Investigation into the effect of osmosis on potatoes

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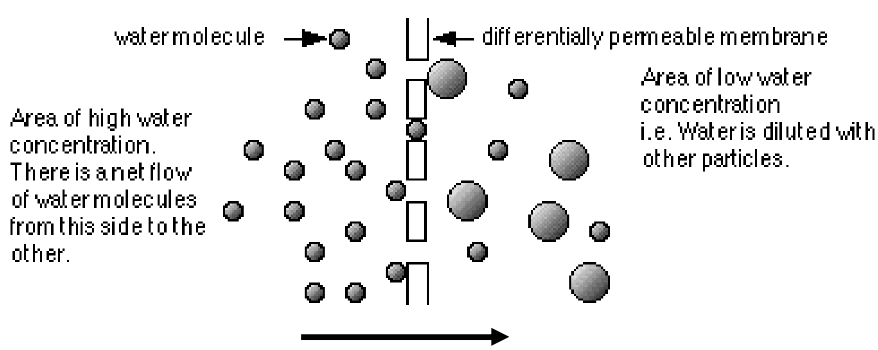
Background

Osmosis is a specialised form of diffusion where water molecules from a higher water concentration (hypotonic) diffuse through a partially permeable membrane to a lower water concentration (hypertonic).

When a substance dissolves in water to form a solution that substance attracts water molecules therefore reducing the number of free water molecules in a solution which in effect reduces the concentration. Free water molecules can travel faster through partially permeable membranes than larger molecules of other substances that have a cloud of water molecules surrounding due to their smaller size

Therefore when there are two solutions either side of a partially permeable membrane with a hypotonic solution on one side and a hypertonic solution on the other side the greater number of free water molecules in the hypotonic solution will move through the membrane faster than the higher number of large solute molecules with their water molecules surrounding them in the hypertonic solution and as there are less free water molecules in the hypertonic solution which are also moving more slowly, than those in the hypotonic solution due to the increased level of solute molecules, there will be a higher rate of movement of free water molecules from the hypotonic solution to the hypertonic solution and so the water concentration in the hypotonic solution will begin to decrease while the hypertonic solution's water concentration will increase until there is an equilibrium and the movement from either side to the other side is equal and then the water concentration on either side will not change unless more solute is added to either solution.

