Transpiration is the evaporation of water from plants. It occurs chiefly in the leaves while their stomata (tiny openings in the undersurface of a leaf) are open for the passage of CO\textsubscript{2} and O\textsubscript{2} during photosynthesis. Air that is not fully saturated with water vapor (100% humidity) will dry the surfaces of cells with which it comes in contact. So the photosynthesizing leaf loses substantial amount of water by evaporation. This transpired water must be replaced by the transport of more water from the soil to the leaves through the xylem of the roots and stem. Transpiration accounts for approximately 10% of all evaporating water on this planet. As leaves transpire, the outward flow of water lowers the pressure in the leaf, creating a vacuum that pulls water upward. This force is responsible for most of the water flow in plants, including lifting water to the tops of trees.

**Introduction**

The amount of water needed daily by plants for the growth and maintenance of tissues is small in comparison to the amount that is lost through the process of transpiration and guttation. If this water is not replaced, the plant will wilt and may die. The transport up from the roots in the xylem is governed by differences in water potential (the potential energy of water molecules to move from a place of higher concentration to an area of lower concentration). These differences account for water movement from cell to cell and over long distances in the plant. Gravity, pressure, and solute concentration all contribute to water potential and water always moves from an area of high (or less negative) water potential to an area of low (or more negative) water potential. The movement itself is facilitated by osmosis, root pressure, transpiration (transpirational pull) and adhesion/cohesion (capillary action) of water molecules.

**The overall process:**

Minerals actively transported into the root accumulate in the xylem, increase solute concentration and decrease water potential. Water moves in by osmosis. As water enters the xylem, it forces fluid up the xylem due to hydrostatic root pressure. But this pressure can only move fluid a short distance. The most significant force moving the water and dissolved minerals in the xylem is upward pull as a result of transpiration, which creates a negative tension. The “pull” on the water from transpiration is increased as a result of cohesion and adhesion of water molecules.

**The details:**

Transpiration begins with evaporation of water through the stomates (stomata-\textit{pl}), small openings in the leaf surface, which open into air spaces that surround the spongy parenchyma mesophyll cells of the leaf. The moist air in these spaces has a higher water potential than the outside air, and water tends to evaporate from the leaf surface. The moisture in the air spaces is replaced by water from the adjacent spongy parenchyma mesophyll cells, lowering their water potential. Water will then move into the spongy parenchyma mesophyll cells by osmosis from surrounding cells with the higher water potentials including the xylem. As each water molecule moves into a spongy parenchyma mesophyll cell, it exerts a pull on the column of water molecules existing in the xylem all the way from the leaves to the roots. This transpirational pull is caused by (1) the cohesion of water molecules to one another due to hydrogen bond formation, (2) by adhesion of water molecules to the walls of the xylem cells, which aids in offsetting the downward pull of gravity. The upward transpirational pull on the fluid in the xylem causes a tension (negative pressure) to form in the xylem, pulling the xylem walls inward. The tension also contributes to the lowering of the water potential in the xylem. This decrease in water potential, transmitted all the way from the leaf to the roots, causes water to move inward from the soil, across the cortex of the root, and into the xylem.

Evaporation through the open stomates is a major route of water loss in the plant. However, the stomates must open to allow the entry of CO\textsubscript{2} used in photosynthesis. Therefore, a balance must be maintained between the gain of CO\textsubscript{2} and the loss of water by regulating the opening and closing of stomates on the leaf surface. Many environmental conditions influence the opening and closing of the stomates and also affect the rate of transpiration. Temperature, light intensity, air currents, and humidity are some of these factors. Different plants also vary in the rate of transpiration and in the regulation of stomatal opening.
Some Key Review Concepts

- Movement of Water in Plants
  - Water enters a plant through the root hairs, passes through the tissues of the root into the cortex and then into the xylem. This water travels up through the xylem vessel element and tracheid cells into the leaves. *Transpiration (the evaporation of water from the leaves) is the major factor that pulls the water up through the plant.* It is important to recognize that this upward conducting tissue is continuous through vascular (tracheophyte) plants, starting at the roots and continuing upward through the plant to the leaves.

- Transpiration
  - There are hundreds of stomata in the epidermis (cuticle) of a leaf. Most are located in the lower epidermis. This reduces water loss because the lower surface receives less solar radiation than the upper surface. Each stoma allows the carbon dioxide necessary for photosynthesis to enter, while oxygen gas is released and water evaporates through each one in transpiration.

