CHAPTER 5:

TRANSPORT OF SUBSTANCES IN THE WATER CYCLE

A: DO YOU THINK THE AMOUNT OF WATER ON EARTH IS FIXED?

The previous chapters analyzed parts of the complex path of water cycling on Earth. In this chapter, we will integrate the entire picture, which includes the passage of water through Earth's systems: the hydrosphere, geosphere, biosphere, and atmosphere.

Activity 1:

Another look at the water cycle in nature

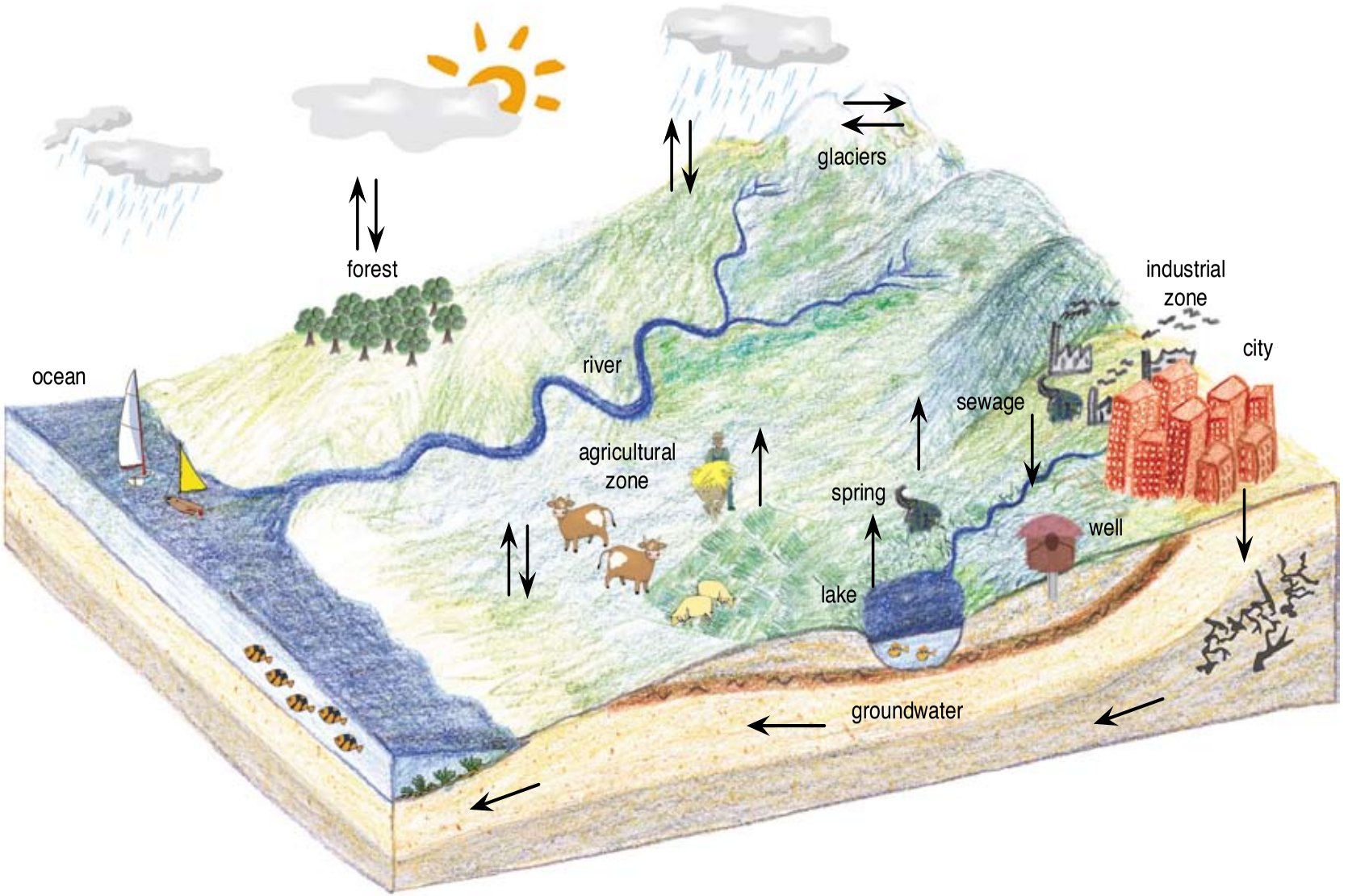
1. On the next page, you'll find an illustration that represents the water cycle in nature. Arrows show the direction of flow* from site to site. Next to each arrow, write down the name of the process that links these two sites.
2. Use this list of processes to get started:

- Dissolution
- Evaporation
- Melting
- Condensation
- Infiltration
- Groundwater flow
- Precipitation (rainfall)
- Surface water runoff
- Freezing

3. Write at least three movements that take place during the journey of water from one location to another on Earth.

Name of substance	From Site "A"...	...To Site "B"	Through the process
Ex: the mineral calcite ($CaCO_3$)	Limestone rock	Groundwater	Dissolution

* Flow: The amount of matter per unit area and time, for example: g/m^2 day.


glaciers
forest
industrial
zone
city
ocean
river
sewage
agricultural
zone
spring
well
lake
groundwater

Activity 2:

Balance in the water cycle in nature

Here, we present a graph showing the amount of water that evaporates, and the amount of water that precipitates as rainfall over a year.

Look at the graph and answer the following questions.