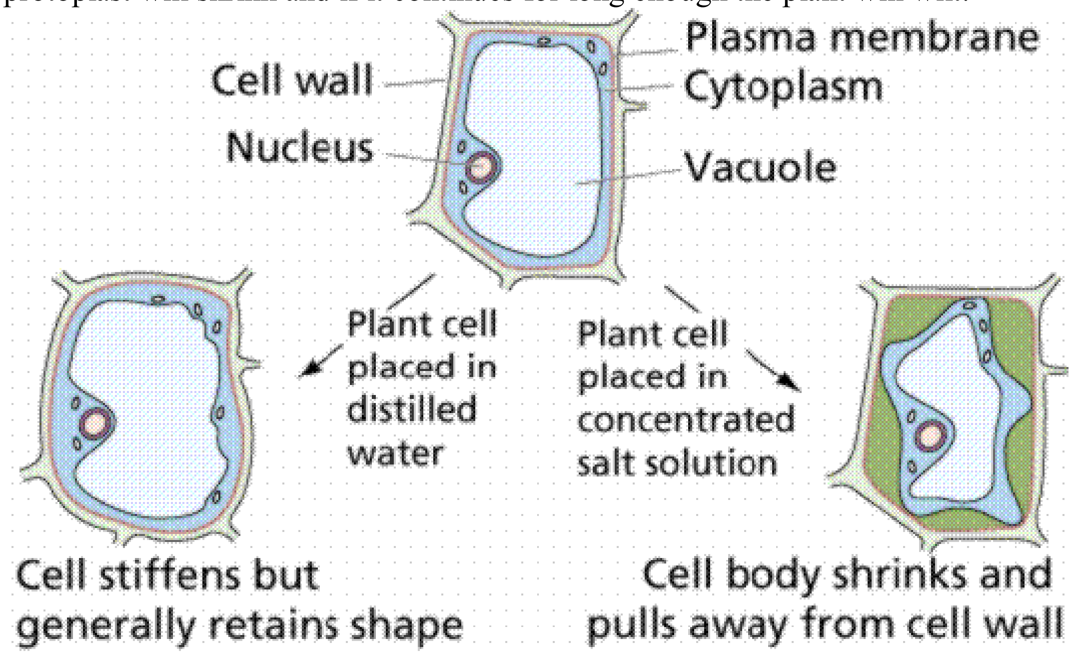


Net Flow of Water

Osmosis is a very important process in a living organism, where the cell membrane is an organic partially permeable membrane, because of the need for the distribution of water as substances in the cytoplasm of a cell must be kept at a specific concentration for many body processes to take place successfully.

As well as moving down concentration gradients water in osmosis moves across pressure gradients as well as many other gradients including temperature and entropy gradients and these gradients come under water potential which is the driving force behind osmosis and so it can be described as the ability of water to move. Water potential is the chemical potential of water and it is a measure of the energy available for movement of water molecules in aqueous solutions. Water always moves from a solution with a high water potential to a solution with a low water potential.

In plant cells when water diffuses into the cell the protoplast expands and pushes against the cell wall until it takes up the maximum space it can without the cell wall moving. The cell can then be described as turgid and the turgor pressure is the pressure the protoplast exerts on the cell wall when the cell is turgid. If the opposite happens and water diffuses out of a plant cell the cell becomes plasmolysed and flaccid as the protoplast will shrink and if it continues for long enough the plant will wilt.



In plant cells water potential has two main components which are solute potential and pressure potential.

Solute potential is the effect of dissolved substances on the potential energy of a solution and a hypotonic solution has a high solute water potential while a hypertonic solution has a lower water potential. Solute potential is a always 0 or below with pure water having a solute potential of 0 and a hypertonic solution having a smaller solute potential. Solute potential is the key factor in water potential because as we know the major factor in osmosis is the movement of water from a higher water concentration to a lower water concentration which is in effect from a solution with a higher solute potential to one with a lower solute potential.

Pressure potential is hydrostatic pressure and so a turgid plant cell with a large hydrostatic pressure has got a higher pressure potential than that of a plasmolysed cell. In a turgid cell the pressure potential is positive while when a plant cell is not turgid the pressure potential is negative and so pressure potential is usually negative.

The equation linking water potential, solute potential and pressure potential is:

$$\Psi_w = \Psi_s + \Psi_p$$

Water potential = Solute potential + Pressure potential

Kilopascals (KPa) Kilopascals (KPa) Kilopascals (KPa)

In a plant water will move by osmosis into and out of cells due to differences in water potential between the cell and its surroundings. The speed at which water moves in and out of a cell is dependant on the difference between the water potential of the cell and its surroundings. If there is a very large difference between the cell's and the surrounding water potential than the water will diffuse in or out of the cell very quickly but if there

Investigation Outline

Potatoes of the same size will be placed into situations where the solute potential is lower in the solution surrounding the potato then that of the water potential in the potato cells and then my partner and I will see what happens to the potato. We will do the same thing but also in situations where the solute potential is higher in the solution surrounding the potato then that of the water potential in the potato cells. From the results of the changes in the potato we will also then be able to work out the water potential of the potato cells as that will be where there is no change in the potatoes' mass and length. At this point the cell's pressure potential will be 0 and from the concentration of the sugar solution we will be able to work out the solution's solute potential at room temperature. To make the experiment fair we will try to keep all the variables the same e.g. temperature, length of time kept in solution. We will also place three potatoes into each solution and use an average to get more accurate results. The solute potential of the sugar solution that the potatoes will be placed in will be varied by the molarity of the sugar solution. The potatoes will all be placed into the same volume of sugar solution. The potatoes will all be of the same type and they will have been all peeled but not washed as then osmosis could occur.