- Guard Cells
  - Guard cells are cells that make up part of the dermal leaf tissue and 2 guard cells surround each stoma. They help to regulate the rate of transpiration by opening and closing the stomata using a K+ (potassium ion)/water influx or release mechanism.

- Lab Design
  - In this lab, you use a potometer. A potometer is a device that measures the rate at which a plant draws up water. Since the plant draws up water as it loses it by transpiration, you are able to measure the rate of transpiration.
  - You will set up 4 potometers to measure the rate of transpiration of 4 different scenarios. The four different situations are:
    - room temperature (control),
    - mist (simulates high humidity conditions)
    - wind (simulates dry conditions)
    - bright light (increased temperature & photosynthesis)
  - You will measure the water loss in each of the potometers every 3 minutes for 30 minutes.
  - You will also need to measure the surface area of the leaf.
  - In the other part of the lab, you will need to be able to recognize the following plant structures: xylem, phloem, parenchyma, and epidermis.

- Analysis of Results
  - With the data, you will need to calculate the water loss per minute by taking the final amount of water loss (ml) and dividing it by the Leaf Surface area. You will trace leaves to find the leaf surface area.
    - water loss per minute (in ml/cm\(^2\)) = the final amount of water loss (ml) / the leaf surface area (cm\(^2\))
**ACTUAL LAB PROCEDURE**

**Exercise 9A Transpiration**
In this lab, you will measure transpiration under various laboratory conditions using a **potometer**. Four suggested plant species are *Coleus*, *Oleander*, *Zebrina*, and two week old bean seedlings.

**Materials**
- mL pipette, plant cutting, ring stand, clamps, clear plastic tubing, petroleum jelly, fan, lamp, spray bottle, and plastic bag.

**Procedures**
1. Place the tip of a 0.1 mL pipette into a 16-inch piece of clear plastic tubing.
2. Submerge the tubing and the pipette in a shallow tray of water. Draw water through the tubing until all the air bubbles are eliminated.
3. Remove any buds from the plant.
4. Remove one (1), which is close in size/shape to the other leaves on your plant. This is a representation of all leaves on your and you will calculate the surface area of this leaf.
5. Carefully cut your plant stem under water. This step is very important, because no air bubbles must be introduced into the xylem.
6. While your plant and tubing are submerged, insert the freshly cut stem into the open end of the tubing.
7. Your potometer should look like:

![Potometer Diagram](image)

8. If necessary use petroleum jelly to make an airtight seal surrounding the stem after it has been inserted into the tube. **Do not put petroleum jelly on the end of the stem.**
9. Let the potometer equilibrate for 10 minutes before recording the time zero reading.
10. Expose the plant in the tubing to the following treatments
   a). Room conditions
   b). Floodlight (bright light)
   c). Fan (place at least 1 meter from the plant, on low speed, creating a gentle breeze)
   d). Mist (mist leaves with water and cover with a transparent upside down/inverted fish aquarium)
11. Read the level of water in the pipette at the beginning of the experiment (t=0) and record data in your data table.
12. Continue to record the water level in the pipette every 3 minutes for 30 minutes and record the data in your data table.
AP Lab #9: Plant Transpiration Virtual Lab

Directions to Virtual Lab

- BEFORE you move on to this virtual lab, please make sure you have READ and completed the Chapter 36 Study Guide in your textbook.

PROCEDURE


- Under Labs, select virtual labs. Select Plant Transpiration from the list of labs.

PURPOSE/PROBLEM

What is the purpose of this lab? What are you trying to determine?

__________________________________________________________________________________________________  
__________________________________________________________________________________________________

HYPOTHESES

Create a hypothesis for EACH potometer condition. Please use the “If…then…because…” format.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Hypothesis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control (normal)</td>
<td></td>
</tr>
<tr>
<td>Bright Light</td>
<td></td>
</tr>
<tr>
<td>(warm temp)</td>
<td></td>
</tr>
<tr>
<td>Fan (windy)</td>
<td></td>
</tr>
<tr>
<td>Mist (humid)</td>
<td></td>
</tr>
</tbody>
</table>
MATERIALS
- Click the “X” to get out of the “PROBLEM.”
- Now look at the Checklist on the Explore part of the virtual lab.
- Select each item being used in the lab.
  o You need to click on EACH material inside the PICTURE of the lab. Read the description that appears for each item. Fill in the box below:

<table>
<thead>
<tr>
<th>Material</th>
<th>Purpose/ Why are you using it?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potometer</td>
<td></td>
</tr>
<tr>
<td>Pipette</td>
<td></td>
</tr>
<tr>
<td>Air tight seal</td>
<td></td>
</tr>
<tr>
<td>Geranium seedlings</td>
<td></td>
</tr>
<tr>
<td>Fan</td>
<td></td>
</tr>
<tr>
<td>Light</td>
<td></td>
</tr>
<tr>
<td>Spray bottle/plastic bag</td>
<td></td>
</tr>
<tr>
<td>Graph paper</td>
<td></td>
</tr>
</tbody>
</table>

- Once you have selected all the items (8 total), the procedure box in the upper left hand corner will light up to a dark grey color.
- You can now click procedure to start the lab.

PROCEDURE
- Follow the steps to the lab given on the screen until you complete all thirteen (13) steps.
- While completing the procedure, fill in your “Data/Results” part of your worksheet below.
- NOTE
  o you do NOT need to print this lab notebook at any time.
  o While “conducting” the virtual experiment you may keep your DATA (lab) NOTEBOOK OPEN and fill in data while you click on the virtual lab set up.

DATA/RESULTS
- NOTE
  o You have to enter your data into the “LAB NOTEBOOK” in the virtual lab (top righthand corner of the screen) AND also rewrite it into the data table below.

Table 1. Predictions for Plant Transpiration Lab

<table>
<thead>
<tr>
<th>Rank</th>
<th>Predictions (write the word: normal, humid, windy, or warm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(lowest rate of transpiration)</td>
</tr>
<tr>
<td>2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>(highest rate of transpiration)</td>
</tr>
</tbody>
</table>
Table 2. Transpiration Amounts with Different Environmental Conditions

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Water Level (mL)</th>
<th>0 minutes</th>
<th>10 minutes</th>
<th>20 minutes</th>
<th>30 minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Windy</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Warm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Humid</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3. Rate of Transpiration with Different Environmental Conditions

-o Note
- If you scroll down in your lab virtual notebook, you will see the data that needs to be added into this data table. You will have to figure out the Rate of Transpiration (mL/m²) by plugging in the data into the equation in the lab virtual notebook.

***The equation to use to determine the Rate of Transpiration is:***

\[
\frac{\text{Total Water Loss (ml)}}{\text{Total Surface Area of Leaves (m}^2\text{)}}
\]

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Total Water Loss (ml)</th>
<th>Total Surface Area of Leaves (cm²)</th>
<th>Total Surface Area of Leaves (m²)</th>
<th>Rate of Transpiration (ml/ m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Windy</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Warm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Humid</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

For each treatment, graph the data for each time interval.

For this graph you will need to determine the following:

a. The independent variable: _____________________________ (x-axis)

b. The dependent variable: _____________________________ (y-axis)
1. Calculate the rate (average amount of water loss per minute per square meter) for each of the following conditions:
   a. Normal:
   b. Windy:
   c. Warm:
   d. Humid:

2. Explain why each of the conditions causes an increase or decrease in transpiration compared with the control.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Effect</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Windy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Warm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Humid</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3. Explain the role of water potential in the movement of water from soil through the plant and into the air.

4. What is the advantage of closed stomata to a plant when water is in short supply? What are the disadvantages?

5. Describe several adaptations that enable plants to reduce water loss from their leaves. Include both structural and physiological adaptations.

6. A 1 hectare field contains 2500 bean plants having a total leaf surface area of 557m². Ambient temperature is 21°C, winds are calm, and humidity is 45%. If each plant is transpiring at the average rate of 4.18ml/min/m², how much water is lost from the field each hour due to transpiration? Show your calculations below.
7. How would you expect the following conditions to affect the rate at which water is transpired from the 1 hectare field described in #6?

   a. Ambient temperature of 35°C:

   b. Winds of 15-25 km/h:

   c. Relative Humidity of 100%:

   d. Ambient temperature of 35°C, winds of 15-25 km/h:

8. Describe one mechanism used by a plant to maintain homeostasis.

9. Propose a scenarios in which the organism responds to a change in the environment to maintain homeostatic balance.

10. Predict what would happen if the organism did not have the ability to maintain this homeostatic mechanism.

11. Growth and dynamic homeostasis are maintained by the constant movement of molecules across membranes. Explain a mechanisms of molecular movement of water through a plant. Include how molecular properties and plant anatomy contribute to this process.