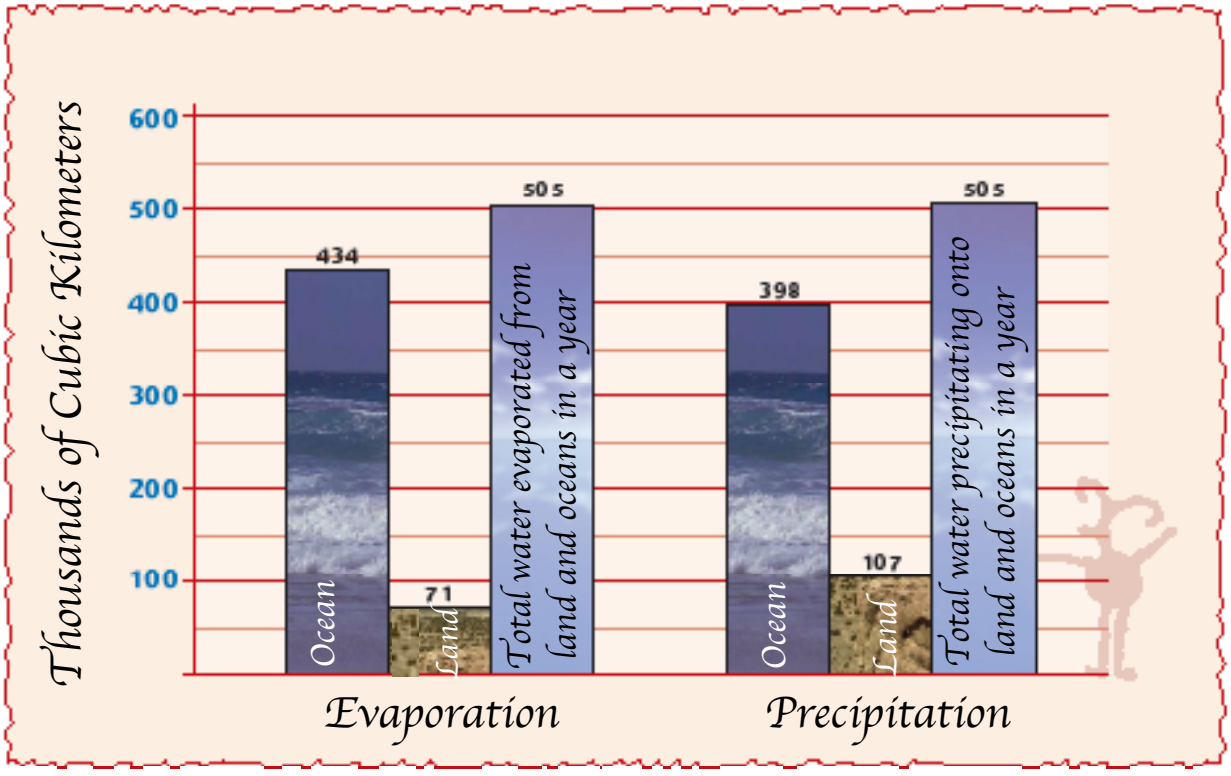


Figure: Equilibrium in the Water Cycle in Nature
Chart data taken from Press, F. and Siever, R. (2000). Understanding Earth. W.H. Freeman and Company. New York - ISBN 0716735040.

Graph Analysis

1. Write three conclusions you can deduce from the graph.
2. Circle the correct answer:
   a. The amount of water in the water cycle in nature is not fixed. right/wrong
   b. The amount of water that evaporates from the oceans is greater than the amount the oceans receive as rainfall. right/wrong
   c. The amount of water that falls as precipitation on the surface is always equal to the amount of water that evaporates from it. right/wrong
   d. In the water cycle, the total amount of water that evaporates in a year is equal to the amount of water that falls as precipitation each year. right/wrong
3. The amount of water in the entire water cycle is fixed. However, oceans evaporate about 40,000 cubic kilometers **more** water than the amount they receive as a direct result of rainfall. How can you explain this?

Hint: look back at the information on cloud formation (pages 142-143).

Points to consider:

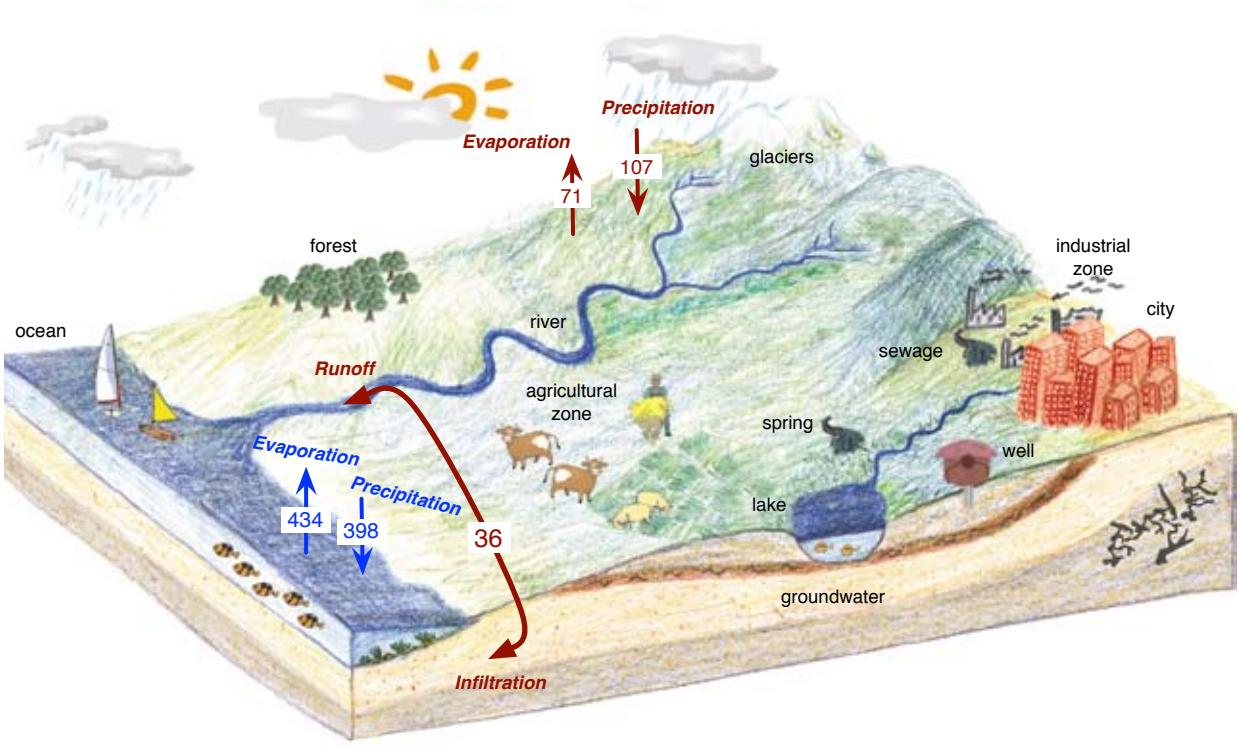
1. In your opinion, is the amount of water in the oceans growing from one year to the next, as a result of the entry of water into the ocean from groundwater and rivers? Explain.
2. The amount of water in the oceans is 1.32×10^9 cubic kilometers. In your opinion, can humans influence the amount of water in the oceans? Explain.
3. In recent years, a large number of scientists have argued that the Earth's atmosphere is getting warmer. We know that radiation from the sun causes evaporation of water from the surface of the Earth and oceans. In your opinion, can the quantity of water on Earth decrease as a result of global warming? Explain.

Activity 3:

What happens to water in the water cycle in nature?

In the previous activity, we concluded that the amount of water on the surface of the Earth is fixed. We also found that the amount of water that falls on the Earth's surface as precipitation is always greater than the amount of water that evaporates from it.

Below is a picture that shows the water balance in the water cycle in nature.
The numbers represent the amount of water moving in nature from one place to another through various processes of the water cycle.



* Data taken from Press, F. and Siever, R. (2000). Understanding Earth. W.H. Freeman and Company. New York- ISBN 0716735040.

