Investigation Into The Rate of Water Uptake By Transpiration.

Hypothesis:

The rate of water uptake in a plant is directly proportional to the surface area of the leaves on the plant. As the surface area is reduced, the time taken for the water to travel up the stem over the same distance will increase.

Background Knowledge:

Plants add a considerable volume of moisture to the atmosphere. After absorbing water through their roots, the water travels up the stem to the leaves where over 99% of the absorbed water is lost through the leaves by a process named transpiration. The Sun provides the energy required to turn the water in the leaves into a vapour, causing it to diffuse out of the plant and into the atmosphere. Water evaporates from the leaves and causes a force that pulls the water up the stem. The water travels through the vessels in the vascular bundles and this flow of water is called the transpiration stream.

Vascular tissue is made up of xylem and phloem. These tissues are concerned with the translocation (transport) of water and nutrients around the plant. Xylem carries mainly water and mineral salts, whereas phloem carries mainly organic solutes in solution, for example sugars. As the vascular tissue forms a transport system around the plant, a large, complex body will develop.

Xylem fibres are thought to have originated from tracheids (single cells that are elongated and lignified), however they are shorter and narrower than tracheids. Overlapping walls are present at the end of the xylem. Phloem resemble xylem as they also have a tubular structure that is modified for translocation. The tubes are composed of living cells, and there are five different cell types: sieve tube elements, companion cells, parenchyma, fibres and schlerids.

See figure 1a that shows how phloem and xylem play an important role in transpiration. Figure 1b shows how gaseous exchange occurs in leaves..

Transpiration is the evaporation of water from leaves; therefore any change that increases or reduces evaporation will have the same effect on transpiration. The following variables can affect the rate of transpiration.

Light intensity – Light itself does not directly affect transpiration, but in daylight the stomata of the leaves are open. This allows the water vapour in the leaves to diffuse out of the plant into the atmosphere. At night, when the stomata are closed, transpiration rates are greatly reduced. Generally, transpiration speeds up when the light intensity increases as the stomata respond to changes in the light intensity.

Humidity – If the air is very humid it can accept very little from the plants and therefore transpiration slows down. In dry air, the diffusion of water vapour from the leaf to the atmosphere will be rapid.

Temperature – Warm air can hold more water than cool air. Thus, transpiration will take place more rapidly in warm air. When the sun shines on the leaves, they will absorb heat as well as light. This warms them up and increases the rate of transpiration.

Air movements – In still air, the region surrounding a transpiring leaf will become saturated with water vapour so that no more can escape from the leaf. In these conditions, transpiration will slow down. In moving air, the water vapour will be swept away from the leaf as fast as it diffuses out. This will increase the rate of transpiration.

Leaf surface area – A reduction in leaf surface area will reduce the rate of transpiration, as there will be a smaller distribution of stomatal pores.

Cuticle – The thinner the leaf cuticle layer, the greater the rate of cuticular transpiration. The upper surface of dicotyledonous leaves generally has a thicker cuticle compared with the lower layer. Thick, waxy cuticles can virtually eliminate cuticular transpiration and the shine reflects solar radiation.

Stomata – The greater the number of stomata per unit area, the greater the rate of transpiration. Plants showing xeromorphic adaptations usually have reduced numbers of stomata. In dicotyledonous plants, the lower leaf surface usually possesses more stomata than the upper surface.

In order to make this a fair experiment, the following precautions need to be taken. My experiment will be conducted inside a science lab at school, away from the windows. The light intensity should not change during the experiment. The humidity of the air will not change within the laboratory. There is a thermostat located within the laboratories, and therefore the temperature should remain constant. There is an air conditioning unit installed in order to control the temperature, but it should not affect my experiment. I am unable to change the thickness of the cuticle, but I will use the same plant for each attempt. I will also not be able to change the number of stomata present on the leaf's surface; therefore I will assume that there will be an equal spread of stomata over each and every surface.

All of these are factors that may affect the experiment, but hopefully I will be able to conduct a fair test.

Plan:

For this experiment I will be using a simple potometer (from *poto* meaning drink and *meter* meaning measure) to measure the rate of water uptake in a plant, and how this rate is affected by leaf surface area.

Apparatus:

1. Privet plant (used as it has many leaves that may be easily counted and that are about the same size)
2. Capillary tubing with water used as a meniscus scale (each mm on the scale is equivalent to $1mm^7$ of water – I will use 50mm)
3. Beaker of water
4. Stand (this will help to support the plant)
5. Stop clock (showing minutes, seconds and 1/10th second)

See figure 2 that shows how I will set up the apparatus. It must be secure on the tabletop. This is so that it is not dangerous in any way to anyone else.

