Diffusion Through a Cell Membrane

# Introduction

Substances, such as water, ions, and molecules needed for cellular processes, can enter and leave cells by a passive process such as diffusion. Diffusion is random movement of molecules but has a net direction toward regions of lower concentration in order to reach an equilibrium.

Simple passive diffusion occurs when small molecules pass through the lipid bilayer of a cell membrane. Facilitated diffusion depends on carrier proteins imbedded in the membrane to allow specific substances to pass through, that might not be able to diffuse through the cell membrane.

# Importance

The rate of diffusion is affected by properties of the cell, the diffusing molecule, and the surrounding solution. We can use simple equations and graphs to examine how particular molecules and their concentration affect the rate of diffusion. We can also compare simple and facilitated diffusion.

# Questions

How do rates of simple and facilitated diffusion differ in response to a concentration gradient?

Simple Diffusion

# Variables

|  |  |
| --- | --- |
| n | number of molecules inside cell (mol) |
| t | time (seconds) |
| P | permeability constant for a particular molecule (cm/sec) |
| A | surface area of the cell membrane (cm2) |
| C | concentration of diffusing molecule (mol/cm3) |
| x | width of cell membrane (cm) |

# Methods

The rate of simple diffusion can be expressed by a modification of Fick's Law for small, nonpolar molecules. The rate of diffusion, dn/dt, is the change in the number of diffusing molecules inside the cell over time.

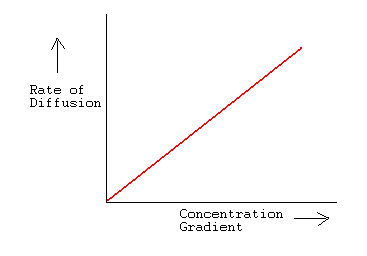
Since the net movement of diffusing molecules depends on the concentration gradient, the rate of diffusion is directly proportional to the concentration gradient (dC/dx) across the membrane. The concentration gradient, dC/dx, is the difference in molecule concentration inside and outside of the cell across a cell membrane of width dx. This is equivalent to (Cout - Cin)/x where Cout and Cin are the substrate concentrations inside and outside the cell, and x is the width of the cell membrane. When the concentration outside the cell (Cout) is larger than inside the cell (Cin), the concentration gradient (dC/dx) will be positive, and net movement will be into the cell (positive value of dn/dt).

We can describe the rate of diffusion as directly proportional to the concentration gradient by the following equation:

|  |  |
| --- | --- |
|  | LaTeX Code: \[ \frac{dn}{dt} = P \times A \times \Bigg( \frac{dC}{dx} \Bigg) \] |

where A is the membrane area and P is the permeability constant. P is a constant relating the ease of entry of a molecule into the cell depending on the molecule's size and lipid solubility.

Notice that when A and P are constants, this equation simply describes a line where dn/dt is a function of dC/dx. If we graph the rate of diffusion as a function of the concentration gradient, we get a simple linear function.



# Interpretation

Notice the rate of diffusion increases as the concentration gradient increases. If the concentration of molecules outside the cell is very high relative to the internal cell concentration, the rate of diffusion will also be high. If the internal and external concentrations are similar (low concentration gradient) the rate of diffusion will be low.

Facilitated Diffusion

# Variables

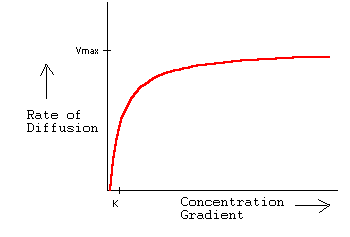
|  |  |
| --- | --- |
| n | number of molecules inside cell |
| t | time (seconds) |
| Vmax | saturation constant (mol/cm3/sec) |
| K | constant determining speed of saturation (mol/cm4) |
| C | concentration of diffusing molecule (mol/cm3) |
| x | width of cell membrane (cm) |