A. The water balance on the Earth's surface (crust)

1. In the table, write down how much water reaches the Earth's surface and how much comes out of it.

Process by which water moves from one site to another	Quantity of water flowing in the process (in 1,000 km³)
Precipitation	
Evaporation from the surface	
Amount that remains	

2. What happens to water that evaporates from the surface into the atmosphere?
3. Describe two phenomena that provide evidence of the transportation of water in the crust (where the water does not reach the atmosphere).

B. The balance of water in the oceans

1. In the table, write down how much water reaches the oceans and how much comes out of it.

Process by which water moves from one site to another	Quantity of water flowing in the process (in 1,000 km³)
Precipitation	
Evaporation from the surface	
Amount that remains	

2. What happens to water that does not return to the ocean as precipitation?

MOVEMENT OF WATER FROM THE OCEAN INTO THE ATMOSPHERE

Activity 1:

How does water evaporate in nature?

In this activity, we will conduct a simulation experiment to examine the mechanism of evaporation of ocean water (salty) and condensation of water vapor in clouds (freshwater). Also, we will examine how this simulation is similar to, and different from processes in nature.

Materials: A Styrofoam cup that can hold 30 mL of water, one teaspoon of salt, a stand that holds a light bulb (or lamp) of at least 100 Watts, 2 watch glasses of about 7-8 cm in diameter, a 100 mL graduated cylinder.

Experiment

a. Place a watch glass in the refrigerator, preferably in the freezer.

b. Pour 30 mL of water into a Styrofoam cup, and add a teaspoon of salt to the water. Stir well and taste the water.

c. Cover the cup with the second watch glass.

d. Use the bulb (or lamp) to illuminate the glass for at least 25 minutes.

e. After 25 minutes, turn the light off, and place the cold watch glass (which was in the freezer) on the cup (instead of the hot watch glass). Be careful! Put your fingers into the water vapor that condensed on the cold glass, and taste it.

Classification

1. Summarize the processes you observed by completing the following statements.
   - The warming of salt water in the glass caused the _____ of water moving at a faster rate.
   - The water molecules left the surface of the liquid as a _____.
   - Salts dissolved in the water solution are not _____ and therefore remained in the cup.
   - The cold glass with which we covered the cup caused the _____ of water vapor present in the ambient air.
   - Water _____ and water droplets became _____.
2. What is left in the cup after the water evaporated?
3. Draw a line linking the components of the experiment with the natural phenomenon it simulates (write the letter and number it corresponds to in your notebook).

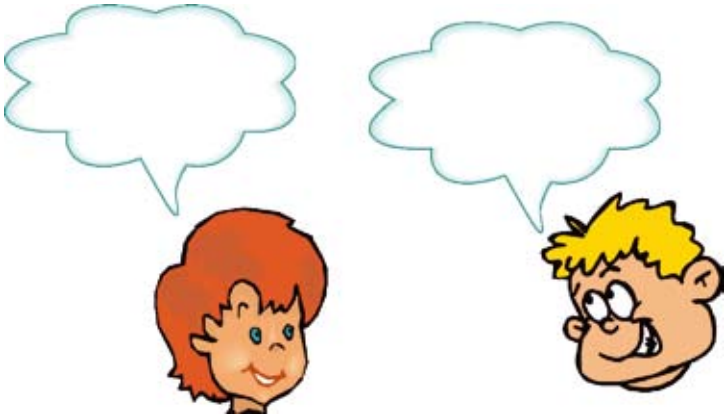
Components of the experiment		Natural phenomena
1. Salt water solution in the cup		a. Sunlight
2. Fresh water		b. Ascent of water vapor to a layer of cold air
3. Does not exist in the simulation		c. Condensation nuclei for water vapor
4. Heating the container		d. Ocean
5. Cold watch glass		e. Water from a cloud

In this activity, we learned how water evaporates from the ocean into the atmosphere of planet Earth.

In one school, students claimed that a cloud formed over Lake Titicaca (whose water comes

from melting glaciers in the Andes) is different in composition and taste, compared with a cloud created over the Dead Sea (which has a salt concentration of 230 g/L - seven times higher than the average ocean).

1. What is your opinion on this issue?
2. Discuss your argument with the members of your group and write down the conclusions you arrive at regarding this issue.



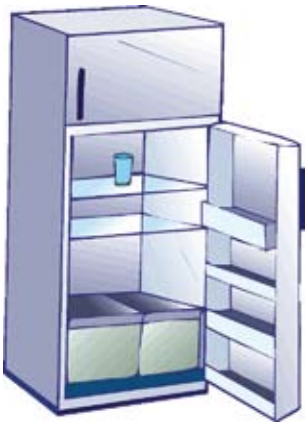
Activity 2:

Does water evaporate as well in the cold?

In the previous activity, we conducted a simulation of the evaporation of ocean water. The rate of evaporation from the ocean has a great influence on the formation of clouds and the climate of Earth. This activity will examine the rate of evaporation from the oceans and seas surrounding countries where winter temperatures are very low.

Materials: A refrigerator, 2- 100 mL beakers; labels; pencil; tap water; **patience**.

Experiment



Development of the Experiment:

1. Fill each beaker with 100 mL of water from the tap.
2. Stick a label on each beaker so that it extends from the bottom to the top.
3. Use a pencil to mark the initial level of water in the beakers.
4. Place one cup in the refrigerator of your home, and one outside the refrigerator for a period of two weeks.
5. Do you think the rate of evaporation will be different in the two glasses?
6. Be careful to note the level of water reduction due to evaporation on the label every two days.
7. Record how much the amount the water level decreased in each vessel, in mm.

		Day 2	Day 4	Day 6	Day 8	Day 10	Day 12	Day 14
Evaporation rate (mm)	In the refrigerator							
	Outside the refrigerator							

Activities in Excel

A. Prepare a chart that describes the rate of evaporation of water inside and outside the refrigerator, and its relationship (dependence) with temperature, using Excel® or another spreadsheet software on the computer.

B. Try to describe the process that took place in the experiment using the elements of scientific thinking: observation, hypothesis, additional information, and conclusion. Refer to concepts such as particle movement, surface, gas, liquid, temperature, and air.

C. Read "Thinking Scientifically" which appears on page 24, and answer the following questions:

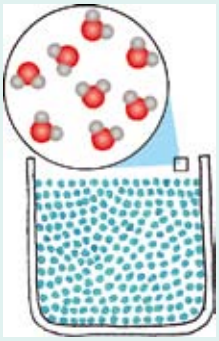
1. What is the research question in this experiment?
2. In your opinion, what is the variable that influences (independent) in this experiment? And what is the variable that is influenced (dependent)?
3. What is the change that took place in this experiment in the beakers of water that helps you answer the research question?
4. Which of the two beakers is the control?
5. Why should you not include graphical data obtained from the experiments of different groups?

Hint: This experiment was conducted in each of your homes.