Predictions

I predict that the potato cylinders will increase in size as the original water potential of the sugar solution increases but not proportionally because, as explained above, the rate of water diffusion is dependant on the difference between the water potential of the cell and its surroundings therefore as the original water potential of the solution decreases there is a smaller difference between the water potential of the solution and that of the cell's and if the original water potential of the sugar solution is lower than that of the cell's the potato cylinders will decrease in size.

Experiment planning

In order to be able to check whether my main experiment would work well we conducted a preliminary experiment which we then evaluated to see how we could improve for my main experiment.

Preliminary Experiment

Method

We placed three lengths of 3.5 cm of potato, which had been cut using a scalpel and measure using a ruler, into 5 Petri dishes. In one Petri dish we poured in $10cm^3$ of tap water and $10cm^3$ of 1 Mole/Litre sugar solution making a concentration of 0.5 moles/litre. We then used different ratios of water and 1M sugar solution to produce $20cm^3$ solutions with concentrations of 0.2M, 0.1M, 0.05M and 0M in the other four Petri dishes. We measured the volumes of the sugar solution and water using measuring cylinders. As this was the preliminary experiment we only waited two and a half hours before measuring the new lengths of the potatoes.

Preliminary Results

Original concentration of sugar solution (Moles/Litre)	Original potato cylinders' lengths (cm)	New length of first potato cylinder (cm)	New length of second potato cylinder (cm)	New length of third potato cylinder (cm)	Average new length of cylinders (cm) (2d.p.)	Average % change in length of cylinders (2d.p.)
0.5	3.5	3.5	3.5	3.5	3.5	0
0.2	3.5	3.6	3.6	3.7	3.63	3.71
0.1	3.5	3.7	3.8	3.9	3.8	8.57
0.05	3.5	4.0	4.2	4.2	4.13	18
0	3.5	4.3	4.4	4.1	4.27	22

Preliminary Conclusion

These showed the expected trend though they can be made more accurate as will be explained next.

Evaluation

To make this experiment more accurate for the main experiment a number of differences to the method can be made. This includes leaving the potatoes longer in the Petri dishes in order to be able to see as big a gain or loss in size as possible, using mass as well as length to make sure the potatoes are all similar, using more accurate equipment for measuring the lengths of the potatoes possibly callipers, making sure sensitive electronic scales are used to measure the mass of the potatoes, using a borer to bore cylinders all of the same diameter, possibly using more accurate equipment to measure the volumes of water and sugar solution than a measuring cylinder and we should use distilled water rather than tap water.

We decided to use 4cm rather than 3.5cm in the main experiment for the lengths of potato cylinders just to make it easier to measure and 0.87g was the average mass of the cylinders in the main experiment. We used the same concentrations again and we decided using three cylinders and then averaging out the lengths was accurate enough.

Main Experiment

Method

We placed three cylinders of diameter 0.5cm, length 4cm and mass 0.87g of potato, which had been bored through a potato using the same borer, then the lengths were measured using a ruler to the nearest millimetre and the masses were measured using sensitive electronic scales to the nearest hundredth of a gram, into 5 Petri dishes. We used different ratios of water and 1M sugar solution to produce 20cm^3 solutions with concentrations of 0.5M, 0.2M, 0.1M, 0.05M and 0M in five Petri dishes.
The ratios are as follows:

Concentration of sugar solution (Moles/Litre)	Volume of Water used (cm^3)	Volume of 1M sugar solution used (cm^3)
0.5	10	10
0.2	16	4
0.1	18	2
0.05	19	1
0	20	0

We measured the volumes of the sugar solution and water using measuring cylinders. We waited six hours before measuring the new masses and lengths of the potato cylinders. We dried the potatoes before weighing them as to prevent the weighing of excess sugar solution but we made sure that we did not squeeze the cylinder as that could have changed the length.

