GENERAL PHYSIOLOGY
(LECTURE 4)
DIFFUSION

BY

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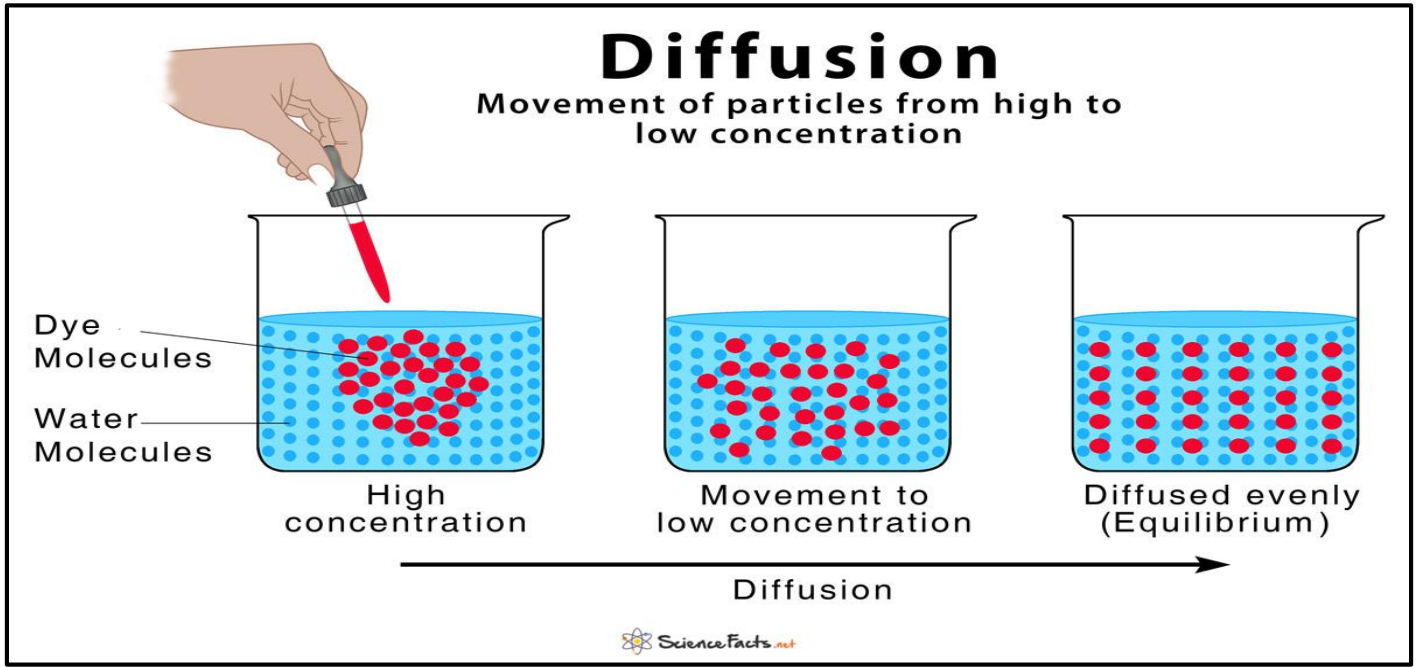
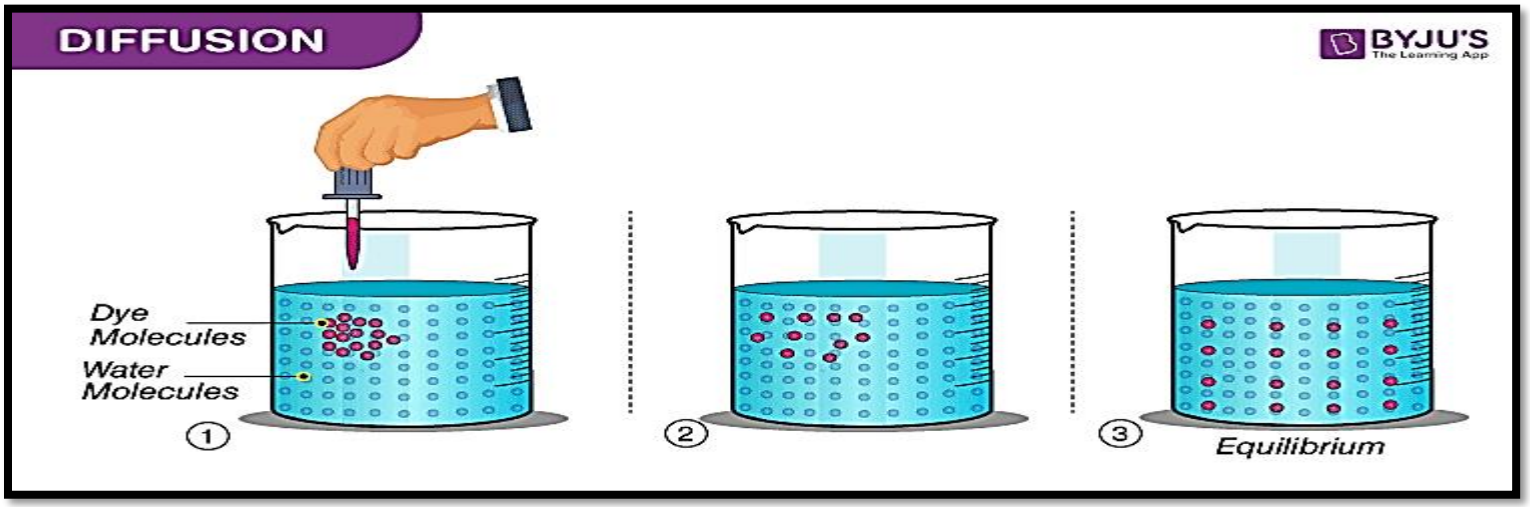
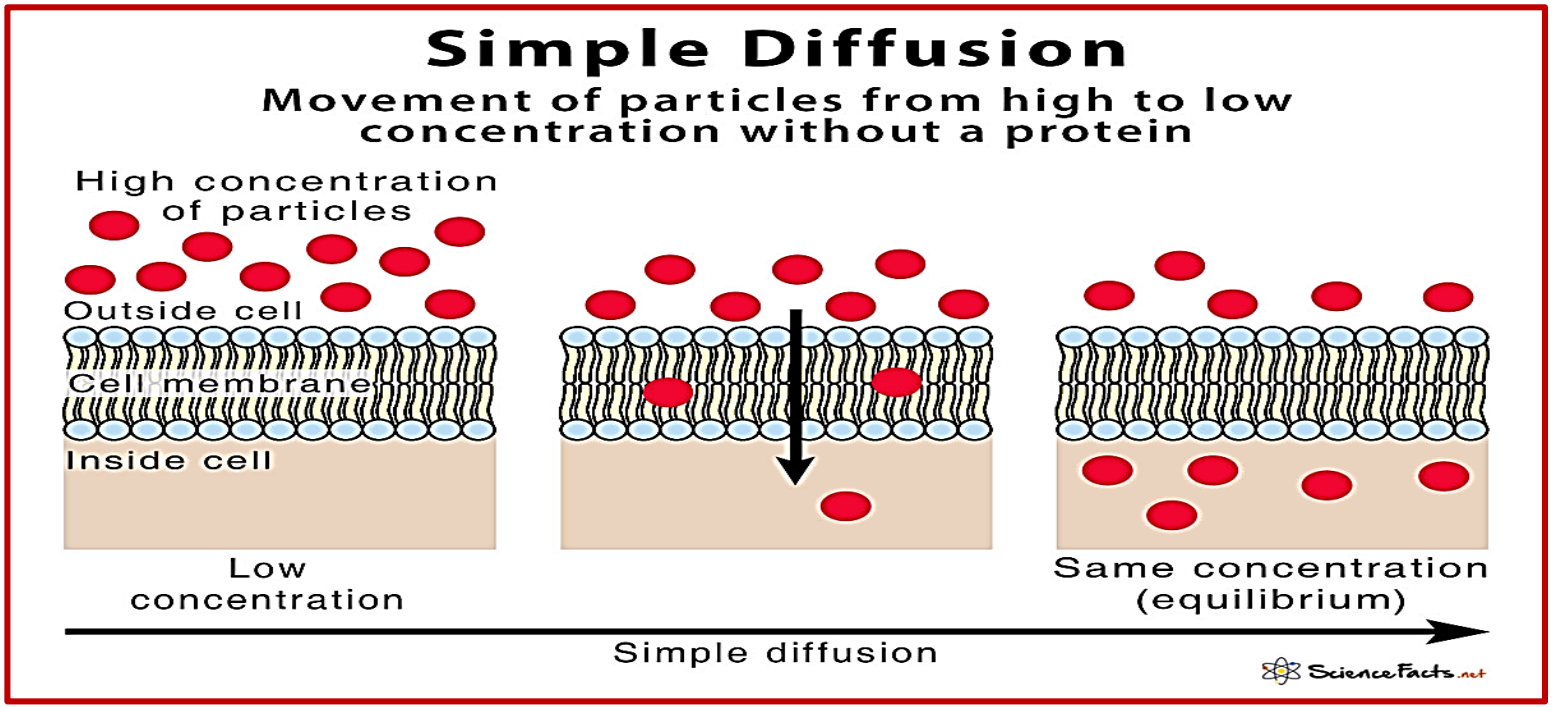