Knowledge Organization

Those of you who studied "The Structure of Matter - Vacuum and Particles" used magic glasses to help you imagine the change in the physical state of water. If you had access to magic glasses through which you could see the physical changes in water, how would you describe what happens during evaporation?

The evaporation of a liquid involves the dispersal of molecules of matter. This is a state in which they are bonded together in a higher density (liquid) to a state in which they are scattered with a large distance between them (gas) and therefore they are characterized by a lower density. Because the scattering is only possible if there is movement, evaporation begins the moment molecules begin moving in liquid form. Heating the liquid can increase the speed of movement of the molecules as they begin moving faster and faster. As a result of this movement, some of the molecules detach from the liquid surface, and move away - that is, they evaporate. Although, at low temperatures, the molecules move, the movement is relatively slow.



Activity 3:

The forces of attraction between particles of water

1. What physical condition of water molecules will attract each other with the greater force: when water is in a liquid or a gaseous state? Explain.

30 water molecules in liquid state	**30 water molecules in gaseous state**

2. Try to draw 30 water molecules as they would look in a liquid state, and in a gaseous state.
3. In your opinion, why is it only the water that is on the surface of the liquid that evaporates (the area is in contact with air)?

Additional Information

In the gaseous state, the attractive force between water molecules is very weak. In liquids, and especially in solids, the force of attraction is higher. Water molecules found in the bottom of the liquid cannot leave, because in any direction they move, they collide with other water molecules. In contrast, for the water molecules found at the surface of the liquid, i.e. in the area in contact with the air, it is easier to disconnect from the rest of the liquid particles because there are fewer water molecules around. If a molecule of water leaves the liquid, it moves between the spaces of the air molecules, and becomes part of the mixture of gases in the air. These water molecules, driven now by the collisions between the molecules found outside the surface of the liquid, are known as **water vapor**. The humidity level in the air increases.

Relative Humidity: percentage of water molecules in a gaseous state, with respect to the maximum capacity of the atmosphere (at the same conditions of temperature and pressure) that contain this type of molecule.

Surfing the Internet

Activity 4:

A movie to study what makes up clouds

http://www.youtube.com/watch?v=uoHCMGBgIFQ

In the last activity, we found that most of the water on Earth evaporates from the ocean, and returns to the ocean as precipitation, and that this is related to the fact that two-thirds of the Earth's surface is covered by oceans. We will try to find out how the process of evaporation from the ocean to the atmosphere influences the properties of water in the water cycle in nature. In this activity, we will discuss from what clouds are made.

MOVEMENT OF WATER FROM PLANTS TO THE ATMOSPHERE

In the previous chapters, we explored the transport of water from the groundwater system (geosphere) to the oceans (hydrosphere), as well as the transport of ocean water into the air (atmosphere). In this chapter, we focus on the connection between water and the biosphere. Try to understand the mechanism that enables the movement of water from the roots of the trees to the top of them, and what this movement says about the rest of the Earth System.

Activity 1:

Do plants lose water?

Experiment

Materials:

3 50 mL graduated cylinders numbered 1, 2, 3, and marked with a horizontal line at a height of 2 cm below the top edge, a stopper with a hole, a stopper with no hole, a stem with leaves, clay, a waterproof marker, an analytical scale.

Development of the experiment:

a. Fill three cylinders with tap water to the marked line.
b. On cylinder #1, place the stopper with no hole.
c. Cover cylinder #2 with the stopper with a hole. Insert the stem of the plant, and seal the edges with clay between the stem and the hole.
d. Leave cylinder #3 uncapped.
e. Weigh each of the systems (plant + cylinder) at the beginning of the experiment, and after six days. Record your findings in the table.
f. Measure the height of the water in the three samples every two days (every other day) **for six days**, at a fixed time. Summarize your findings in the table on the next page.

Observations

1. Describe what happened in each of the cylinders.
2. In your opinion, what is the research question in this experiment?
3. Which of the cylinders is the control?
4. What is the role of the control cylinder?

Time	Cylinder 1 Covered with stopper with no hole, and no plant	Cylinder 2 Covered with stopper with hole, and plant	Cylinder 3 No stopper, and no plant
Weight at the beginning of the experiment (g)			
Decreased level of water after 2 days (mL)			
Decreased level of water after 4 days (mL)			
Decreased level of water after 6 days (mL)			
Weight at the end of the experiment (g)			

Conclusion

1. What are your conclusions as a result of the experiment?
2. Why did the level of the water in the test tube with the cap remain unchanged?
3. In the cylinder with the cap and plant, where did the water go?

4. In the cylinder without the cap or plant, where did the water go?
5. Transpiration is a process through which the water on the surface of a leaf evaporates into the atmosphere. How does this process relate to the results you obtained in this experiment?

Thinking Scientifically

Draw arrows to connect the statements that describe the components of the experiment with the factor being studied in each trial.

Components of the experiment		What are you studying?
1. Control 1.	●	A. Movement of water from plants into the atmosphere
2. Research question.	●	B. In this experiment, we were asked to confirm that the sample with the cap and plant were completely sealed.
3. Variable that influences (independent).	●	C. We performed this experiment only once, so the credibility is in doubt.
4. Factors affecting the credibility of the observation.	●	D. The cylinder with the stopper and no plant is for examining whether water can also disappear from the system if there is no plant present.
5. Variable that is influenced (dependent).	●	E. The water level in the cylinder serves as an indicator to determine if there was water moving through the cylinder into the atmosphere.
6. Control 3.	●	F. The cylinder with no cap and no plant allows us to explore the movement of water through the process of evaporation into the atmosphere.
7. Number of observations (repetitions) of each experiment.	●	G. The presence of a plant in the cylinder.

Surfing the Internet

Visit the websites below, or search for "water cycle" videos on youtube.com. Watch several animations or videos, and then answer the following questions.

http://www.youtube.com/watch?v=rUqIWRW6_Pc&NR=1
http://www.youtube.com/watch?v=RpYFpQHMFsc

1. What are the physical processes represented in the animation and video which occur in the water cycle in nature?
2. Which processes take place in more than one location?
3. Describe the stages of the transportation of matter (water) that occurs in the water cycle in nature, and which appear in the animations or videos.

Activity 2:

Where do plants lose water to?

In the process of transpiration, plants release water vapor into the atmosphere through openings in their leaves known as stomata. Stomata are tiny pores or openings usually found in the outer layer of leaves (epidermis) and through which water vapor leaves the plant. The pores open and close, in most cases, according to the balance of water in the plant. In this activity, you will try to locate the stomata.

Materials: Leaves of *Tradescantia pallida*; clear nail polish; tongs; dropper; miscroscope slide and cover slip; microscope.