Results

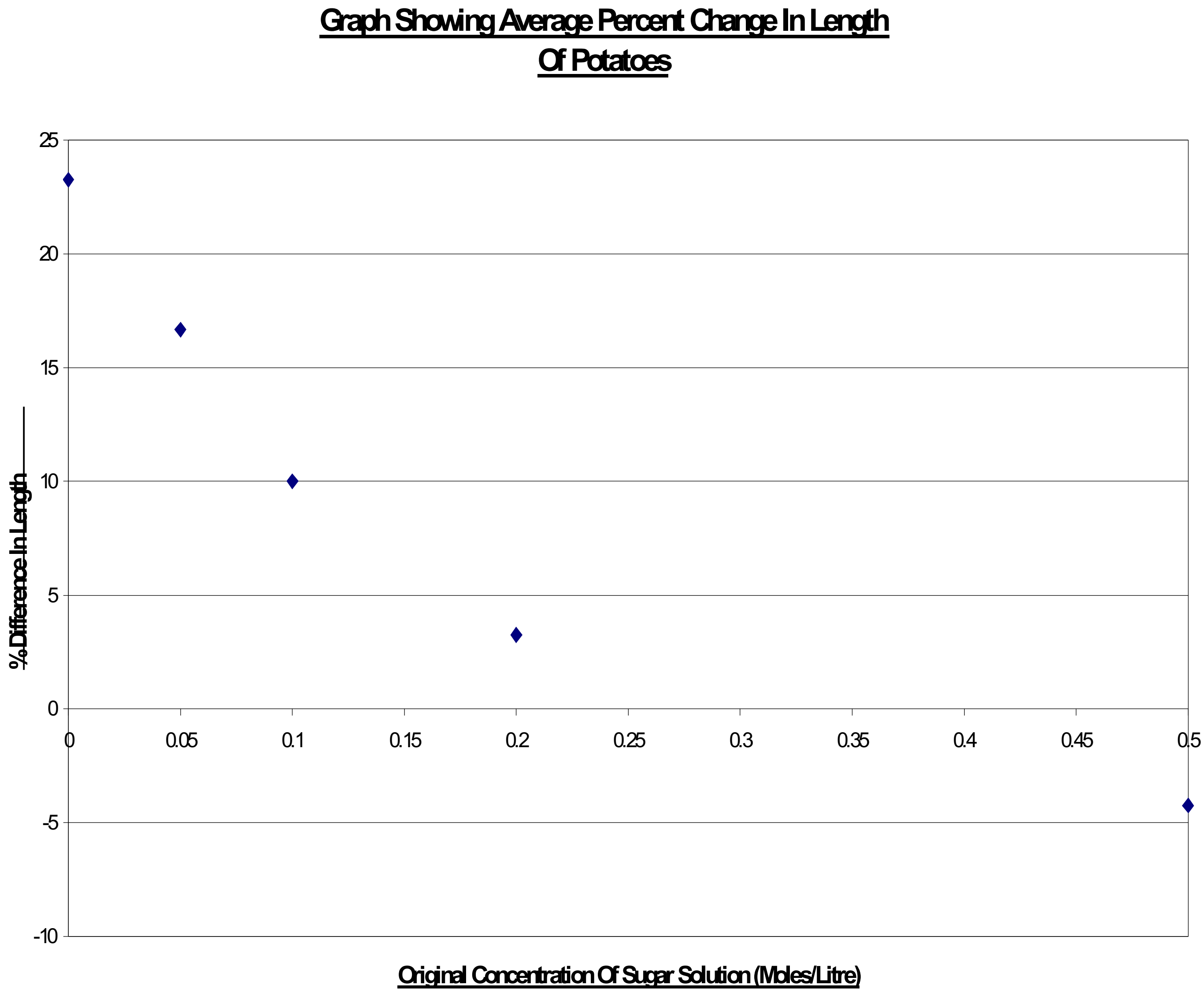
Table of Results of Change in Length of Potato Cylinders

