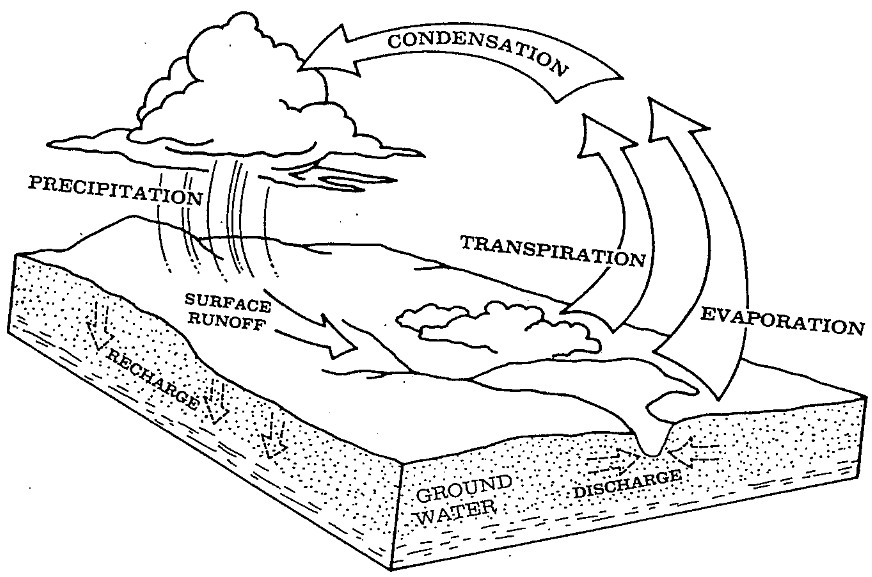
Teaching Activity: The Hydrologic Cycle

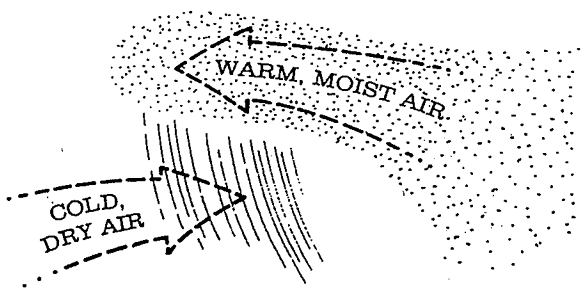
Background: The amount of water in the atmosphere is only enough to supply the needs of the Earth for about 10 days. Because of the limited supply of water in the atmosphere, there must be a constant interchange of water between the atmosphere and the surface of the planet. Aided by the energy from the Sun and the force of gravity, water moves in an endless cycle from the oceans to the atmosphere and back to the oceans again. This circulation is known as the *hydrologic cycle.*



The Earth's Hydrologic Cycle

Water is transferred from the surface to the atmosphere through two processes: *evaporation and transpiration.* In the process of *evaporation,* liquid water is transformed into a gas called water vapor, while *transpiration* is the process by which plants give up moisture through their leaves to the atmosphere. The heat from the Sun drives these processes and transfers water from wet ground, open bodies of water and vegetation to the air. Based on surface area, wind speed and temperature, the average annual evaporation/transpiration rate is seasonally and annually variable with location across the surface of the planet. It is estimated that about 3100 cubic miles (1 cubic mile = 1.1 trillion gallons) of water vapor is contained in the atmosphere at any one time. This vapor is not available as a source of water until it falls to Earth as *precipitation.*

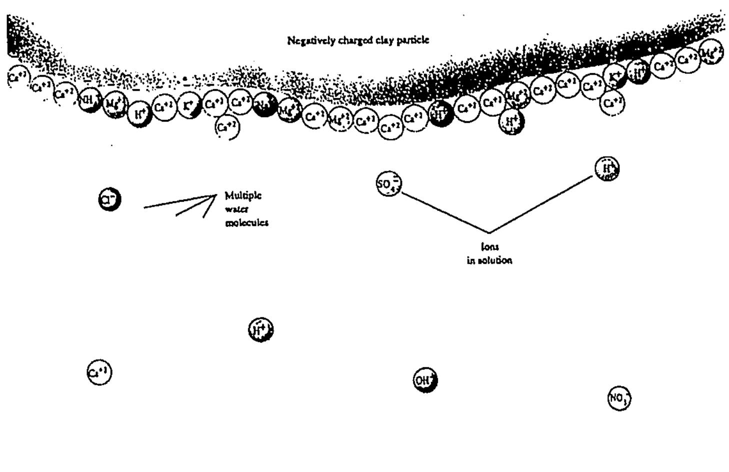
When warm air is lifted to higher and cooler altitudes, water vapor changes back to a liquid through the process of *condensation.* If cooling is sufficient and the air is forced beyond its saturation level, the vapor *condenses* as droplets of water forming rain. Snow forms by a similar process where lower temperatures cause the water to freeze during condensation.