Experiment

Part One:

In this activity, you will use nail polish to make a mold of the stomata in a leaf:

1. On the **bottom of the leaf** spread a uniform layer of nail polish, and let it dry for about 5 minutes.
2. Use the tweezers to carefully pull the nail polish layer off the leaf, and once removed, place it on a drop of water on a glass slide. Cover the slide with a coverslip and observe the slide under a microscope under low, medium, and high magnification.
3. Look at the tiny openings on the prepared slide. On both sides of the openings are **guard cells**. These cells surround the stomatal pore that is open when there is abundant water in the plant, and closed when water is scarce.

   Note: Sometimes, when you prepare a slide, an air bubble gets trapped in the pore of the stoma, and a black spot appears. This spot is unrelated to the stomata.
4. **Observation**
   a. Draw the stomata as it appeared with the highest magnification on the microscope.
   b. Record the magnification next to each drawing.
   c. Write a caption for the stomata drawing as it was seen under the microscope.

Part Two:

1. Drop a little water onto the leaf of the *Tradescantia pallida* plant. Describe what happens using the terms observation and conclusion.
   Additional information: The leaf tissue is covered by a cuticle and waxes, which are fatty materials that repel water (hydrophobic).
2. Hypothesis: In your opinion, is there a link between the observation that you've just made, and the presence of stomata in the leaf tissue? Explain.

Activity 3:

Where do plants absorb water?

So far, we know only part of the mechanism that allows the passage of water from the roots of plants to the tips. We learned that the stomata play an important role, because through these pores, the release of water vapor through the process of transpiration is regulated. In this activity, we will examine where the plant captures the water required to meet the demand generated in the leaves.

Materials: young shoots of wheat germinated on a clay pot; Petri dish; black paper; binoculars; microscope; marker; methylene blue; a glass slide; a glass coverslip; a bowl of water; a dropper; paper towels; a knife.

Development of the activity:

a. Observation through binoculars.

Put the bud on a dark background, and illuminate the bud from the top with a light, and observe through binoculars. Draw the bud and label its parts (be sure to record the magnification of the binoculars and how the bud was prepared). Pay attention to the small filaments found at the ends of the roots. These are called root hairs. The hairs are tubular extensions of young epidermal root cells. They can reach up to 1.5 mm in length.

1. What characterizes the structure of hairs?
2. Try to estimate the number of hairs at the end of a root. Are there tens, hundreds, or thousands?

b. Observation of the bud through a microscope.

1. On a clean glass slide, place a drop of methylene blue. Cut the end of a bud that has many hairs (only 1-2 mm), and place it on the solution on the glass slide, and cover with a coverslip. Clean the excess liquid off the slide with a paper towel. You now have prepared a slide that shows the roots of a wheat bud.
2. Observe the prepared slide through the optical microscope. Begin at a low magnification and gradually increase, drawing what you see. Be sure you draw a large and detailed drawing. Record the method of preparation and level of magnification for the picture you drew.
3. Can you distinguish cell nuclei in the prepared slide?
4. In your opinion, how many cells make up a single hair?
5. Try to infer: how do the hairs absorb water for the root structure?
6. The hairs play an important role in the growth process of the root. In your opinion, how does growth in the root change the top of the plant?

Additional Information

The hairs are very thin and delicate. Their large number enables them to effectively absorb water because there is a great deal of contact with the ground. The hairs are inserted between the soil particles and grow towards the water found in the soil. Water enters the root hairs through their membranes and through the cell wall, which is especially thin and covers the protoplasm of the hairs. Through the hairs, minerals (salts) dissolved in the ground water are also absorbed.

The hairs are **singular** and only located near the ends of the root, and not along the entire root. Water also enters through the other parts of the root, but in a smaller amount, since the root is covered with a thick layer of cells that do not have hairs. To grow and develop, the root lengthens and branches. The ends lengthen, expand, and penetrate deeper into the ground, and new hairs are produced continuously near the ends of the new roots. Along with the creation of new hairs near the ends that are elongating, the mature root hairs die in areas of the root that are more developed.

Activity 4:

How does the water move from the roots to the leaves?

In the previous activity, we learned that the root hairs are located in an area where they can increase the absorption of water for the plant. Earlier, we learned that through the stomata, mostly found on the underside of leaves, water is released through the process of transpiration. This activity will examine the mechanism in the plant that allows the rise of water from the root to the stem, and even higher into the leaves, for example, in trees.

Materials: a white carnation or chrysanthemum with a long stem (15 cm); two 100 mL graduated cylinders; filter paper; a rubber band; red or blue food coloring.

Experiment

Development of the experiment:

1. Into each tube, pour 15 mL of water colored with red food coloring.
2. Place the stem of the white carnation into one of the tubes.
3. Cut the filter paper into a rectangle, about 15 cm by 10 cm. Fold it out so that it resembles the petals of a flower, like the photo to the right.
4. Place the filter paper into the second tube.

Place the two samples in the sun for half an hour.

1. Explain the results of the experiment using the components of scientific thinking: observation, hypothesis, additional information, and conclusion.
2. Cut the stem of the carnation along its length (cut a slit) and width (cross-section). What is the direction that matter is guided in the stem - along its length, or along its width?
3. In your opinion, what caused the water to ascend (rise)?
4. In a living plant, will water only rise?
5. What can you learn from this observation about the mechanism of water ascent in plants?

Activity 5:

How does water rise up the stem of a plant? Simulation experiment

In the activity, we saw that water rises along the plant from the roots to the leaves, which are found in the treetops. In this activity, try to understand what allows the continual movement of water in the system, which can reach tens of meters long for the water transportation system of tall trees. Try to understand this, based on the information we have accumulated in the previous activities.

Materials: 50 g of plaster; a narrow glass tube (diameter of about 5 mm); a beaker; food coloring; a support stand; pliers; wooden clips (clothespins); 2 small plastic cups; a 75 W lamp.

Experiment

Experimental process:

a. Pour the plaster into the plastic cup. Gradually add water and stir well until the mixture is smooth and thick.
b. Pour the plaster slurry into another small plastic cup until it is half full.
c. Fill the glass tube with water. Be careful that no air bubbles enter the tube, and that it is filled with water to the ends.

d. Insert the glass tube into the plaster so that it sinks in at least 1 cm. Be careful that the water in the pipe does not leak out. Hold the tube firmly in an upright position into the plaster for about 40 mins until the plaster hardens.
e. After the plaster has hardened, break the plastic cup, and remove the plaster and glass tube filled with water. Use a free finger to keep the end of the tube plugged, and insert the end into the beaker that contains the colored water.
f. Release your finger from the end of the tube once it is immersed in the colored water. Hold the plaster with the wooden clips as shown in the illustration.
g. Place the lamp close to the setup, and shine the light onto the plaster.

Observations

Observe the model and describe what is happening.

Conclusion

1. What is your **conclusion** based on the results of this experiment?
2. Determine the factors that may have influenced the rise of water in the tube.
3. If you had magic glasses through which you could see the water particles and glass particles, how do you think the process that took place in the tube would look? Try to describe the phenomenon with a drawing.