DIFFUSION

Definition:

- Diffusion is the process by which a gas or a substance in a solution expands, because of the motion of its particles, to fill all the available volume.
- It is the free movement of substance molecules (particles) through the cell membrane from area of **HIGH concentration to area of LOW concentration (concentration gradient)** caused by their **kinetic energy**.
- It is **a passive process (requiring no energy)**.
- **With (down) gradient**.
- It is produced by the **kinetic motion of the molecules** (which makes them in a continuous random movement), and it occurs in the direction of their **concentration (= chemical)**; i.e. from areas of high concentration to areas of lower concentration or **electrical gradients**.
- In the body, substances diffuse not only within the same compartment but also through cell membranes. This occurs through either the **lipid bilayer or the proteins** embedded in it, **depending on the molecular size, lipid solubility and charge of the substance**.


DIFFUSION
BYJU'S
The Learning App
Dye Molecules
Water Molecules
1
2
3
Equilibrium


Simple Diffusion
Movement of particles from high to low concentration without a protein
High concentration of particles
Outside cell
Cell membrane
Inside cell
Low concentration
Same concentration (equilibrium)
Simple diffusion
ScienceFacts.net

FACTORS AFFECTING DIFFUSION

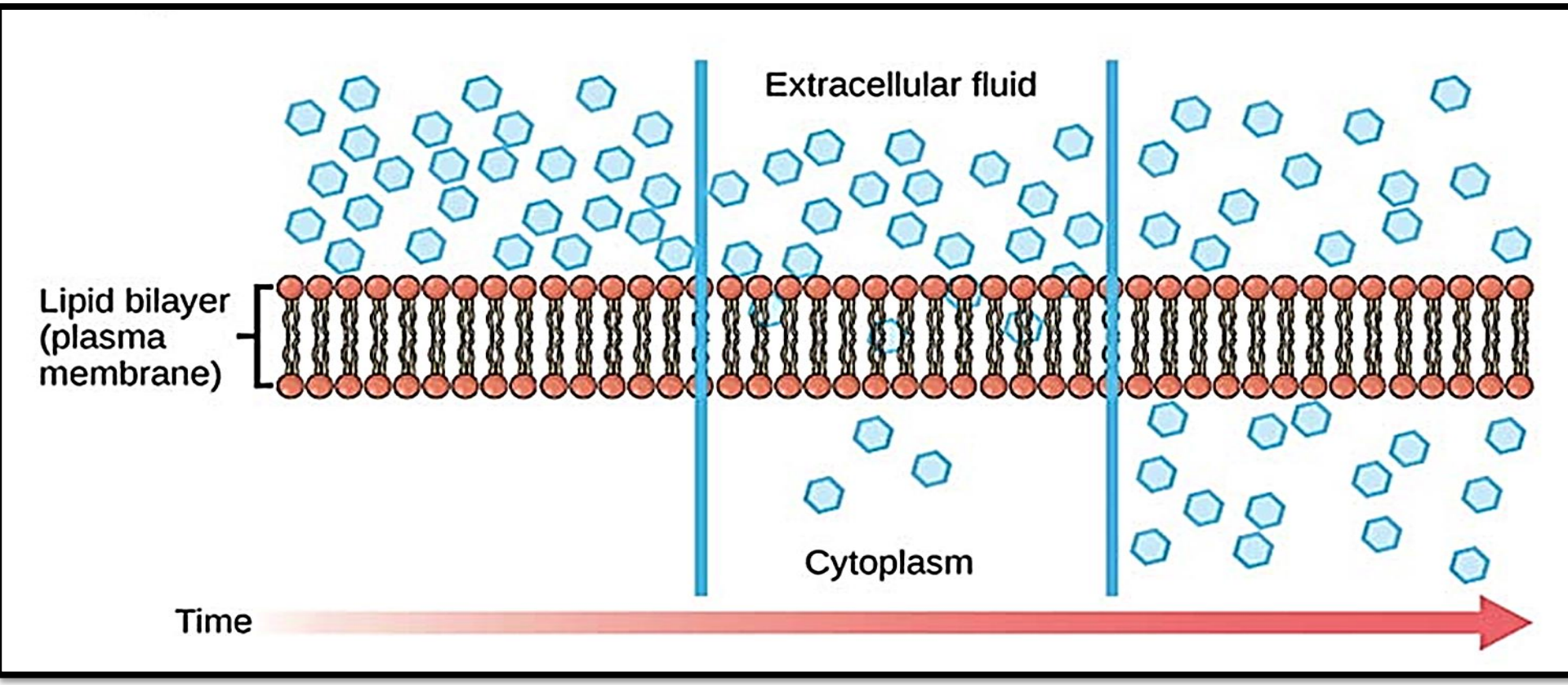
- **The rate of diffusion is directly proportional to:**

1. Concentration difference (gradient) of the substance across the cell membrane.
2. Temperature(↑temperature→ ↑kinetic energy).
3. The surface area of the membrane through which diffusion occurs.