Method:

1. I will cut a privet plant underwater about 3cm up the stem. This will remove any blockages in the xylem from when the plant was cut previously. The xylem must not be crushed, so the plant will be cut at an angle with a sharp blade. The plant will be cut underwater to prevent any air bubbles getting into the xylem, as this may affect the final results.
2. I will submerge the capillary tube in the same water bowl. It will be attached to the plant, making sure no air bubbles are inside. I must make sure the open end of the capillary tube is also underwater so that all of the apparatus can be lifted out.
3. This will make sure that the whole system is completely airtight. When the plant transpires, water will be pulled along the tubing. I will allow the apparatus to equilibrate for about 5 minutes.
4. I am going to introduce an air bubble into the system. Holding the tubing out of the water for a minute can do this.
5. I will make sure the bubble starts at the correct place on the scale, and time how long it takes for the bubble to move 50mm. This can be achieved by allowing the bubble to pass from no.1 to no.5 on the scale. Afterwards I will move the bubble back with the water.
6. I will note the times in the table.
7. I am going to repeat each attempt three times. This should give me enough readings to be able to calculate the mean average if need be. Each measurement will be taken from the same point of the bubble.

Figure 3 shows how I am going to make sure the bubble is at the correct place on the scale. The bubble can be moved backwards by opening the tap from the reservoir and allowing more water in.

8. Ten leaves will be removed and the surface area of the leaves calculated. The test will be repeated again. Each time I will remove ten leaves, and the last test I conduct will have only ten leaves on the plant.

9. I will be conducting a practice experiment, with just one reading for each set of leaves that I remove. This will appear in my results as **1st attempt.**
10. Three other readings will be taken with another branch of the same privet plant. It is the surface area of this second branch that I will record. The surface area will be used to compare how the rate of uptake will change against the number of leaves I will be removing.

Safety Procedures:

- I will not be using any hazardous substances, but I must be careful not to spill any water on the workbench.
- The sharp blade must be used with care, as it is very sharp and fingers can be cut easily. When they are not being used, the blades must be kept inside their box so that other people will not hurt themselves if they are left lying around.
- I will not break any branches off the privet hedge that I will not be using for the experiment. This means that I will not be disturbing any organisms unnecessarily that live on the plant.
- The apparatus must be positioned steadily on the surface. It is quite bulky, and I must be careful not to knock it over and spill the water.

Predictions:

I predict that if the surface area of the plant's leaves is reduced the rate of uptake will slow down. This is because the number of stomata will be reduced, and transpiration rates will be reduced. I predict that the rate will decrease in proportion to the number of leaves removed, for example if the number of leaves is reduced by 50%, the rate of uptake will be reduced by 50%. The rate of transpiration is directly proportional to the surface area of the leaves on the plant. This is assuming that all other variables will remain constant. I am assuming that there will be an equal distribution of stomata on all of the leaves, and also that the surface area of each set of 10 leaves I remove will be approximately the same. For example, each set may have a combined surface area of 50 cm^5.

See [illegible] that shows how I predict the rate of uptake will change. As I am unsure of the rate at present, I have left the axis unlabelled and shown only the general trend.

Method:

This was carried out as stated earlier, with no changes made to the original plan. The first attempt was carried out on a different branch to the other three attempts. This was to test the experiment, and it also gave me an approximate time of the whole experiment.

Results:

Time of Water Uptake (seconds)				
Number of Leaves	**1st Attempt**	**2nd Attempt**	**3rd Attempt**	**4th Attempt**
100	362	375	367	384
90	423	427	434	485
80	409	423	423	409
70	375	463	423	471
60	458	485	480	497
50	505	561	543	609
40	404	694	574	684
30	409	781	609	704
20	704	892	704	735
10	1612	962	862	943

I choose to display the rate of water uptake (mm/second) rather than the time taken to travel 50mm as this gave a more accurate indication of how quickly the bubble travelled:

$$\frac{50mm}{\text{Time taken (s)}} = \text{Rate in mm/second}$$

Rate of Water Uptake (mm/second)				
Number of Leaves	**1st Attempt**	**2nd Attempt**	**3rd Attempt**	**4th Attempt**
100	0.138	0.133	0.136	0.130
90	0.118	0.117	0.115	0.103
80	0.122	0.118	0.118	0.122
70	0.133	0.107	0.118	0.106
60	0.109	0.103	0.104	0.101
50	0.099	0.089	0.092	0.082
40	0.124	0.072	0.087	0.073
30	0.122	0.064	0.082	0.071
20	0.071	0.056	0.071	0.068
10	0.031	0.052	0.058	0.053

I have plotted the results graph in a conventional way, with the number of leaves starting at 10 and leading up to 100. Although I carried out the experiment from 100 downwards, it seemed logical to plot the results the other way around. This shows the pattern clearly. I did carry out an experiment for 0 leaves, but the rate was too slow, and it is for this reason that I have not displayed the results I found.

Figure 5 shows the results. The rates are shown, as these are easily comparable numbers to work with. They give a more accurate view of how quickly the bubble travelled per 50mm.