Additional Information

The force of attraction between particles is the reason for the adhesion and bonding of the water particles to each other. These **attractive forces** are responsible for the adhesion of water droplets to the walls of the vessels of the plant. The rise of a liquid into an empty tube, or within a narrow space is known as **capillary action**.

But listen up! Water on the ground does not rise to the tops of the trees by capillary forces. What determines the rise of water are the differences in the chemical potential, or energy level of the water along the columns of the plant. These differences manifest themselves as suction, generated by the loss of water through the leaves during the process of transpiration.

Connect the components of the experiment with the natural phenomenon it represents. Match each number to a letter.

Components of the experiment			Natural Phenomena
1. Glass tube	●	●	a. Water
2. Plaster block	●	●	b. The cells that make up the vessels in the stem of the plant
3. The micropores in the plaster	●	●	c. The leaf
4. Artificial lighting	●	●	d. Sunlight
5. Not in the simulation	●	●	e. Stomata
6. Water	●	●	f. Vessels on the stem of the plant

Activity 6:

Capillary action in the soil

In the previous activity, we were introduced to a property - the presence of attractive forces between water particles - that allows water to play an important role in life. These attractive forces are responsible for the physical phenomenon known as capillary action, and are manifested in two ways:

1. The forces of attraction between water particles themselves.
2. The forces of attraction between the particles of water and solid surfaces, which enable the rise of the particles along the walls of thin tubes.

The result is the formation of a water column that rises against the force of gravity.

In this activity, you will study the phenomenon of capillary action and its importance in the soil.

Additional Information

The capillary action phenomenon is manifested in the ability of water to generate a continuous column of water that rises in slender pipes and through cracks and small spaces, against the force of gravity. This phenomenon, which is associated with properties of water, is one that allows for the transportation of water in the **biosphere** (the world of living things on planet Earth). However, the capillary action phenomenon also occurs in the **geosphere** (the rocky/inert world), as discussed in the next activity.

Try to infer: How can plants absorb water from the soil, even well after the last rainfall?

Experiment

In this activity, you will try to partially answer the question: How do plants absorb water from the soil, even weeks or months after a rain?
Materials: a Petri dish; white paper towel; sandy soil; water.

Development of the experiment

a. Place the paper towel in the dish.
b. Get the paper towel very wet.
c. Fill the dish with dry sandy soil and wait 10 minutes, and then make another observation after another 30 minutes.

Observations

1. What change occurred in the level of soil moisture after 10 minutes?
2. What change occurred in the level of soil moisture after 30 minutes?

Conclusion

What conclusions do you arrive at after making the observations?

Hypothesis

In your opinion, how is the paper towel similar to water on Earth?

Direction of water movement in soil due to the process of capillary action

Additional Information

Capillary action also occurs on the ground. This phenomenon is largely responsible for the drying of the soil due to the rise of water to the surface of the soil and the subsequent evaporation from the soil into the atmosphere. Capillarity is the mechanism in which water has an adhesion force with the soil particles. The liquid water climbs and ascends along the micropores of the soil, similar to microcapillaries (very thin tubes).

Activity 7:

What role does transpiration of plants have on the groundwater system?

1. During a sunny summer, a subtropical pine forest can transpire 7 to 8 m^3 per hectare ($1m^3$ = 1,000 liters). What is the volume of this water? Assuming that the daily requirements of an urban family (4 members) is about 800 to 1,000 liters (excluding a swimming pool): The consumption of how many families is equivalent to the flow of forest transpiration during the warmer months?

Note: 2/3 of domestic consumption is related to the bathroom.

Pine forest in California

2. On the illustration to the right, label the parts of the following systems that represent the Earth: biosphere (living things), geosphere (soil and rocks), atmosphere (air), hydrosphere (water).

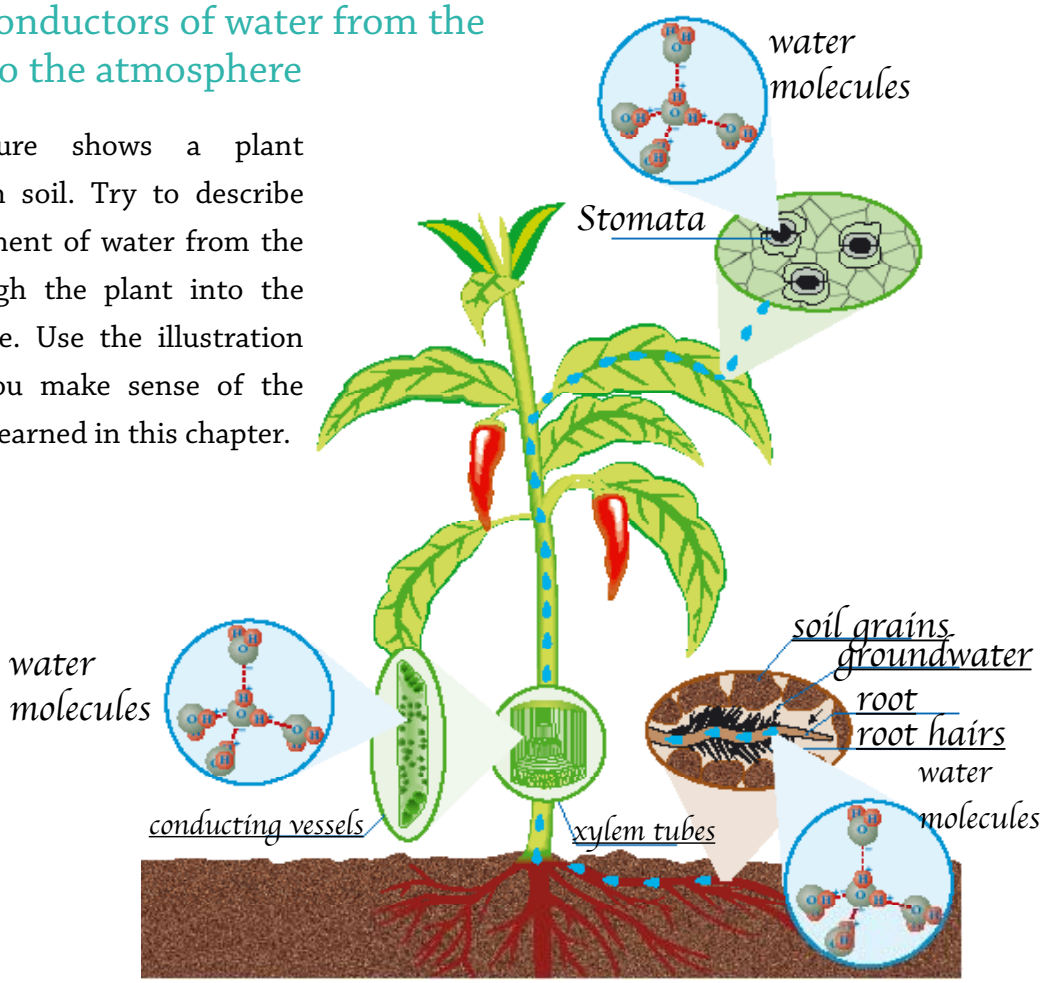
3. What influence does evaporation of water from the trees have on the different systems? (biosphere, geosphere, atmosphere, hydrosphere)

Activity 8:

Synthesis Activity - Plants and the movement of water into the atmosphere

Part One: Organization of knowledge - plants as conductors of water from the ground into the atmosphere

1. This picture shows a plant growing in soil. Try to describe the movement of water from the soil through the plant into the atmosphere. Use the illustration to help you make sense of the processes learned in this chapter.



