Why passive diffusion happens – free energy considerations

Spontaneous movement

Experimentally it can be shown that if equal volumes of water and an aqueous solution are separated by a partially permeable membrane, solute particles (molecules or ions) move through the membrane until their concentration is the same either side of it. This happens spontaneously. No energy is required.

It is a dynamic process. Solute particles move from the solution into the water. Some move back. Particles move to and fro until there are solutions of equal concentrations on both sides. A position of dynamic equilibrium is reached. This represents the greatest disorder and, therefore, the highest entropy that the system can have.

Click here to see an animation:

http://www.presentingscience.com/quantumcasino/simulations/entropyanddisorder.html

Gibbs free energy

Gibbs free energy, G, may be thought of as the energy available to do useful work that is stored in system. A change in free energy, ΔG, is related to the change in enthalpy, ΔH, and the change in entropy, ΔS, by the equation:

$$\Delta G = \Delta H - T\Delta S$$

(T is the temperature in Kelvin of the system)

For a change to be thermodynamically feasible, ΔG, must be less than zero.

Free energy and passive diffusion

For non-ionised molecular solutes the difference in the free energy of 1 mole of solute at concentration c_1 in one compartment to another compartment where its concentration is c_2 is given by:

$$\Delta G = RT ln \frac{c_1}{c_2}$$

where,

ΔG = difference in free energy (J mol^{-1})

R = the gas constant, 8.31 (J K^{-1} mol^{-1})

T = temperature (K)

c_1 = concentration of solute on one side of the membrane (mol dm^{-3})

c_2 = concentration of solute on the other side of the membrane (mol dm^{-3})

It can be seen from the equation that the difference in free energy depends on the magnitude of the concentration gradient. The larger the concentration difference, the greater the value for ΔG.

When the concentration is the same on both sides of the membrane, $c_1 = c_2$.

Therefore, $\Delta G = RT$ ln1

Since ln1 = 0

Then $\Delta G = 0$

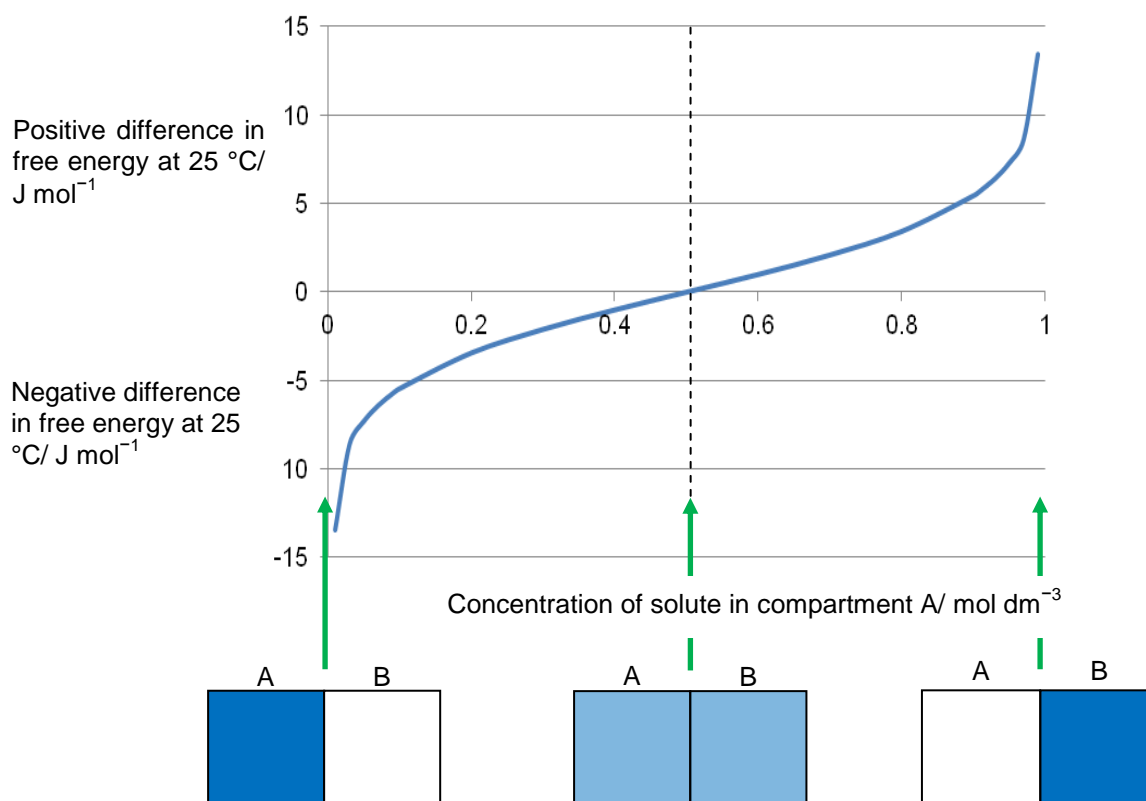Consider two compartments, A and B, separated by a partially permeable membrane:

Figure The difference in free energy of solute in compartment A and solute compartment B, where the compartments are separated by a partially permeable membrane. The free energy difference is lowest when the concentrations either side of the membrane are close to one another.

Charged solutes

For charged solutes, the equation becomes:

$$\Delta G = RT \ln \frac{C_1}{C_2} + zFE$$

where,

z = the charge on the solute particle

F = Faraday's constant

E = the potential difference between the solutions separated by the partially permeable membrane.

Finding out

How could you calculate the difference in entropy of two solutions separated by a partially permeable membrane?