# Methods

Unlike simple diffusion, facilitated diffusion involves a limited number of carrier proteins. At low concentrations, molecules pass through the carrier proteins in a way similar to that of simple diffusion. At high solute concentrations, however, all the proteins are occupied with the diffusing molecules. Increasing the solute concentration further will not change the rate of diffusion. In other words, there is some maximum rate of diffusion (Vmax) when all the carrier pro teins are saturated. Therefore, we can not use a simple linear equation to describe the rate of diffusion. The rate of diffusion will increase with increasing solute concentration, but must asymptotically approach the saturation rate, Vmax. How quick ly the carrier proteins become saturated can be described by the variable K, the concentration gradient at which the rate of diffusion is 1/2 Vmax. K and Vmax depend on properties of the diffusing molecule, such as its permeability (P), as well as the surface area (A) of the cell, but for simplification we give the equation as:

|  |  |
| --- | --- |
|  | LaTeX Code: \[ \frac{dn}{dt} = \frac{V\_{Max}}{1 + K / ( \frac{dC}{dx} ) } \] |

We can graph this equation, dn/dt as a function of dC/dx, to see how the rate of diffusion changes with increasing solute concentration outside the cell.



# Interpretation

By graphing this equation, we see that at low concentrations of solute, the rate of diffusion into a cell occurs almost linearly, like simple diffusion. Notice that at low solute concentrations, the slope is much steeper than that of simple diffusion. Facilitated diffusion can increase the rate of diffusion of particular molecules at low concentrations. However, the rate of facilitated diffusion levels off with increasing solute concentration. Additional increases in external solute concentration cannot increase the rate of diffusion once carrier proteins are saturated.

# Conclusion

Passive diffusion of solute into a cell is linearly related to the concentration of solute outside the cell. Carrier proteins increase the rate of diffusion by allowing more solute to enter the cell. Facilitated diffusion, however, approaches a maximum rate as the carrier proteins become saturated with solute.

# Additional Questions

Simple Diffusion

1. We graphed dn/dt as a function of dC/dx. What is the slope of this line? What do increases or decreases in the slope mean biologically?

2. Now assume the concentration gradient is a constant. How does the rate of diffusion (dn/dt) change with the surface area (A) of the cell and the permeability (P) of the diffusing molecule? Graph dn/dt as a function of A or P and describe the function.

Facilitated diffusion

1. Look at the equation for facilitated diffusion and find the horizontal asymptote. What happens to dn/dt as dC/dx approaches infinity?

2. Try graphing this equation with different values for K. How does this change the concentration at which the carrier proteins are saturated?

3. Compare simple and facilitated diffusion of glucose into erythrocytes by graphing rate of diffusion (micromoles per hour) as a function of external glucose concentration (mmol/cm3). For facilitated diffusion, Vmax=500 micromoles per hour and K=1.5 mmol/cm3. For simple diffusion, A x P is 3 cm3/hour.

# Source

Darnell, J., H. Lodish, and D. Baltimore. 1986. *Molecular Cell Biology*. Scientific American Books, Inc., New York

LeFevre, P. G. 1961. Sugar transport in the red blood cell: Structure-activity relationships in substrates and antagonists. *Pharmacological Review 13*:39-70.

# About this Resource

This material was originally distributed as part of “Alternative Routes to Quantitative Literacy for the Life Sciences[[1]](#endnote-1)” - National Science Foundation Award DUE-9752339 to the University of Tennessee, Knoxville for August 1, 1998 - July 31, 2000. Principal Investigator: Louis J. Gross. Co-Principal Investigators: Beth C. Mullin and Susan E. Riechert.

This material is now being revised as part of the “Resources for Improving Quantitative Skills in Community College Biology[[2]](#endnote-2)” project. As part of that project is also aligned with the OpenStax Biology Textbook[[3]](#endnote-3).

It is published using the QUBES Open Education Resources publishing platform[[4]](#endnote-4).

1. http://www.tiem.utk.edu/~gross/bioed/ [↑](#endnote-ref-1)
2. https://qubeshub.org/community/groups/quantbioatcc/ [↑](#endnote-ref-2)
3. https://openstax.org/details/books/biology-2e [↑](#endnote-ref-3)
4. https://qubeshub.org/qubesresources/publications/1042/ [↑](#endnote-ref-4)