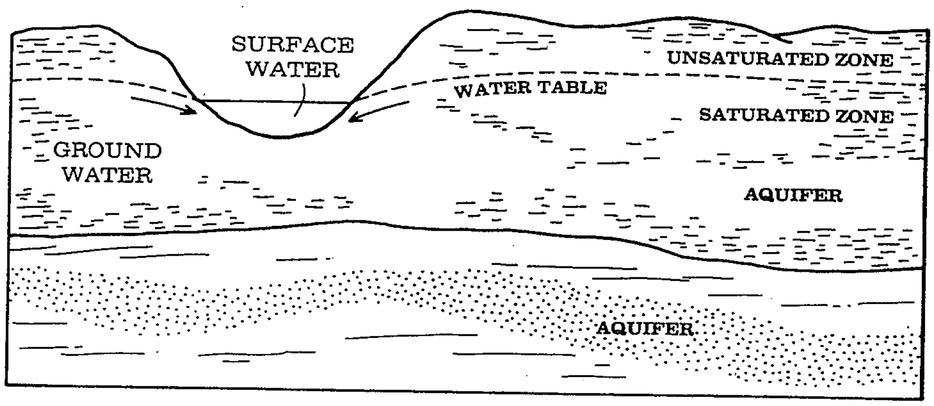
Condensation occurs when the air is cooled sufficiently.

Falling to the Earth's surface in various forms, *surface water* accumulates temporarily on vegetation, the soil and in lakes and rivers. When the soil surface has absorbed as much water as it can and precipitation continues, the additional water flows over the land surface and runs directly into lakes and streams as *runoff* and eventually returns to the ocean or to a closed drainage basins where it is again subject to evaporation. In temperature regions, runoff is generally the greatest during spring snow-melt, and after summer thunderstorms which can produce heavy rainfall in localized areas over a short period of time. Other variables affecting runoff include the slope of the land, types and quantity of vegetation, types and conditions of soil, and duration and intensity of precipitation.

Water is absorbed into the soil surface through the process of *infiltration.* Infiltration occurs as water flows rapidly through the larger openings between soil particles under the influence of gravity. It also takes place as a gradual wetting of smaller particles by *capillary action.* Capillary action causes the water to form a thin film around a soil particles because there is a stronger attraction between the soil particles and the water molecule than there is between the water molecules themselves.



Water infiltrating the ground first enters an area of soil where some of the spaces between the soil particles are filled with air; come of the water is consumed by plants and a small amount is held on the soil particles. Surplus water percolates downward to an area where all available cracks and spaces are filled with water. It may eventually reach an aquifer, an underground layer of rock or a deposit of sand, silt, or clay permeable enough to contain and transmit *ground water.* Water beneath the Earth's surface generally moves very slowly (a few feet per year is not uncommon). The movement is affected by the capacity of the material to transmit fluids (permeability), the difference in elevation between the recharge area and the discharge area and the force of gravity.



Occurrence and Movement of Ground Water

Ground water used today may have traveled through the hydrologic cycle many times since the Earth was formed. Some remains underground for long periods of time; other water moves slowly between the grains of soil or in cracks in rock material until it reaches a point where it can discharge at the surface as a lake or stream. Some of it may be tapped by the root systems of plant or used to sustain animal life. Regardless of the manner in which ground water leaves the ground, when it does, it is then subject to the processes of transpiration and evaporation, once again beginning the hydrologic cycle.

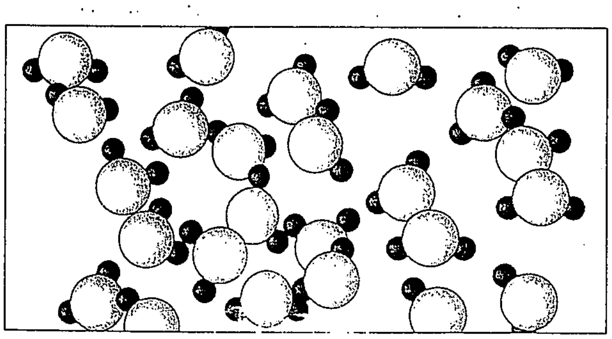
Important Terms: Hydrologic cycle, atmosphere, gravity, evaporation, transpiration, condensation, precipitation, runoff, surface water, infiltration, ground water, capillary action, aquifer, permeability, discharge/recharge area;

Objectives:

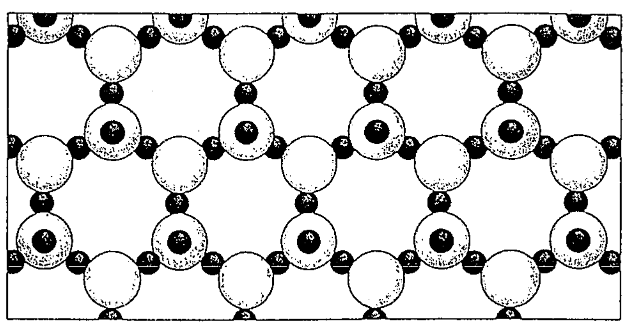
- To model the relationship between the states of matter (specifically water) and heat energy;
- To simulate the Earth's water cycle;
- To evaluate / quantify the exchange of water within the Earth's hydrologic cycle;

