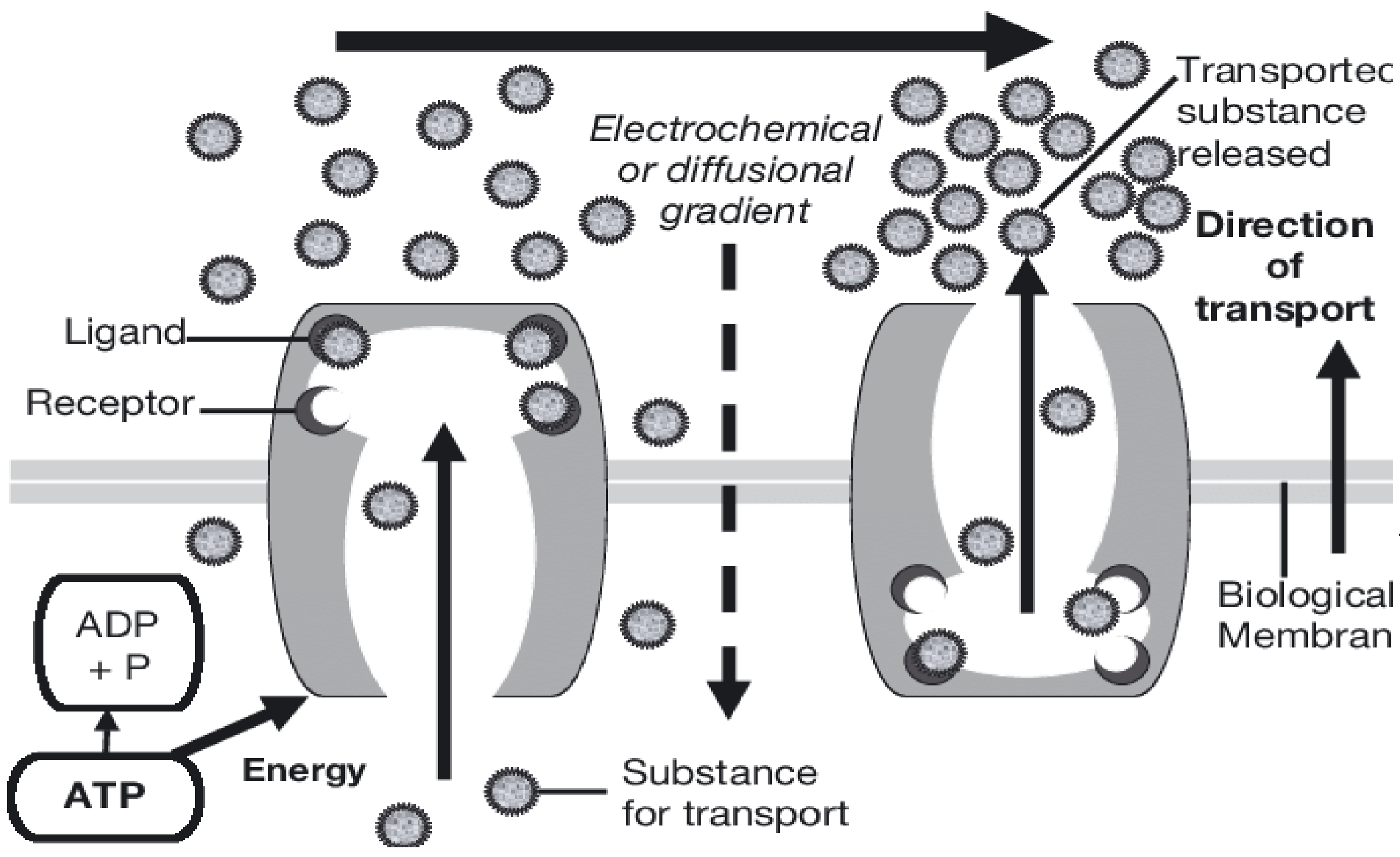

Figure 3. ATP-driven active transport across a biological membrane. *Adapted from Quinnell et al (2004)*

Unlike passive mechanisms, active transport requires metabolic energy (ATP) and specialized carrier proteins to move molecules against their concentration gradients (Lodish et al., 2008).

A key example is the sodium-potassium pump that maintains electrochemical gradients critical for nerve impulse transmission (Silverthorn, 2012). In plants, proton pumps in root cells actively absorb minerals from the soil even when concentrations outside are lower (Sherwood, 2012).

Process	Energy Requirement	Direction of Movement	Example
Diffusion	No energy (passive)	High → Low	Oxygen exchange
Osmosis	No energy (passive)	Water → Higher solute	Root water uptake
Active Transport	Requires ATP	Low → High	Sodium-potassium pump

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Summary

Diffusion, osmosis, and active transport form the foundation of cellular exchange systems. While diffusion and osmosis enable passive molecular movement, active transport uses energy to maintain concentration differences vital for life (Silverthorn, 2012). Their integration preserves homeostasis in cells, tissues, and entire organisms. Understanding these mechanisms is essential in explaining phenomena from plant water balance to nerve physiology (Campbell et al., 2020; Sherwood, 2012).