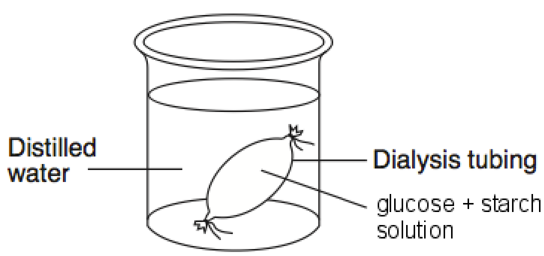
Diffusion, Osmosis and Active Transport

Part A: Diffusion

A living cell interacts constantly with the environmental medium that surrounds it. The plasma membrane surrounding a cell is a living, selectively permeable structure. It helps to regulate which materials enter and leave the cell. **Diffusion** is the random movement of molecules from an area of higher concentration of those molecules to an area of lower concentration. For example, if you were to open a bag of delicious popcorn in one corner of a room, it would not be long before someone in the opposite corner would detect the smell of popcorn. The bag contains a higher concentration of popcorn smell molecules than the room does and, therefore, those molecules diffuse from the area of higher concentration to the area of lower concentration. Eventually a dynamic equilibrium will be reached; the concentration of popcorn smell molecules will be approximately equal throughout the room and no *net* movement of those molecules will occur from one area to the other, even though the random molecular motion of those molecules continues.

Small solute molecules and water molecules can move freely through a selectively permeable membrane, but larger molecules will pass through more slowly or not at all. In medicine, the movement of a solute through a selectively permeable membrane is called **dialysis.** The size of the minute pores in dialysis tubing determines which substances can pass through the membrane. By detecting the presence of particular molecules on each side of a piece of dialysis tubing, we can determine which molecules passed through the tubing and which did not.

Figure 1



Imagine that a solution of glucose and starch is placed inside a bag made of dialysis tubing (See Figure 1). Distilled water is placed in a beaker, outside the dialysis bag. Iodine is added to the water in the beaker until it is a faint yellow color. The solutions in the bag and beaker were subjected to the Lugol and Clinitest tests (Initial Color) and then again after 20 minutes (Final Color).

Q. 1 Make a prediction about the movement of glucose and starch.

Q. 2 How could the presence of glucose and starch in the water be detected?

The results are given in Table 1.

Table 1 Initial and final results of Lugol and Clinitest tests on contents of bag and beaker

Initial Contents		Lugol test		Clinitest	
		Initial Color	Final Color	Initial Color	Final Color
Bag	15% glucose/1% starch	purple	purple	orange	orange
Beaker	H_2O + IKI	yellow	yellow	blue	green

Note: Initial means before the 20 minutes; final means after the 20 minutes.

Q. 3 Describe the Lugol test for starch and the use of Clinitest tablets for detecting glucose. (Iodine turns purple or blue in the presence of starch. A blue Clinitest result is negative for reducing sugars, green and orange are positive.)

Q. 4 What do the results tell us about the movement of glucose and starch? (****** Students should recognize that iodine can enter the bag from the surrounding solution but starch is unable to leave the bag. In procedure A, there should be no positive result for starch outside the bag, showing that starch is unable to pass through the membrane. In some cases, failure to properly rinse the bag might result in a small amount of contamination and give a faint positive result.)

Q. 5 Is the membrane selectively permeable? Explain. (The membrane is selectively permeable because it allows iodine to cross but not starch.)

Q. 6 Suppose that a second dialysis bag filled with a 5% starch solution is placed in a beaker filled with a 10% starch solution. Describe the direction of movement of starch and water. (The solution in the tube is hypotonic so water would move from the tube into the surrounding solution, causing the bag to shrink.)

Q. 7 A single starch molecule may have thousands of atoms, a glucose molecule has 24, and the ions of dissolved salt are the size of single atoms. Each of these is placed in a separate dialysis bag suspended in water. State what would happen to each and predict the rate of diffusion in each case. (The rate of diffusion is inversely proportional to the particle size. Salt will diffuse most quickly, glucose less quickly, and starch will diffuse the most slowly, but is too large to pass through the membrane.)

Q. 8 Starch is a source of glucose molecules which cells can use for energy. Why is the chemical digestion of starch necessary for cells to be able to use it? (Starch molecules are too big to pass through the membranes of cells lining the small intestine. They must be digested into much smaller molecules (like glucose) in order to be absorbed.)