- **The rate of diffusion is inversely proportional to:**

1. The thickness of the membrane (distance of diffusion).
2. The square root of molecular weight of the substance.

$$\text{The diffusion rate} \propto \frac{\text{concentration difference. Surface area. temperature}}{\sqrt{\text{Molecular weight . membrane thickness}}}$$

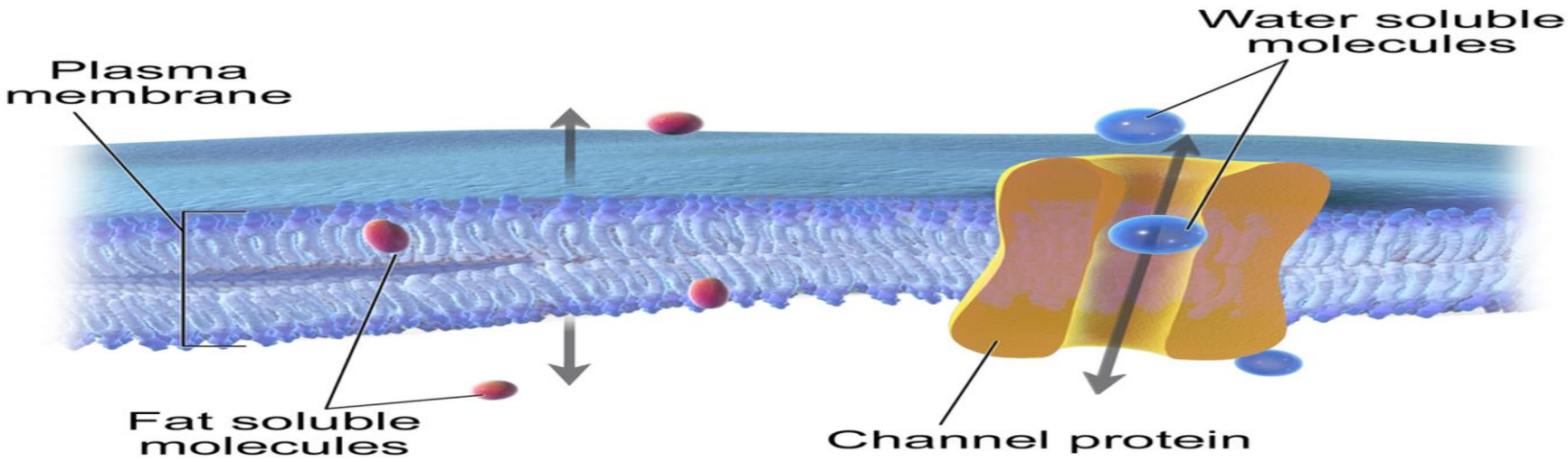


Diffusion across cell membranes can be divided into 2 main types:

1. Simple diffusion.
2. Facilitated diffusion.

1. SIMPLE DIFFUSION

Simple diffusion means that kinetic movement of molecules or ions occurs through a membrane opening or through intermolecular spaces **without any interaction with carrier proteins** in the membrane. This occurs through the **lipid bilayer** as well as through **channels (pores)** proteins in the cell membrane called the channel proteins.



Diffusion Across the Plasma Membrane

Simple diffusion can occur through the cell membrane by these pathways:

(1) Through the lipid bilayer if the diffusing substance is lipid soluble.

(2) Through watery protein channels that penetrate all the way through the membrane.

(3) Through both.

Simple diffusion across the cell membrane:

A. Simple diffusion of lipid soluble substances through lipid bilayer

1. Lipid solubility:

Lipid soluble molecules as **O_2 and CO_2** diffuse through phospholipids bilayer. So, they cross the cell membranes easily.

The greater the lipid solubility of the substance, the greater the rate of diffusion.

- The molecular weight of O_2 is smaller than that of CO_2 (32 and 44 respectively), thus the diffusion rate of O_2 would be more rapid. However, since the **solubility coefficient of CO_2** is much higher than that of O2, **the diffusion rate of CO_2 is normally about 20 times more than that of O_2**.
- **Why CO_2 is more diffusible than O_2 through cell membrane inspite of its higher molecular weight?**

Due to its highest solubility coefficient (lipid solubility).