2. What are your main conclusions regarding the statement: "plants are conductors of water from the ground into the atmosphere," as a result of the last seven activities conducted?
3. Organize your knowledge in the following way: at the top of the table are the concepts learned in this chapter (the names of the experiments are in the left column). Next to each experiment, indicate with a check (✔) below each concept learned in this experiment.

Concepts / Experiment	Transpiration	Capillary action	Stomata	Water absorption	Tubes of conduction	Suction	Evaporation
Do plants lose water?							
Where do plants lose water to?							
Where do plants absorb water?							
How does the water move from the roots to the leaves?							
How does water rise up the stem of a plant?							
Capillary action in the soil							
What role does transpiration of plants have on the groundwater system?							

Part Two: Observe a photograph

Look at the cover photo of this chapter, and try to calculate the height of the trees in this forest.

Use the photo to describe, in a few sentences, the mechanism that enables the rise of water in the trees of the forest from the roots to the tops of trees that are tens of meters high.

Important: Use the information you've accumulated in the activities in this chapter in your description.

Part Three: Analysis of additional information

Read the additional information found on the following pages, and under each, write down the observation, and the conclusion we reached with the experiments conducted in this chapter. See the following example.

Do plants lose water?

Everything that is exposed to air loses water: a wet floor, wet clothes, a pool, a freshly watered lawn, living things, plants, etc. This loss of water takes place due to the process of evaporation of water when exposed to air, and its transformation to water vapor (a gas). The loss of water into the air as water vapor is known as **evaporation**, and when this occurs from a plant, it is called **transpiration**. The rate of water loss depends on many factors, among which is the surface area to volume ratio of the body exposed to air. You probably know that laundry extended over a large area dries faster than when it is crumpled.

The evaporation process takes large amounts of water from plants and moves it into the atmosphere. Forest researchers have studied the amount of water that evaporates daily from the surface of the leaves and needles of pine trees, and moves into the atmosphere.

Additional Information

Forest researchers showed that during the summer, each hectare of pine trees (10,000 m^2) evaporated about 7,000 liters of water to the atmosphere daily.

Observation: In the activity "Do plants lose water?" we saw that the weight of the graduated cylinder + plant after six days was lower compared to its weight on the first day of the experiment.

Conclusion: plants are carrying out a process of losing water to the atmosphere.

How do plants lose water?

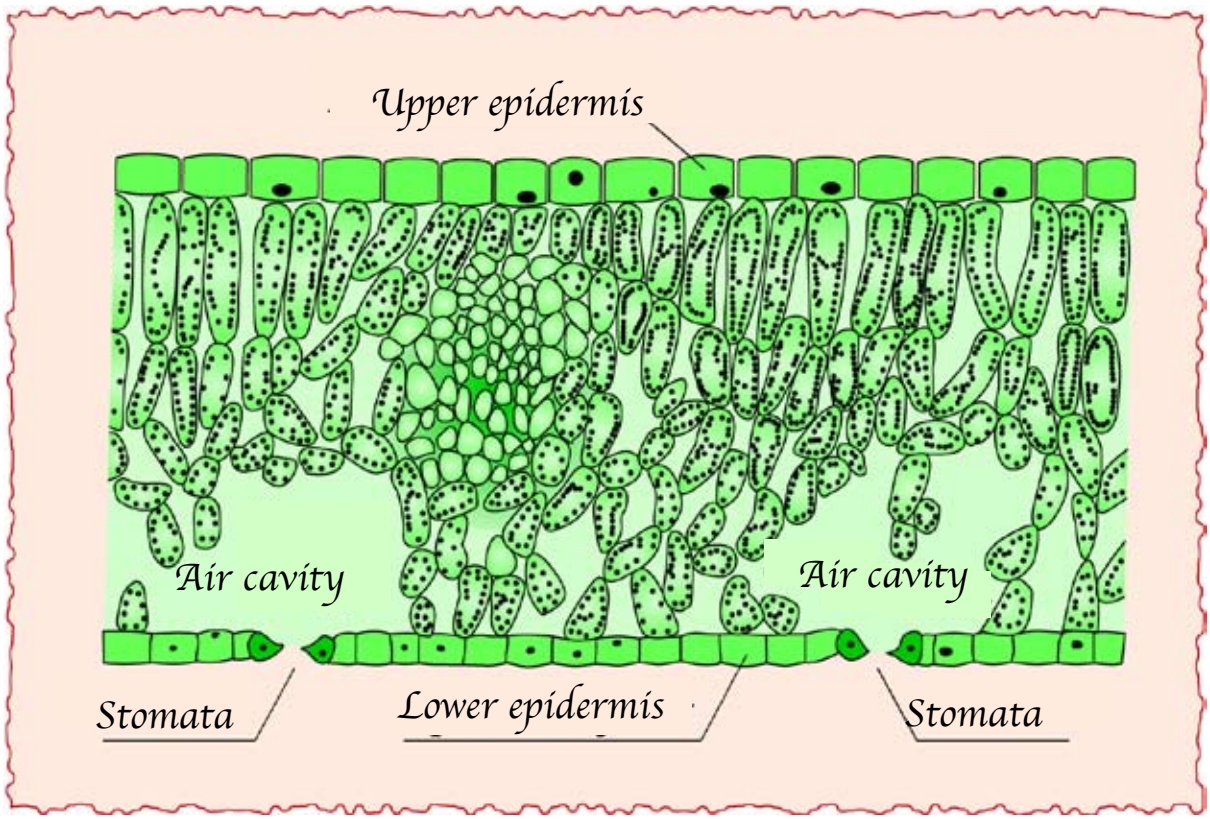
Plants, like all living multicellular organisms, are surrounded by an outer layer (epidermis) that consists of cells. When we look through the microscope, the stoma of leaves or stems can be identified because of relatively large cells that form structures whose shape looks like a mouth. This is why the structures are called stomata. "Stoma" is Greek for mouth.