Original concentration of sugar solution (Moles/Litre)	Original potato cylinders' lengths (cm)	New length of first potato cylinder (cm)	New length of second potato cylinder (cm)	New length of third potato cylinder (cm)	Average new length of cylinders (cm) (2d.p.)	Average % change in length of cylinders (2d.p.)
0.5	4	3.9	3.8	3.8	3.83	-4.25
0.2	4	4.2	4	4.2	4.13	3.25
0.1	4	4.6	4.3	4.3	4.4	10
0.05	4	4.7	4.6	4.7	4.67	16.66
0	4	5	4.9	4.9	4.93	23.25

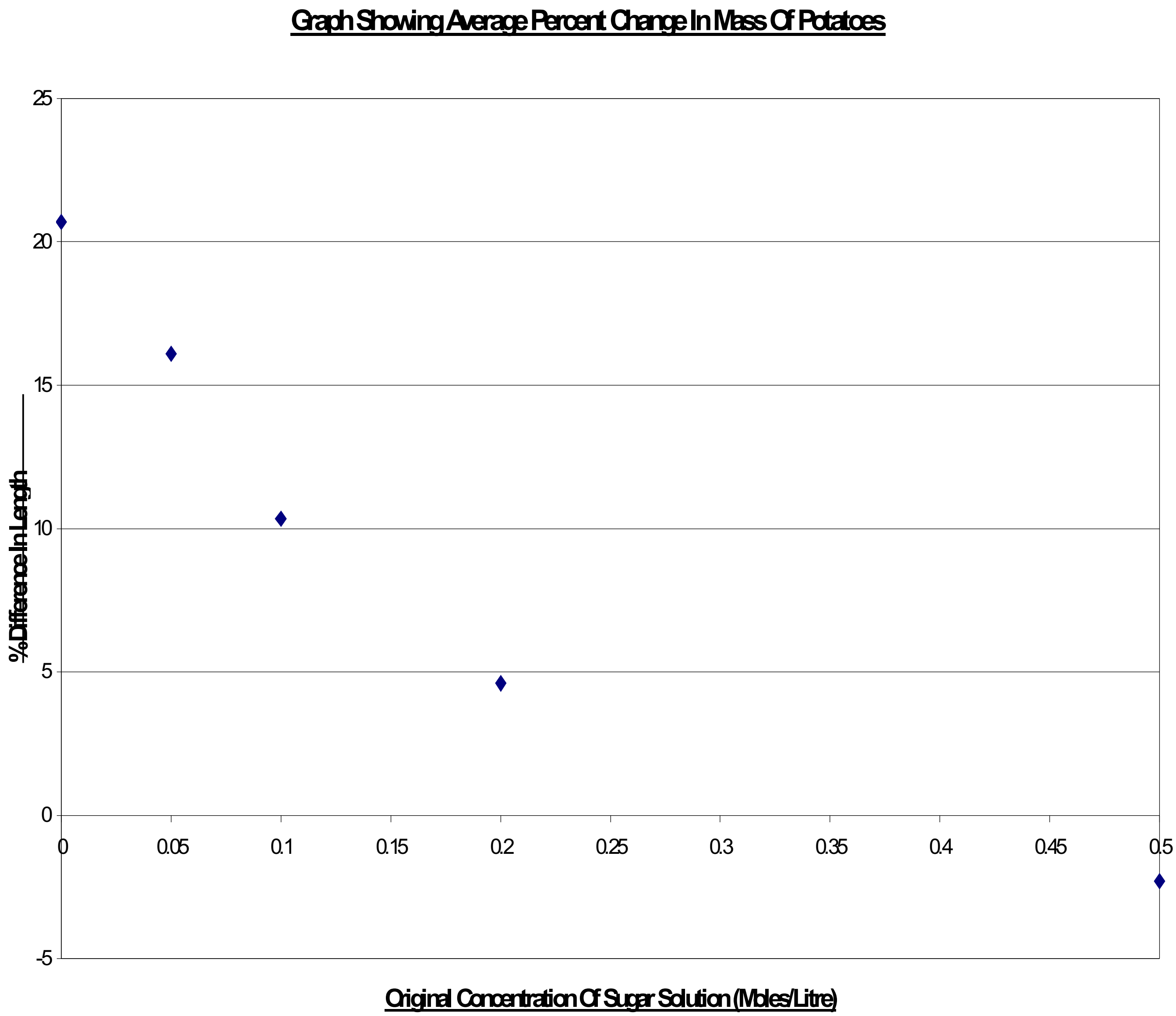
Table of Results of Change in Length of Potato Cylinders

