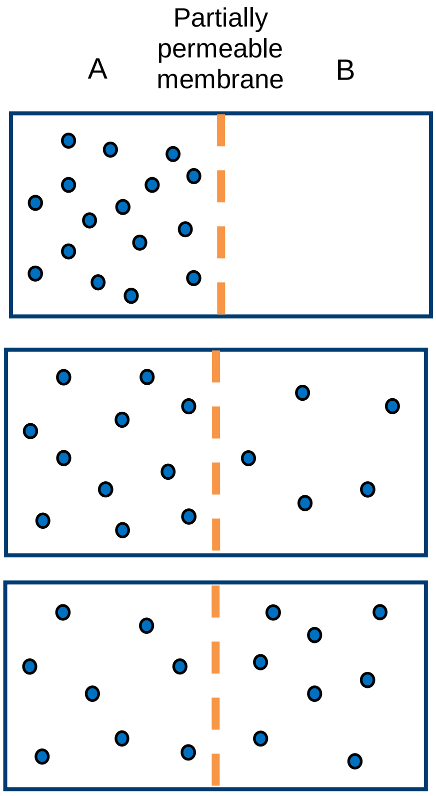
Rate of passive diffusion

The process of passive diffusion

Passive diffusion is a spontaneous reversible process. Solute particles diffuse through the membrane and back again until a position of dynamic equilibrium is reached and the concentration of solute on each side of the membrane is the same.



Aqueous solution separated from water by a partially permeable membrane. Initially, solute particles pass through the membrane from compartment A into compartment B, which contains water.

Solute particles that moved into compartment B move back into compartment A. However, since the rate depends on the concentration of solute, the rate from A to B is faster than B to A.

Eventually the concentration in both compartments is the same. Solute particles continue to move from A to B and from B to A, but now they do so at the same rate so the concentrations do not change. The system is in dynamic equilibrium.

Figure 1 The process of passive diffusion.

Thermodynamics explains why diffusion happens (see *Why passive diffusion happens – entropy considerations* and *Why passive diffusion happens – free energy considerations*). However, thermodynamics does not explain:

- the differences in rates of diffusion of different solute particles through a partially permeable membrane;
- the differences in rates of diffusion of a solute particle through different partially permeable membranes.

This is the kinetics of the process.

Kinetics

Different solutes diffuse through partially permeable membranes at different rates.

The rate of passive diffusion of molecules through a partially permeable membrane is temperature dependent and also depends on:

- the membrane's material, thickness and surface area available for diffusion;

- the size of solute molecules and their concentration difference either side of the membrane.

The situation is much the same for ionic solutes, but rate of diffusion is also affected by the need to have an electrically neutral solution either side of the membrane.

The rate of passive diffusion of solute particles through the membrane is first order. In other words, it is directly proportional to the concentration of the solute particles.

If the volumes of solution and water are the same on both sides of the membrane, it can be said that,

	Compartment A	Compartment B
Initial concentration of solute particles / mol dm^{-3}	a	0
Concentrations after time, *t* / mol dm^{-3}	$(a - x)$	x
Concentrations at equilibrium / mol dm^{-3}	0.5*a*	0.5*a*

At time t,

- the rate of diffusion from compartment A to compartment B is given by:

$$\left(\frac{\delta x}{\delta t}\right)_{A\ to\ B} = k(a-x)$$

- the rate of diffusion from compartment B to compartment is given by:

$$\left(\frac{\delta x}{\delta t}\right)_{B\ to\ A} = kx$$

where *k* = the rate constant (equal for forward and reverse diffusion)

So the overall rate of diffusion from A to B is given by

$$\left(\frac{\delta x}{\delta t}\right)_{overall} = k(a-x) - kx = k(a-2x)$$

Integration of this equation gives:

$t = -\frac{1}{2k}\ln(a-2x) + \ integration\ constant$

When *t* = 0, *x* = 0, therefore:

$$t = -\frac{1}{2k}ln(a-2x) + \frac{1}{2k}\ln{(a)}$$

$$t = \frac{1}{2k}\ln\left\{\frac{a}{(a-2x)}\right\}$$

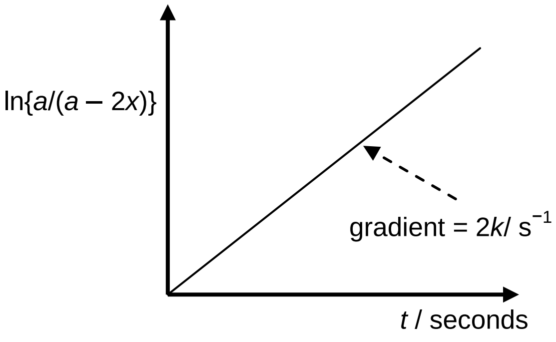


Figure 2 The rate constant, *k*, may be obtained from the gradient of this straight line graph.

This equation may be rearranged to give:

$$ln\left\{\frac{a}{(a-2x)}\right\} = 2kt$$

Finding out

A first order change has a specific half-life.

What is ‘half life’ and how might it be determined for the diffusion of a coloured molecular solute?