Diffusion Across Respiratory Membrane

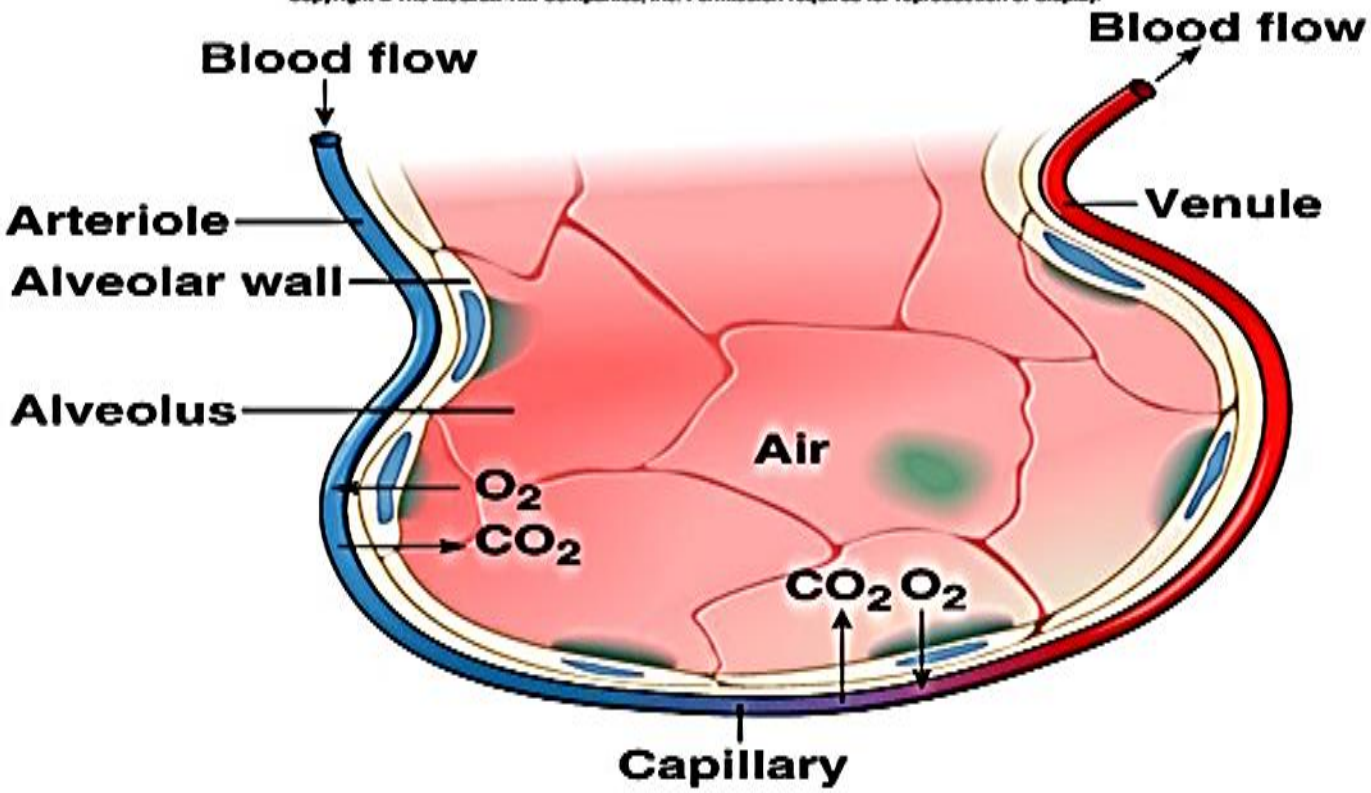
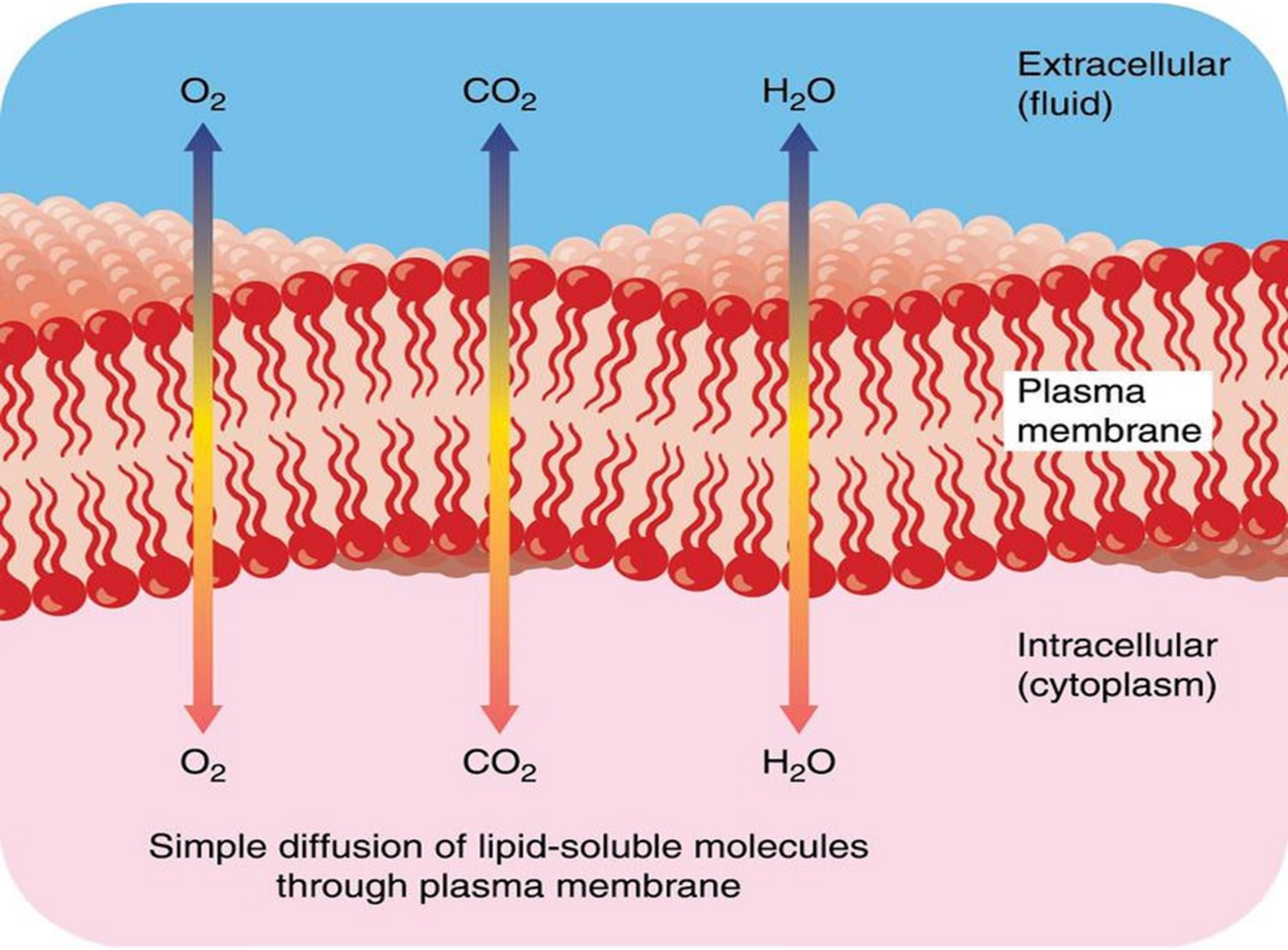


Figure from: Hole's Human A&P, 12th edition, 2010



Simple diffusion of lipid-soluble molecules through plasma membrane

B. Simple diffusion through protein channels:

The protein channels are distinguished by two important characteristics:

(1) They are often **selectively permeable** to certain substances,

(2) Some channels are continuously open (= leak channels) but Many of the **channels can be opened or closed by gates**.

(1) Selective Permeability of Protein Channels:

- ✓ Many of the protein channels are highly selective for transport of one or more specific ions or molecules.
- ✓ This results from the characteristics of the channel itself, such as its **diameter**, its **shape**, and **the nature of the electrical charges along its inside surfaces**.
- ✓ An example, one of the most important of the protein channels, **Sodium channel**. **The inner surfaces of this channel are strongly negatively charged**. These strong negative charges can pull small dehydrated sodium ions into these channels, actually pulling the sodium ions away from their hydrating water molecules. Thus, the **sodium channel is specifically selective for passage of sodium ions**.

- ✓ Conversely, another set of protein channels is selective for potassium transport, **Potassium channels**.
- ✓ These channels are **slightly smaller than the sodium channels** but they are **not negatively charged**. Therefore, no strong attractive force is pulling ions into the channels, and the potassium ions are not pulled away from the water molecules that hydrate them.
- ✓ **The hydrated form of the potassium ion is considerably smaller than the hydrated form of sodium** because the **sodium ion attracts far more water molecules than does potassium**. Therefore, the smaller hydrated potassium ions can pass easily through this small channel, whereas the larger hydrated sodium ions are rejected, thus providing **selective permeability for a specific ion**.

(2) Gating of protein channels:

It provides a means of controlling ion permeability of the channels.