Original Concentration Of sugar solution (Moles/Litre)	Original potato cylinders' mass (g)	New mass of first potato cylinder (g)	New mass of second potato cylinder (g)	New mass of third potato cylinder (g)	Average new mass of potato cylinders (g) (2d.p.)	Average % change in mass of cylinders (2d.p.)
0.5	0.87	0.86	0.84	0.84	0.85	-2.3
0.2	0.87	0.91	0.9	0.92	0.91	4.6
0.1	0.87	0.97	0.95	0.95	0.96	10.34
0.05	0.87	1.03	1.00	1.01	1.01	16
0	0.87	1.06	1.05	1.05	1.05	20.69

Graphs



Graph Showing Average Percent Change In Length Of Potatoes
25
20
15
10
5
0
-5
-10
% Difference In Length
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Original Concentration Of Sugar Solution (Moles/Litre)



Conclusion

As can be seen from the graphs as the original water potential of sugar solution surrounding the potatoes increased the potatoes' length and mass increased though not proportionally as predicted. Under a certain original water potential of the surrounding sugar solution the mass and length of the potatoes decreased from their original size.

The line showing % change in length intersects the x-axis at approximately 0.38M (2.d.p.) which is when there is no change in length and so the water potential of the contents inside the potato and the sugar solution are equal. The line of % change in mass intersects the x-axis at approximately 0.43M (2.d.p.). These two values give an average original concentration of sugar solution when there is no change in size of 0.405M.

Therefore using the values given in this table:

Table of solute potentials of sucrose solutions (at 20°C)

Concentration of sucrose solution (Moles/Litre)	Solute potential KPa
0.05	-130
0.10	-260
0.15	-410
0.20	-540
0.25	-680
0.30	-820
0.35	-970
0.40	-1120
0.45	-1280
0.50	-1450
0.55	-1620
0.60	-1800
0.65	-1980
0.70	-2180
0.75	-2370
0.80	-2580
0.85	-2790
0.90	-3010
0.95	-3250
1.00	-3510
1.50	-6670
2.00	-11810

It can be worked out that when the original concentration of sugar solution is 0.405M the water potential (as pressure potential is 0 in solution) is approximately -1134 kilopascals and as we know when there is no net loss or gain of water by the cell the water potential of the cell and that of the solution's must be equal and so the original water potential of the potato cylinders we used is also approximately -1134KPa. The results then go on to show that when the original concentration of the sugar solution is 0.5M the original water potential of the sugar solution is -1450KPa and this is lower than that of the potatoes' and the potato cylinders decreased in size at this original concentration. This shows that water does travel from a higher water potential (the potato cell) to a lower water potential (the surrounding solution) as predicted. The opposite then happens when the original concentration of the sugar solution is above 0.405M because than the original water potential of the solution is higher than that of the potato and also pressure potential begins to play a role as pressure potential is positive when the potato is increasing in size and so this increases the potato's water potential meaning that if the original water potential of a solution is 5% more than the potato cell original water potential (about -1134KPa) the water will move in at a slower rate than if the original water potential of the solution is 5% less than that of the potato cell because of pressure potential as it will increase the water potential of the potato cell increasing in size.

Evaluation

We unfortunately were not able to use all of the suggestions I made in the evaluation after the preliminary experiment so the experiment could have been made more accurate by using distilled water, more sensitive length measuring equipment than a ruler, more accurate equipment to measure the volumes of the sugar solution and water and we could have also measure the volume of solution outside the potato when measuring the results to see whether there was a net gain or loss of water outside the potato.

The results were all quite accurate showing no real inconsistencies.