It is clear from the graph that there is an increase in the time taken as the number of leaves decreases. The rate slows down, and the bubble travels more slowly. This is due to the decreasing rate of transpiration. As the number of leaves decreases, the numbers of stomata decrease and the rate of transpiration slows down. As the transpiration rate slows down, the rate of uptake is slowed down to prevent further water loss.

Conclusion:

My results show that the rate of uptake slowed down as more leaves were removed, and as the surface area of the plant decreased.

The first attempt proved very useful, as I did not anticipate that the air-conditioning unit would affect my results as much as it did. The graph that I drew with the rates of water uptake shows clearly all four attempts. From this, I can see that the mean average rate for 100 leaves was 0.134mm/second. The mean average rate for 10 leaves was 0.049mm/second.

This experiment has matched my predictions, however not quite as well as I had hoped. I had predicted that when the leaf surface area was reduced by 50%, the rate of water uptake would decrease by 50%. This was not the case. The mean rate of transpiration for 50 leaves is not 50% of the mean average for 100 leaves; it is nearer to 67%. The mean rate of water uptake for 50 leaves was 0.091mm/second.

The anomalies from the first attempt have been marked as A, B and C. A and B have higher rates of water uptake than expected. This was because the air conditioning unit came on and moved the air around the leaves more quickly, thus causing the plant to transpire more quickly. C also has a higher rate of water uptake than expected due to the light intensity changing. The first attempt was conducted in front of a window, and when the Sun came out the light intensity increased. The other three attempts were not conducted directly in front of a window. The time taken to transpire increases as the leaf surface area decreases. This is due to the removal of stomatal pores that allow the plant to exchange gases and water vapour. To prevent dehydration, the pores close to prevent further water loss and the rate of transpiration slows down.

There was only one other anomaly throughout the whole experiment. This has been marked on the results graph as D, and occurred on the fourth attempt for 90 leaves. Although I had moved the apparatus away from the air-conditioning unit previously, on this occasion the breeze still affected my results. It did not disturb the air surrounding the leaf, as it did previously. This would have increased the rate of uptake. The cooler air meant that transpiration slowed down, having a direct effect on the rate of water uptake.

The rate of transpiration was fastest for all four attempts when there were all 100 leaves on the plant, and slowest when there were only 10 leaves on the plant. All of the conditions were kept constant; therefore it was the stomatal quantity that affected the rate of transpiration.

It was important that I measured the rate of uptake and not the rate of transpiration. Transpiration is very difficult to measure. The volume of water taken up is far greater than the volume of water given out through transpiration. This is because a large volume of water is used by the plant for turgidity, photosynthesis and other biological functions such as hydrolytic processes.

My results shown in *Figure 5* are almost linear. This matches my predicted graph, and is due to the proportion of leaves removed at each time.

Although I did not realise at the time, I was removing approximately 10% of the leaves each time. This was purely coincidental, and was only discovered when I plotted the surface area against the number of leaves in *Figure 6*. The trend shown in *Figure 5* is mirrored in *Figure 6*. This pattern may also have followed my predictions for another reason. The stomatal distribution across the leaf surface area may have been equal across all 100 leaves. If this was true, the total number of stomatal pores would have decreased in proportion to the number of leaves too.

Evaluation:

The first attempt was affected by the air-conditioning and light intensity. However, this was my practise experiment and I decided to then use another branch, approximately the same size for the next three attempts. All of the surface area calculations shown in *Figure 6* are for the second branch. I made sure that the air-conditioning would not start during the second experiment, and also that I did not set up the apparatus next to another window. When the Sun shone through the window, it was very bright and the light intensity increased. I did not realise that these two factors could affect the rate of transpiration as much as they did.

I did not take into account the stomatal distribution in either of my two experiments. This would have been an interesting variable to look at, however I found that I was short on time. I would have liked to have looked at the lower epidermis underneath a microscope, and made an approximate stomatal count. I could have seen if they were evenly spread, and if not, still made an estimated rate of uptake from my other results.

My results were very pleasing overall. They followed my predicted trend and I have been able to see why, due to measuring the total surface area of the second branch. I have accounted for my anomalies as the experiment was affected by factors beyond my control. I had not realised that the air-conditioning and positioning of the apparatus would affect the experiment in such an extreme fashion. Factors such as light intensity and the temperature of the surrounding air may only change slightly, but have a larger effect on the overall experiment.

I would have liked to repeat the experiment again, so that I could obtain more results. This would give me a more significant mean average, and I would have been able to leave out the anomalies in the analysis. A source of error may have been counting the number of leaves rather than the surface area. Nevertheless, it turned out that I was removing the leaves by nearly 10% each time.

I would improve the experiment by measuring the stomatal distribution next time. This will allow me to calculate a more significant rate of uptake by calculating how much water is taken in through each stomatal pore. I could then estimate how much water should be taken in. If I was able to calculate the transpiration rate as well, I would be able to work out how much water was being used within the plant.

Generally, this experiment was conducted well. The anomalies were not large enough to change the trend in any way, and the overall results were beneficial in proving the hypothesis correct.