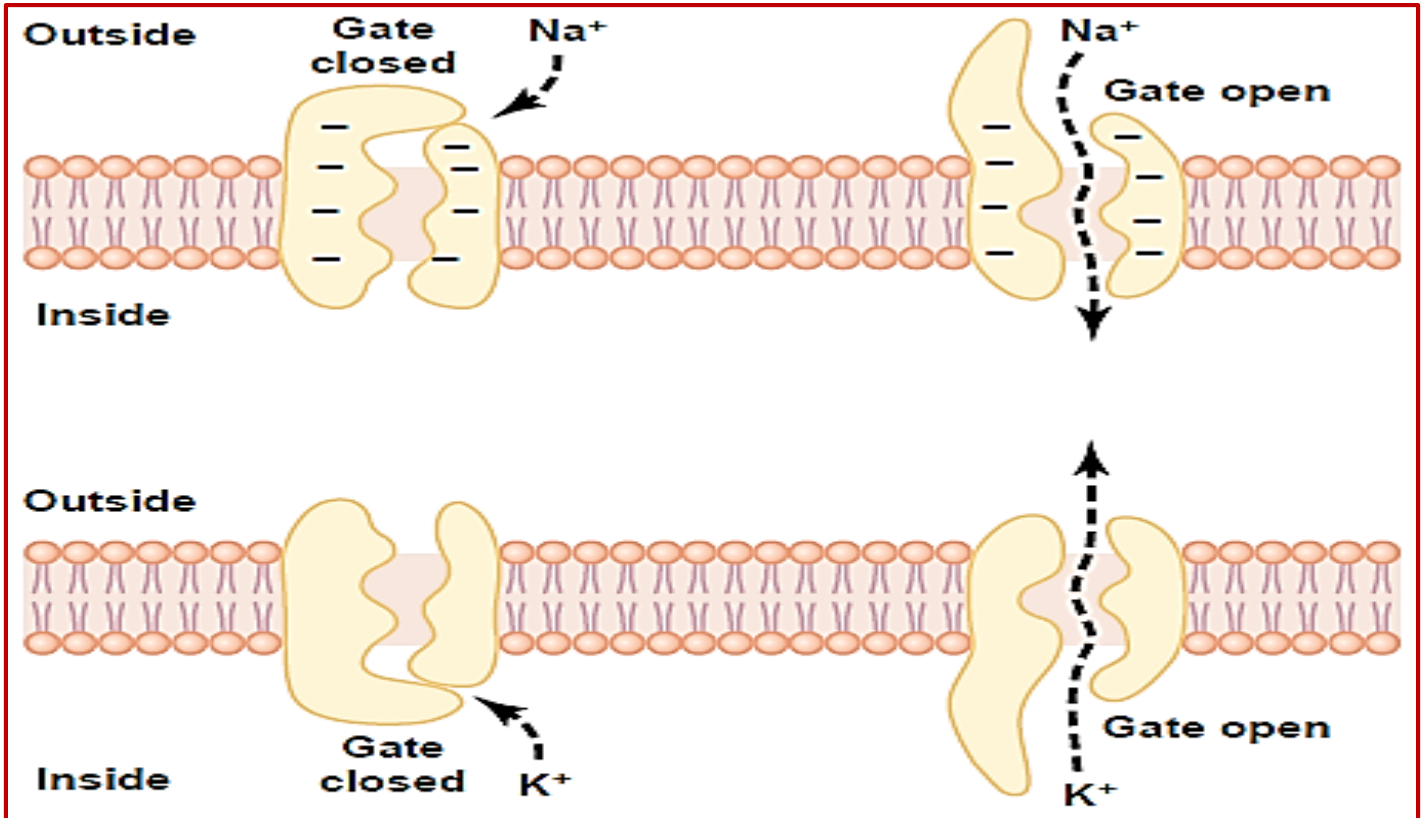


Figure 4–4

Transport of sodium and potassium ions through protein channels. Also shown are conformational changes in the protein molecules to open or close "gates" guarding the channels.

Diffusion of Water and Other Lipid-Insoluble Molecules Through Protein Channels:

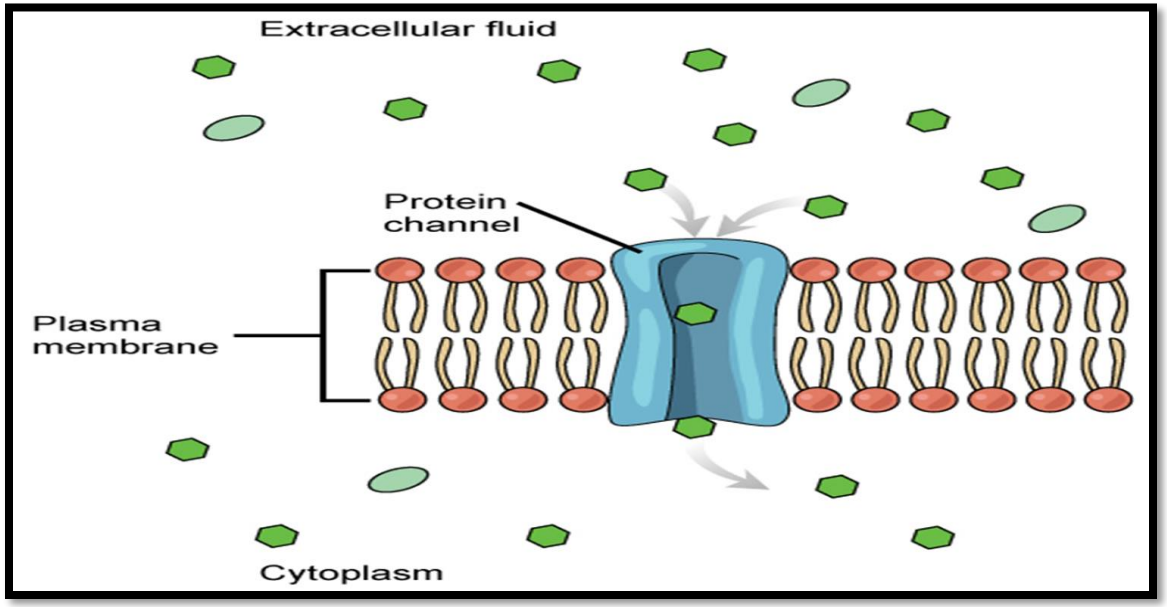
Water soluble molecules (as ions):

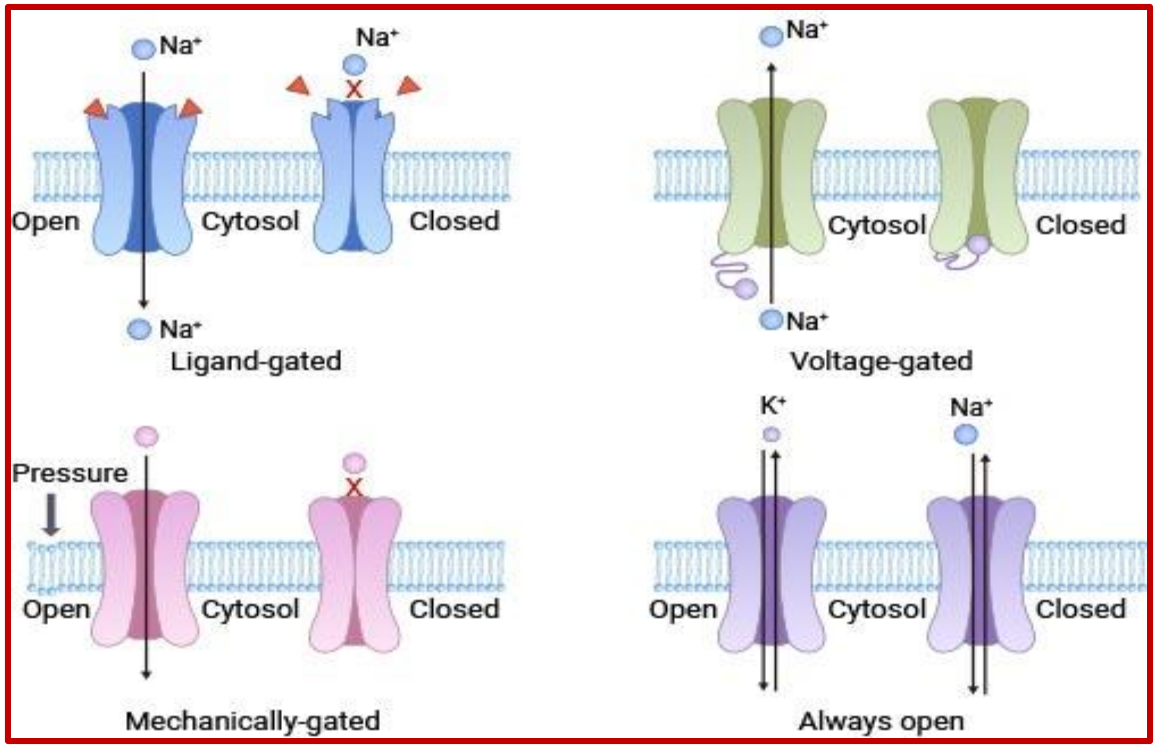
They can pass through trans-membrane protein channels depending on:

1. Molecular size of the diffusing molecule should be less than that of the channel diameter.

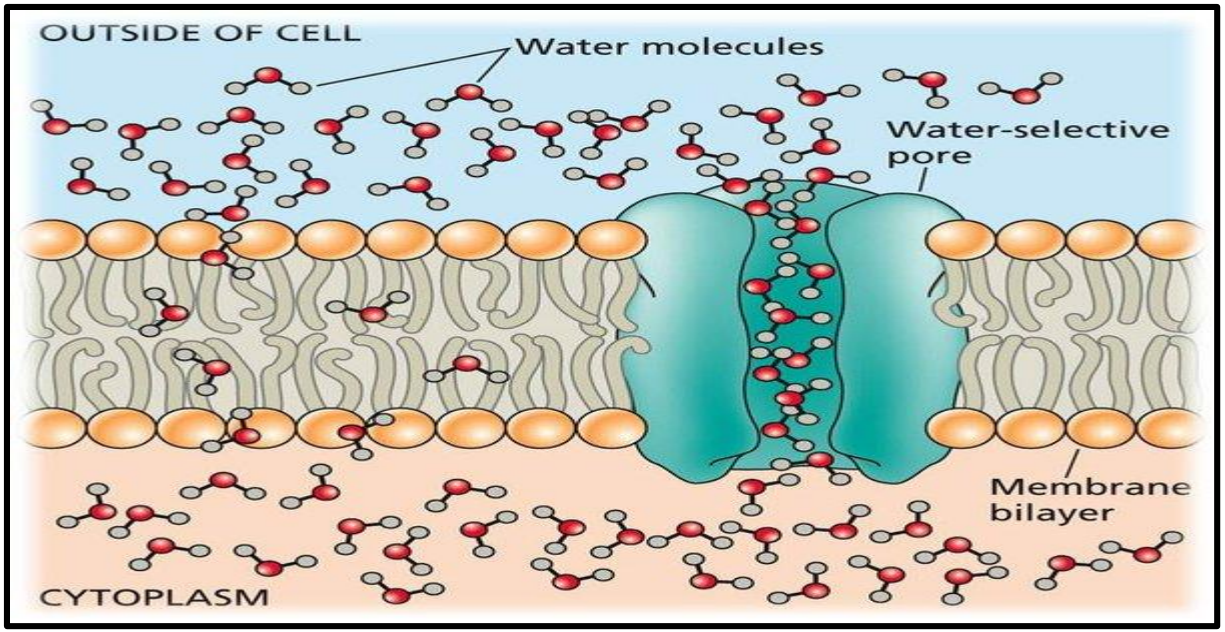
2. The electric charge on the channels. Opposite charges (attract) enhances diffusion while similar charges (repel) oppose diffusion.

3. The greater the hydration energy of the molecule, the thicker is the water jacket around and the slower is the diffusion rate.


Extracellular fluid
Protein channel
Plasma membrane
Cytoplasm


Na+
Na+
Open
Cytosol
Closed
Na+
Ligand-gated
Na+
Cytosol
Closed
Na+
Voltage-gated
Pressure
Open
Cytosol
Closed
Mechanically-gated
K+
Na+
Open
Cytosol
Closed
Always open

Water is the ONLY substance that can diffuse through phospholipid layer of the cell membrane (in addition to protein channels) due to its smaller molecular size and kinetic energy is very high.



2. FACILITATED DIFFUSION

- It occurs when the diffusing substance is:
- ✓ Lipid insoluble.
- ✓ Water soluble.
- ✓ Cannot pass by simple diffusion (through channels) due to **large molecular weight** as **glucose**.
- This mechanism of diffusion also moves substances **passively** in the direction of their **chemical or electrical gradients**, but it requires transport proteins called **carrier proteins** (so it is called **carrier-mediated diffusion**).
- The molecules of substances that diffuse by this mechanism (e.g. glucose and amino acids) bind to one of the carrier proteins. This causes **conformational change in the protein** which leads to movement of the bound molecule from one of the cell to the other i.e. the carrier protein facilitates diffusion of the substance to the other side.
- In many sites, facilitated diffusion is regulated by hormones e.g. insulin can increase the rate of glucose diffusion into the cells 10-20 fold.

Mechanism:

The substance (S) combines with a transmembrane protein carrier (C) on one surface forming a C-S complex → conformational change → C- S complex changes position to the opposite surface and the substance leaves the carrier → conformational change of the carrier again to return to original conformation to bind another molecule of (S) and the process is repeated.

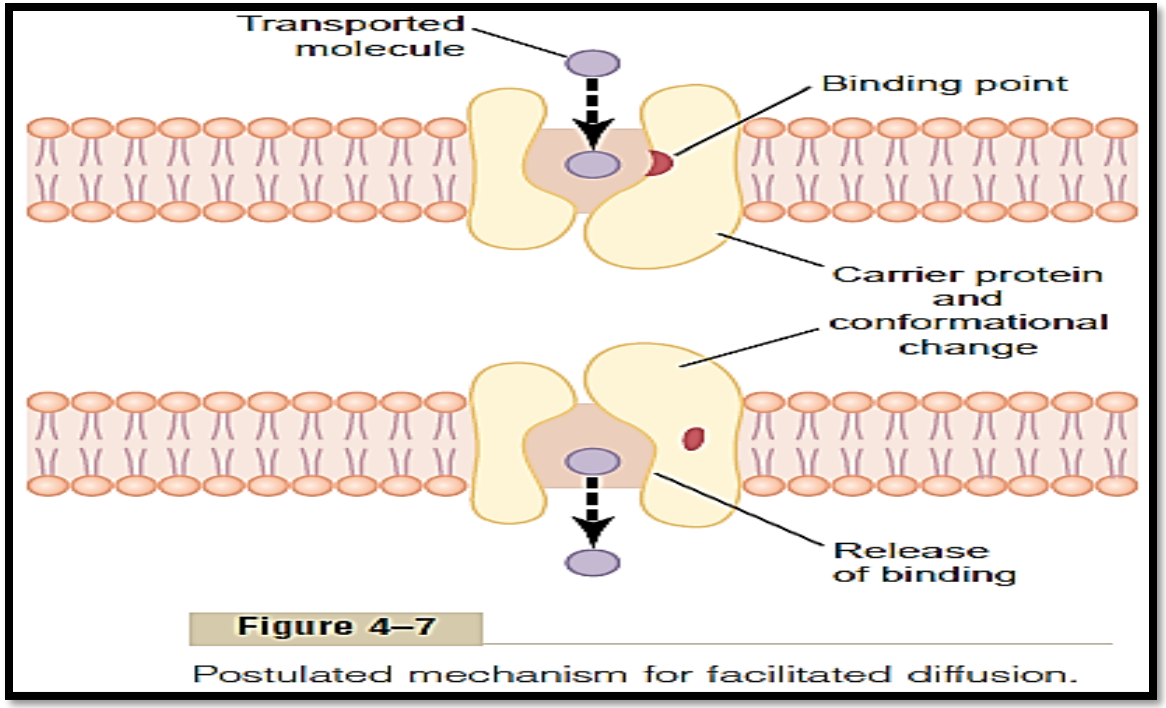


Figure 4–7

Postulated mechanism for facilitated diffusion.