The stomata lead to a large air cavity that takes up much of the internal volume of the leaf. Therefore, the interface between the leaf tissue and air is much larger than the outer surface of the leaf.

Stomata consist of two large cells known as **guard cells** and they serve as the "lips" of the stomata. When the plant is engorged, guard cells are enlarged (they have greater turgidity) and take the form of two bananas between which there is an opening (pore). The stoma is completely open. In times of higher temperature and radiative energy, the plant may lose too much water. Therefore, guard cells partially lose their turgidity, and the edges of the pore come together, and the pore closes, closing the stomata almost completely.

Observation:

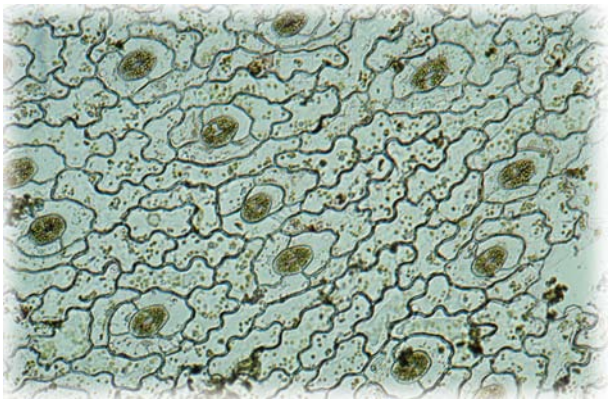
Conclusion:



Cross-section of a leaf

Why do plants need tiny pores in their epidermis?

The pant tissue is exposed directly to light, and is covered by a cuticle made up of cutin and waxes. These are fatty substances that repel water (hydrophobic). Therefore, over 95% of the water lost during the day leaves the plant through the stomata. Only 5% of the water evaporates directly through the cuticle of the leaf. It is through the stomata that gases are exchanged between the plant and its surrounding environment.



Stomata in the epidermis of a fern. Photographed with an optical microscope (X160 magnification)

During the day, the plant absorbs air, mainly carbon dioxide, through the stomata. The plant releases water vapor and oxygen through the stomata as well. During the night, the stomata

are nearly closed, and it absorbs very small amounts of oxygen and releases very small amounts of carbon dioxide. The pores of the stomata lead to cavities of air found in the tissue of the leaf or stem, and in them, gas exchange is carried out. Under certain environmental conditions, stomata are nearly closed, and gas exchange is greatly reduced. Therefore, the plant can regulate gas exchanges with the environment through the stomata.

Observation:

Conclusion:

Can the opening of the stomata harm the plant?

Plants lose large amounts of water through the stomata. Excessive water loss can cause an imbalance in the plant, and a great loss of water can lead to the collapse of the water transportation systems in the plant. Evolutionary processes select for plants that can adapt and adjust their mechanisms to conserve water in unfavorable conditions. The pore size of the stomata changes over the course of a day. In most plants, the stomata are open when it's light, and close almost completely when it's dark. Meanwhile there are plants whose stomata are never closed, or only open at night (family: Cactaceae). In the morning and afternoon, the guard cells absorb water from the neighboring cells of the epidermis. They increase their volume, and the stomata open. Similarly, when the guard cells lose water around noon for example, their volume is reduced, and the stomata can partially close.

In a large number of plants, such as corn, apples, and tomatoes, the number of stomata on the top of the leaf (exposed to direct sunlight) is much smaller than the number of stomata found on the bottom of the leaf. This arrangement allows the stomata to open without generating a significant loss of water.

Observation:

Conclusion:

From where does water for the plant come from?

The main role of the root is the absorption of water and salts dissolved in it, but the root is also associated with plant growth.

In a large number of plants, the root system has branches, therefore a large number of lateral roots significantly increases the overall length of the root, and its surface area. This huge surface area of the root system makes contact with the soil particles, and the water solution in the pores of the soil.

The roots absorb water, especially in the zone of the hairs. These long, and very thin hairs grow between the soil particles and absorb water found in the surrounding environment and the salts dissolved in it.

This solution passes through the cells, their cell walls, membranes, and through the intercellular spaces found in the xylem tubes in the root, which then lead up to the other parts of the plant. It is worth noting the volume of water flowing through the plant, compared with other processes. On a summer day, a corn plant loses one liter of water, but only requires 40 mL for the growth of new leaves, and only 4 mL for the biochemical process of photosynthesis.

Observation:

Conclusion:

What transports the water into the plant?

The drivers of the plant system are composed of two subsystems that have different, but important functions:

a. **Phloem** – System that transports food substances (mainly organic) in the plant. Green leaves produce soluble sugars (mainly glucose) through the process of photosynthesis. Glucose is generated in the leaves, and passes through the phloem in the stem to the organs responsible for consumption and reserves, such as fruit, roots, and shoots. There are plants whose roots have specialized reserves for storing substances, such as carrots, potatoes, sweet potatoes, and radishes. The process of photosynthesis and the transport of food substances in the plant will be examined in more depth in future studies.

b. **Xylem** – System that transports mainly water and minerals through the plant. Xylem transports water and salts from the root to all other parts of the plant. The transport of water takes place in a system of dead cells (vessels) in which the cell walls are thickened. Where the cell has died, a space is opened and facilitates the movement of water. These cells are generally larger in diameter, and longer, and contain many holes that allow water to pass between neighboring cells.

Observation:

Conclusion:

Why water rises in the plant?

Two factors determine the upward movement of water:

1. **Transpiration** – In the air cavities found in the leaves, water turns to vapor (evaporates) and is released into the environment through the process of transpiration. As a result, especially during the day, the leaves generate a lower chemical potential or energy level of water with respect to the roots. You can imagine water traveling up through the ground, like a long train in which each of the cars is a molecule of water. When water molecules evaporate from the leaves, the suction generated by the transpiration pulls the "train." The water in the vessel is sucked up through the transportation system and for each molecule that leaves through the top, another molecule comes in from below. In this way, new water molecules are absorbed through their roots.

   If it were not for the process of transpiration, it would not be possible to move water from the roots to the treetops, because the process of capillary action only helps to explain the water column rises to a few tens of centimeters high. The rate of water transport in plants varies according to the species. In eucalyptus trees, which have a height of 50 meters, the rate of water transport has been measured to be 20-45 meters per hour.

2. **The cohesive forces between water molecules** – The continuity of the water column within the plant is due to the cohesive forces between water molecules. The water is mostly absorbed by the plant through root hairs found at the ends of the root. They move onto the the transportation system, which generates a continuous flow of water through the plant (like columns of water) until it reaches the leaves found at the top. There are cohesive forces between the water molecules and between the water and the walls of the tubes. This is important in order to avoid rupture of the water column and the penetration of air into the system. Air moving into the system would cause the collapse of the water column (a phenomenon called cavitation) and would prevent the arrival of water to the rest of the plant.

Observation:

Conclusion: