Determination of the osmotic pressure of a sugar solution

Aims of the experiment

- To understand the principle of osmosis.
- To understand osmosis as a special case of diffusion.
- To understand transport processes in cells.
- To calculate osmotic pressure and hydrostatic pressure.

Principles

In solutions, all particles are constantly in motion. This is called “Brownian” molecular motion. When concentration gradients exist in solutions, they are compensated by particle motion. Based on Brownian molecular motion, no energy is required for it to take place, and what happens is passive mass transport. This spontaneous concentration equilibration which takes place within a specific space is called diffusion. This process depends on temperature, for example. The higher the temperature, the faster the particles move and the faster the compensation.

If two solutions of different concentrations spatially separated from one another by a permeable membrane, a directed concentration compensation will occur. This is a special case of diffusion, called osmosis. Osmosis comes from the Greek language and means penetration, impact, drive.

Direct concentration compensation takes place in such a way that water molecules migrate from the solution with the lower concentration in the direction of the higher-concentrated solution through a membrane. This membrane is only permeable for small molecules, such as water. Large molecules such as salt or sugar cannot diffuse through it and are held back. The membrane is therefore semi-permeable.

Based on the one-sided concentration compensation, a pressure forms in the cell with the concentrated solution, which is called osmotic pressure. The osmotic pressure is the equilibrium between the pressure of the water flowing in and the wall pressure of the cell. It is defined as:

$$p_{\text{osmotic}} = c \cdot R \cdot T$$

c is the concentration of material, R is the ideal gas constant (0.0831 (l·bar)/(mol·K)) and T is the temperature in Kelvin. Put another way, this process can also be seen as producing osmotic suction in which the water molecules are drawn by the concentrated solution.

In the more concentrated solution, hydrostatic pressure builds up against the membrane due to the migration of water molecules; this pressure is just a further measure of osmotic pressure and is defined as follows:

$$p_{\text{hydrostatic}} = \rho \cdot g \cdot h$$

Fig. 1 Set-up of the experiment

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ρ is the density of the solvent in kg/m^3, g is the gravitational acceleration (9.81 m/s^2) and h is the liquid height in m.

Every aqueous solution of a dissolved material can generate a certain osmotic pressure, and this depends on the concentration of the dissolved material. If equimolar solutions are present in the two cells, the same pressure is generated. This condition is called “isotonic” and is also in effect when the concentration compensation has taken place.

An example for osmosis can be observed in late summer when ripe pears burst open after a rain shower. The skin of the pear is a semipermeable membrane and inside of it the sugar concentration is very high. The water from the raindrops migrates into the interior of the cell in order to compensate for a concentration difference. The pear cannot expand indefinitely, however, and it bursts.

In this experiment, the osmotic pressure of two saccharose solutions of different concentrations will be observed relative to water using an osmotic chamber.

Risk assessment

The chemicals used in the experiment do not present any danger.

Equipment and chemicals

1 Osmosis apparatus, large 662 403
1 Scale for large osmosis apparatus.....667 501
2 Beakers, DURAN, 400 ml, tall.....664 114
1 Measuring cylinder, 250 ml, with plastic base...665 755
1 Electronic balance 440-3N, 200 g : 0.01 g 667 7977
1 Dropping pipette, 150 x 7 mm, set of 10 .....665 953
1 Rubber bulbs, 10 pcs. 665 954
1 Experimental pan.....666 6221
1 D(+) Saccharose, 250 g.....674 6060

Set-up and preparation of the experiment

Set-up of the apparatus

1. The apparatus is set up as can be seen in Fig. 1.

2. To do so, screw on one knurled nut onto each of the four threaded rods.

3. Insert the four threaded rods through the openings provided for them in a lateral support frame such that the knurled nuts are on the outside.

4. Place an osmosis chamber on the support frame. Then add a gasket ring, a semipermeable membrane and the second osmosis chamber.

Note: Make sure that both openings of the osmosis chambers are pointing in the same direction.

5. Fix the apparatus with a second support frame, and finally screw four knurled nuts on from the other side.

6. Insert the capillary tube into the stopper and fasten the osmosis apparatus scale to one of the two.

7. Place the experimental pan under the osmosis apparatus.

Preparation of the experiment

1. For the experiment, prepare a 0.1 molar and a 0.2 molar saccharose solution.

2. Prepare 250 ml of both solutions since the osmosis chamber holds approximately 150 ml.

3. The calculation of the input weights is done as follows:

$$m(\text{saccharose}) = \frac{V(solution) \cdot c(solution)}{M(\text{saccharose})}$$

The calculated input weights are shown in Table 1. Here: M (saccharose) = 342.3 g/mol.

Tab. 1 Input weights of saccharose solutions

	Solution 1	Solution 2
c (saccharose)	0.1 mol/l	0.2 mol/l
Input weight	8.5 g	17 g

4. The input weight is taken directly into the beakers.

5. Measure 250 ml of water with the measuring cylinder and add to the weighed in amounts, then dissolve the saccharose by stirring.

Performing the experiment

1. Fill one of the two chambers with water, no bubbles, up to the upper edge. Use the dropping pipette to help.

2. In the same manner, fill the 0.1 molar saccharose solution (solution 1) into the second chamber.

3. Insert the two capillary tubes with stoppers into the two holes. Fasten the capillary tube with the scale to the chamber with the saccharose solution.

4. Using the scale, now record the fill level for time t = 0.

Note: It does not matter where the liquid level starts after attaching the glass tube.

5. Repeat this procedure every 5 minutes over 30 - 40 minutes. This will allow the osmotic exchange to be monitored.

6. Proceed in exactly the same way with the 0.2 molar solution 2.

Observation

Over a period of 30 - 40 minutes, an increase in the liquid in the capillary tube through the saccharose solution can be observed.

Evaluation

The temporal progress of osmosis

The values recorded in the experiment are listed in Table 2.

Tab. 2 Observed liquid level values.

	Solution 1	Solution 2
***t* / min**	**Height / cm**	
0	10.5	2.7
5	10.7	3.2
10	11.0	3.8
15	11.3	4.3
20	11.5	4.8
25	11.7	5.0
30	12.2	5.3
35	12.8	5.7
40	13.1	6.5

The value for the height at time t = 0 is subtracted from all other values. The net values after deducting the value are listed in Table 3, and are plotted in Figure 2 against time in a graph in order to illustrate the increase in osmotic pressure.

The liquid climbs in both solutions. This happens because water is flowing through the semipermeable membrane into the sugar solution. Due to the flow of water, the liquid level increases in the standpipe, which can be read off. In comparing the two curves (Fig. 2) for the 0.1 and the 0.2 molar-saccharose solutions, it can be seen that the liquid level in

Tab. 3 Change in liquid level over time.

	Solution 1	Solution 2
***t* / min**	**Height / cm**	
0	0	0
5	0.2	0.5
10	0.5	1.1
15	0.8	1.6
20	1	2.1
25	1.2	2.3
30	1.7	2.6
35	2.3	3.0
40	2.6	3.8

the more concentrated solution increases more significantly. The 0.2 molar saccharose solution has higher osmotic pressure. Here, more water molecules are required in order to achieve a concentration compensation between the two chambers.

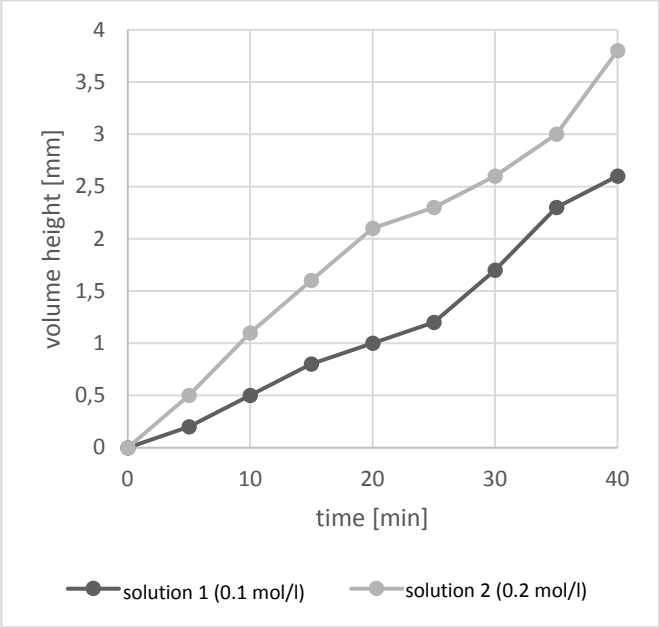

Fig. 2 Comparison of diffusion in saccharose solutions.

The osmotic pressure of the solutions

Using the formulas for osmotic pressure and hydrostatic pressure, the extent to which the liquid column could increase can be calculated until equilibrium is established.

Theoretically, the experiment can be run until the liquid level no longer increases, i.e. until equilibrium has been established. At this point, the hydrostatic pressure of the water column and the osmotic pressure are equal to each other.

The osmotic pressure of the liquid can also be calculated using the following formula:

$$p_{\text{osmotic}} = c \cdot R \cdot T$$

For *R,* it is the same for both at 0.0831 (l*bar)/(mol*K) and at a room temperature of 25 °C *T* = 298 K. All values are put in into the formula for osmotic pressure and the values can be found in Table 4.

Beginning with the osmotic pressure, the height that the liquid level would have to increase in order for it to equal the hydrostatic pressure can now be calculated.

$$p_{\text{hydrostatic}} = \rho \cdot g \cdot h$$

In the process, the pressures must be converted to Pascals or N/m^2. Here: 1 bar equals 100,000 Pa or N/m^2. The density for water is assumed to be 1,000 kg/m^3 and the acceleration due to gravity is 9.81 m/s^2.

Now, the values from Tab. 4 can be multiplied by 100,000 N/m^2 and entered for the hydrostatic pressure, and in this way *h* can be calculated. The results are likewise given in Table 4.

Tab. 4 Molar concentration of saccharose solutions and results for the osmotic pressure, as well as the theoretical liquid level.

	Solution 1	Solution 2
c	0.1 mol/l	0.2 mol/l
$p_{\text{osmotisch}}$	2.48 bar	4.96 bar
h	25.3 m	50.6 m

Results

In this experiment, the osmotic pressure of two saccharose solutions of different concentrations was investigated. They were compared in an osmotic chamber with water. What was shown was that over time the liquid in the standpipe for the chamber with the saccharose solution increases (see Fig. 2). At both concentrations, the volumetric height in the standpipe rose considerably. This effect is much clearer in the more concentrated solution.

The volumetric height would increase in order to equilibrate between the osmotic and the hydrostatic pressure. This would be the case, as listed in Table 4, at 25 and 50 m, respectively. The experiment is therefore stopped before that.

The difference between different molar concentrations and the rate of equilibration and the different height difference after the same period of time can be clearly demonstrated.

Cleaning and disposal

Excess saccharose solutions can be disposed of in the laboratory drain or can be kept in suitable bottles for further experiments. The solutions in the osmosis chamber can also be disposed of in the lab drain.