Properties:

1- Energy (**ATP**) is not required as it is **passive** transport with **concentration gradient**.

2- Need **carrier** protein **(essential)** that aids passage of the molecules through the membrane by binding chemically with them and transporting them through the membrane in this form. e.g the carriers for glucose are called **transporters (GLUT)** and are regulated by insulin hormone. Monosaccharides that have similar structure to glucose as galactose compete for the same carrier and can inhibit the diffusion of glucose **(Competitive inhibition)**.

3- The rate of facilitated diffusion has a transport maximum that is determined by the number and activity of the carrier. As the substance concentration increases, the rate of absorption by facilitated diffusion will increase till it reaches a maximum, above which the rate of diffusion will not increase. This is due to **saturation of the carrier protein** which is limited per each cell **(Saturation property)**.

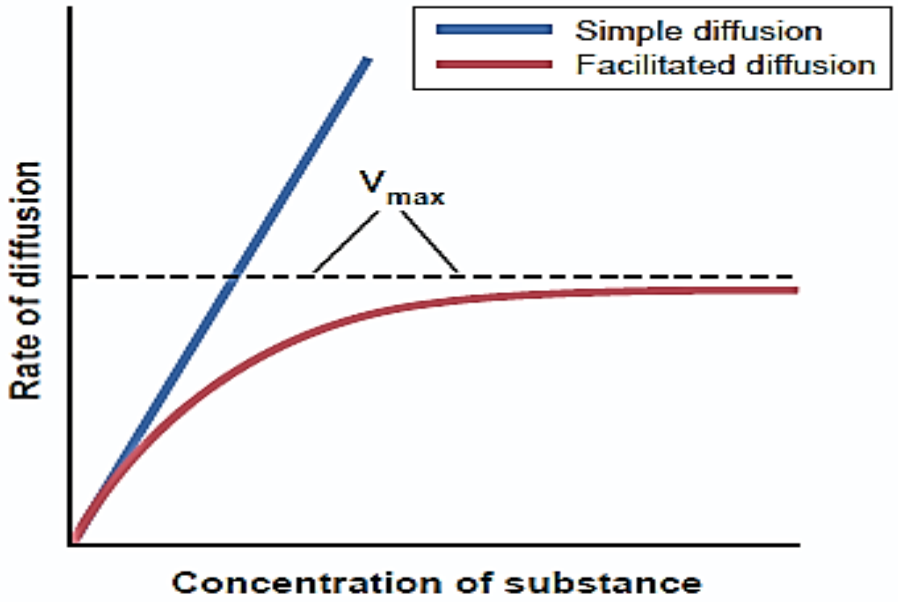
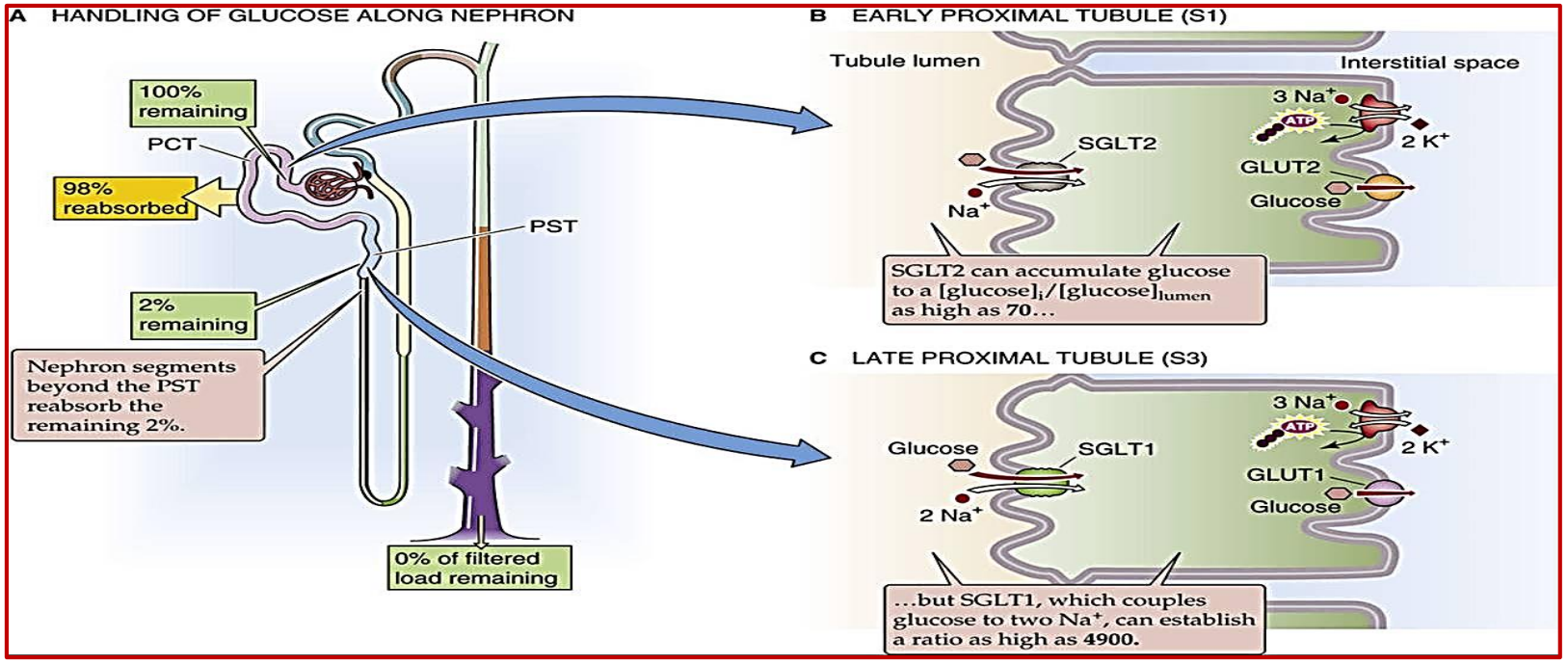
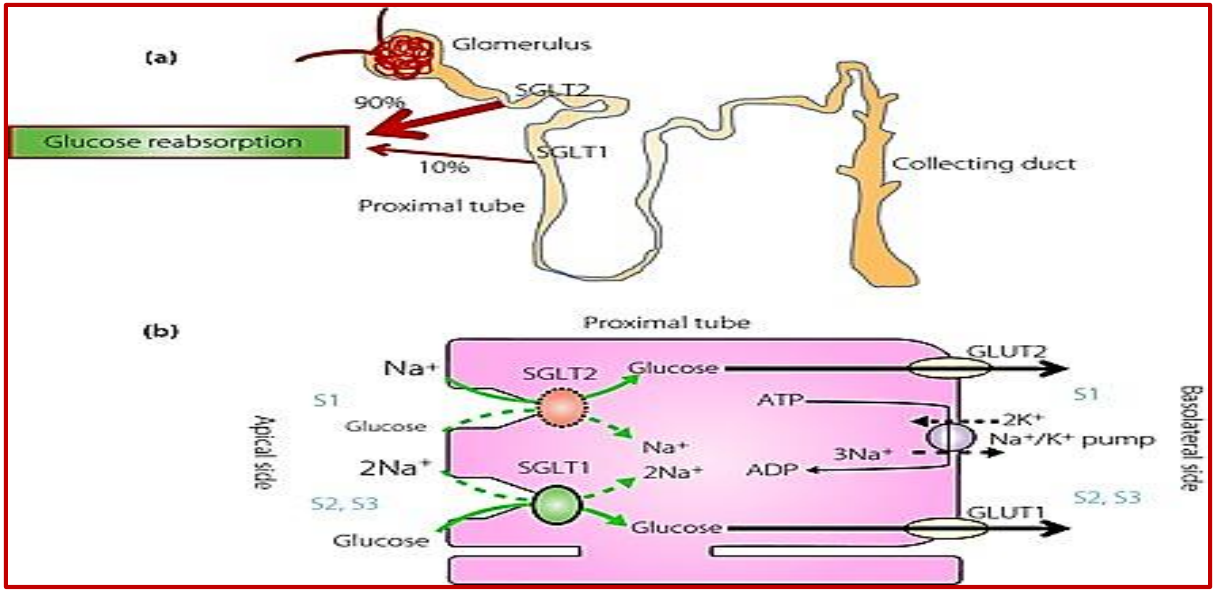
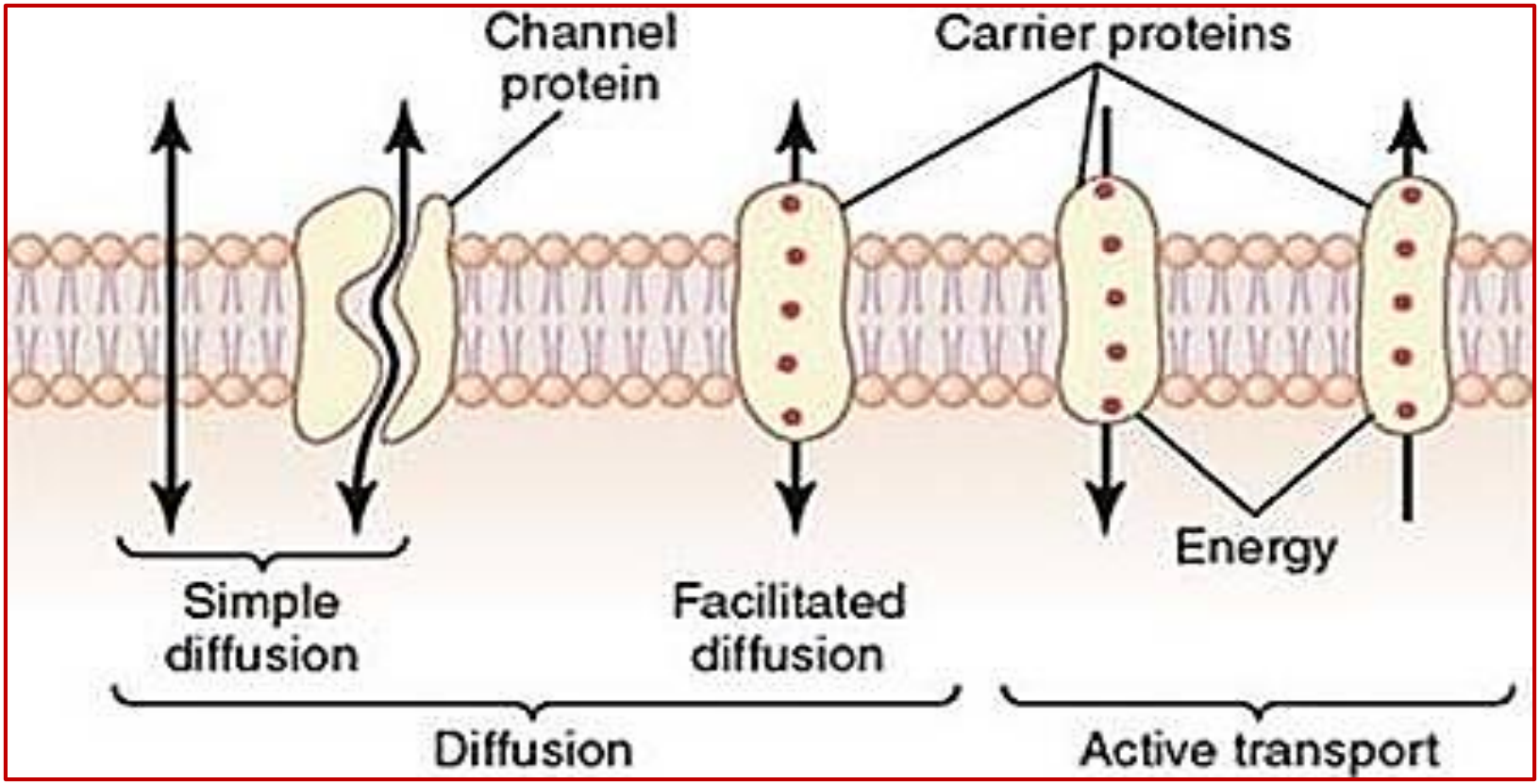