Q. 9 Does this investigation show that starch molecules cannot move across living cell membranes? Explain. (No. This investigation used a non-living membrane so we cannot apply the results to living membranes.)

Part B: Osmosis

Both the cytoplasm of a cell and its external environmental medium consist mainly of water. The plasma membrane is permeable to water. Water will diffuse through membranes in a process called **osmosis**. Osmosis is the diffusion of water through a selectively permeable membrane (a membrane that allows for diffusion of certain solutes and water) from a region of higher water potential (*i.e.*, low [solute]) to a region of lower water potential (*i.e.,* high [solute]). Water potential is the measure of free energy of water in a solution.

When two solutions have the same concentration of solutes, they are said to be **isotonic** to each other. If the two solutions are separated by a selectively permeable membrane, water will move between the two solutions, but there will be no **net** change in the amount of water in either solution. If two solutions differ in the concentration of solutes that each has, the one with more solute (less water) is **hypertonic** to the one with less solute. The solution that has less solute is **hypotonic** to the one with more solute. These words can only be used to compare solutions. Remember that the two solutions could be the cytosol and the extracellular fluid.

Now consider two solutions separated by a selectively permeable membrane. The solution that is hypertonic to the other must have more solute and therefore less water. The water potential of the hypertonic solution is less than the water potential of the hypotonic solution, so the **net** movement of water will be from the hypotonic solution into the hypertonic solution.

Imagine that six dialysis tubing bags are prepared and filled with: distilled water, 0.2 M sucrose, 0.4 M sucrose, 0.6 M sucrose, 0.8 M sucrose, and 1.0 M sucrose. The initial mass of each bag is recorded in Table 2. The bags are placed in six separate beakers of distilled H_2O and left for 30 minutes. Afterward, the final mass of each bag is determined and recorded in Table 2.

Table 2 Initial and final mass of dialysis bags.

Contents of Dialysis Bag	Mass (Initial)	Mass (Final)	ΔMass	Percent Change in Mass*
a) distilled water	28.0	28.0	0	0
b) 0.2 M	26.9	28.5	1.6	6.0
c) 0.4 M	27.0	29.4	2.4	8.9
d) 0.6 M	28.4	32.6	4.2	14.8
e) 0.8 M	28.2	32.0	3.8	13.5
f) 1.0 M	29.9	34.8	4.9	16.4

*To calculate: Percent Change in Mass = [Final Mass - Initial Mass x 100]/ Initial Mass

Q. 10 Graph the percent change in mass versus sucrose concentration.

Q. 11 Explain the relationship between the change in mass and the molarity of sucrose within the dialysis bag. (The percent change in mass increases directly with an increase in the molarity of the sucrose solution. Water moves from a place of lower solute concentration to a place of greater solute concentration. The higher the concentration of solute in dialysis tubing, the more water moves into the tubing in the time period allowed. (Remember that this is net movement.) Water moves from a place of greater water potential to a place of lesser water potential. As the concentration of solute increases in a solution, the water potential will decrease accordingly.)

Q. 12 Pieces of zucchini were placed in sucrose solutions at 22°C for 24 hours and the % change in mass was recorded. The results are shown below:

Table 3: Change in mass of zucchini slices place in sucrose.

Sucrose concentration (M)	% change in mass
0 (distilled water)	20
0.2	10
0.4	-3
0.6	-17
0.8	-25
1.0	-30

Graph the results to find the molar concentration of solutes within the zucchini cells. (The concentration should be read from the graph at the point where the curve crosses the x-axis. (Approximately .36 with this data.))

A series of three microscope slides is prepared as shown in Table 4. A drop of blood is added to each and the red blood cells are observed.

Table 4: Red blood cells and saline solutions

	Solution	Appearance of Red blood cells
Tube 1	3% NaCl	Shrivelled
Tube 2	0.9% NaCl	Biconcave disks
Tube 3	Distilled water	Swollen

Q. 13 Identify the solution in each tube as hypertonic, hypotonic, or isotonic. Justify your answers. (The 3% solution is hypertonic. We know this because the cells in this solution shrivelled as water moved out of them by osmosis. The distilled water was hypotonic. We know this because the cells swelled (and maybe lysed) as water entered them by osmosis. This solution is isotonic to the cells so there should be no noticeable difference. Water molecules would move into and out of the cells at the same rate.)

Q. 14 a) Why is the homeostasis of blood plasma osmolarity important? (Red blood cells must be isotonic to plasma, otherwise they would gain or lose water.)
b) From these data, what can we conclude about the concentration of NaCl in blood plasma? (The data suggest the [NaCl] is 0.9%.)

Q. 15 You have been given three glucose solutions of unknown concentrations and some slices of potato.
a) Design a protocol to enable you to rank the solutions in order from least concentrated to most concentrated. In your protocol you must identify

- a hypothesis
- the independent variable
- the dependent variable
- two variables you will control
- an appropriate control group
- expected results (The potato slices became flaccid as water moves from their cells into the surrounding solution by osmosis. Some slices may have become turgid if they were placed in hypotonic solution as water entered their cells from the surrounding solution.)

b) How did the results enable you to determine the relative concentration of each solution? (The solutions can be placed in order by comparing the degree of flaccidness or turgidity of the potato slices. The most flaccid potato is the one in the most concentrated solution. The most turgid is the one in the least concentrated solution.)

Imagine a carrot is 60% water and 40% solutes. Carrot A is placed in distilled water while carrot B is placed in a solution of 50% solutes.

Q. 16 Predict the effects on each carrot. (Carrot A will become turgid as water enters the cells by osmosis. Carrot B will become flaccid as water leaves the cells by osmosis.)

Q. 17 a) With particular reference to individual cells, describe what would happen to a marine jellyfish placed in a freshwater lake. (The lake water would be hypotonic to the organism so the cells would gain water and possibly lyse. The jellyfish would likely die as it is not adapted to a freshwater environment.)
b) A marine algae (seaweed) is placed in a freshwater lake and the cells are then examined under a microscope. Contrary to the jellyfish, no cells have lysed. Suggest an explanation. (As the algal cells gain water from the hypotonic lake, the cell wall prevents them from lysing.)
c) You planned on bringing some grapes to friend's house for a study party, however the grapes were bought a little early and you noticed they are now wrinkly instead of plump. What could you do to solve this problem and still serve the same grapes? (You could soak the grapes in tap water, a hypotonic

solution. This would cause water to move into the grape cells and restore turgidity.)

Part C: Active Transport

Many unicellular and simple multicellular organisms lack special excretory mechanisms. Harmful metabolic by-products simply diffuse directly across their cell membranes into the surrounding water environment. A number of protists have a specialized excretory device called a contractile vacuole. Protists with contractile vacuoles usually live in water that is hypotonic to their cytoplasm. While contractile vacuoles may excrete some metabolic by-products such as nitrogenous wastes, their primary function is to rid the organism of excess water.

One such protest is the paramecium, which has two contractile vacuoles. The vacuoles gradually enlarge as water enters and they eventually contract, ejecting their contents into the extracellular environment. This process requires energy.

Q. 18 Why are contractile vacuoles necessary? (Water from the hypotonic environment diffuses into the organism.)

Q. 19 Very low concentrations of cyanide cause a rapid decrease in the rate of contraction in contractile vacuoles. Explain the effect of exposure of a paramecium to cyanide. (The paramecium would swell and possibly lyse as it would be less able to expel water that enters by osmosis.)

Q. 20 Some protists living in salt water also have contractile vacuoles but the rate of contraction of their vacuoles is very slow (maybe 3 times per hour). Predict the effect on the rate of contraction by completing Table 5 below.

Table 5: Rate of contraction of vacuole with increasing osmolarity of surrounding fluid.

Osmolarity of solution	Relative rate of contraction of vacuole
1000 (sea water)	
200 (a freshwater lake)	
0 (distilled water)	

Some molecules must be moved into or out of cells from a low concentration to a high concentration. This requires active transport, which uses the energy in ATP to transport molecules across a membrane against a concentration gradient. In an experiment, students expose both living yeasts cells and cells killed by boiling to a dye called congo red. They notice that the boiled cells quickly become red inside while living cells never become red.

Q. 21 Suggest an explanation for their observation. (Congo red diffuses into cells. Living cells are able to remove congo red by active transport while dead cells are not.)