Figure 4–6

Effect of concentration of a substance on rate of diffusion through a membrane by simple diffusion and facilitated diffusion. This shows that facilitated diffusion approaches a maximum rate called the V_{max}.


A HANDLING OF GLUCOSE ALONG NEPHRON
100% remaining
PCT
98% reabsorbed
PST
2% remaining
Nephron segments beyond the PST reabsorb the remaining 2%.
0% of filtered load remaining
B EARLY PROXIMAL TUBULE (S1)
Tubule lumen
Interstitial space
3 Na+
ATP
2 K+
SGLT2
GLUT2
Glucose
Na+
SGLT2 can accumulate glucose to a [glucose]i/[glucose]lumen as high as 70…
C LATE PROXIMAL TUBULE (S3)
Glucose
SGLT1
3 Na+
ATP
2 K+
GLUT1
Glucose
2 Na+
…but SGLT1, which couples glucose to two Na+, can establish a ratio as high as 4900.


(a)
Glomerulus
SGLT2
90%
Glucose reabsorption
SGLT1
10%
Proximal tube
Collecting duct
(b)
Proximal tube
Na+
SGLT2
Glucose
GLUT2
S1
ATP
S1
Glucose
2K+
Na+/K+ pump
Na+
3Na+
2Na+
SGLT1
2Na+
ADP
Apical side
Basolateral side
S2, S3
S2, S3
GLUT1
Glucose
Glucose


Channel protein
Carrier proteins
Energy
Simple diffusion
Facilitated diffusion
Diffusion
Active transport

THANK YOU