Part I: Energy at Work

Background: One particularly striking feature of our planet is the large amount of water present. Earth's water, or hydrosphere, extends far into the atmosphere and lithosphere, the gaseous and solid regions of our planet. Unlike most other substances on Earth, water exists in all three states, or phases, within a relatively narrow temperature range. Water moves quickly from a solid state, or ice, to a liquid, and on to a gas, or vapor. In the drawings that follow, the black spheres represent hydrogen atoms and the larger gray spheres represent oxygen atoms. Each hydrogen-oxygen-hydrogen triplet represents a water molecule that is held together by the attraction of atoms within the molecule. At temperatures above freezing, water molecules slide around one other. This motion prevents water droplets from taking on a definite shape and results in what is called a liquid. When temperatures get low enough to slow down the "bumping" motion of liquid water, the molecules tend to vibrate in place. Having lost much of their heat energy. At this point, attractive forces between atoms are able to hold the atoms in place, creating an ice crystal, which is a solid. If heat energy is added, the order of the crystal is broken and the water returns to a liquid state. It is in the liquid state at 4 degrees C that water is most dense. If even more heat energy is added, the motion may be strong enough to cause the water molecules to overcome their mutual, or intermolecular, attraction and move off into the air, or evaporate.



Liquid water magnified millions of times

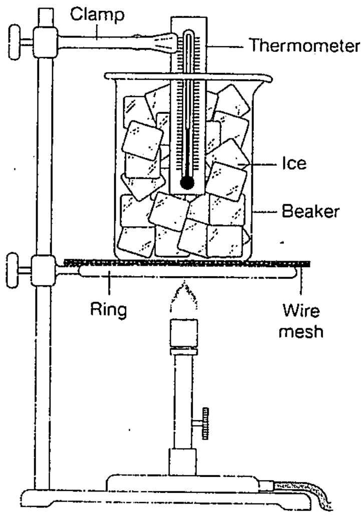


Water molecules as ice crystals

Materials (Per group): Ring stand, ring, thermometer clamp, Celsius thermometer, wire mesh, heat source, 400 mL Pyrex beaker, ice cubes, clock or timer, boiling chips;

Procedure:

1. Equipment should be set up as shown below so that when lighted, the burner flame will be positioned as shown.



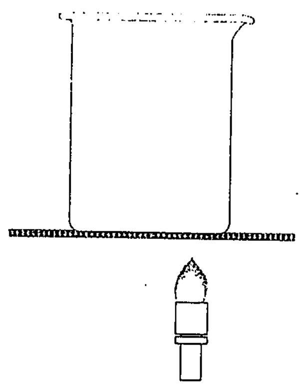
2. When the thermometer has reached) degrees C or stops falling, this value should be recorded in the **Data Table**.

3. ***CAUTION:* Students should wear safety goggles**. Light the burner and adjust the flame.
    - The burner should be placed under the beaker and timing begun.
    - Students should avoid touching the beaker with the thermometer.
    - Steady heating should be maintained during the heating process.

4. The temperature should be recorded every minute until the water reaches a full boil.
    - Students should continue to record the temperature every minute after the water reaches the point of boiling for another 4 minutes.
    - As they are recording the temperatures, they should make note of the following temperatures:
        - the time at which the ice began to melt;
        - the time at which the ice was completely melted;
        - the time at which the water began to boil.

5. After the water has been boiling for 4 minutes, students should remove the burner from under the beaker.

6. They should wait about 30 seconds or until the water has stopped bubbling.
   - Students should then drop in two pinches of rock chips into the beaker.
   - Students should put the beaker back under the beaker so that the flame is off to one side of the bottom of the beaker as shown below.



7. Students should observe the motion of the rock chips in the boiling water.
   - Students should then draw the motion that they observe in the beaker outline provided.

8. Students should turn off the burner and return all equipment.

9. Students should graph the temperature readings from the Data Table on the graph grid provided, showing Temperature vs. Time.

10. Students should complete the ***Analysis and Conclusions*** section.

Student Activity Sheet: Part I: Energy At Work

Background: One particularly striking feature about our planet is the large amount of water present. Earth's water, or hydrosphere, extends far into the atmosphere and lithosphere, the gaseous and solid regions of the planet. Unlike most other substances on Earth, water exists in all three states, or phases, within narrow temperature range. Water moves quickly from a solid state, or ice to a liquid, and on to a gas, or vapor. At temperatures above freezing, water molecules slide around each other. This motion prevents water droplets from taking on a definite shape and results in what is called a liquid. When temperatures get low enough to slow down the "bumping" motion of liquid water, the molecules tend to vibrate in place, creating an ice crystal, which is a solid. If heat energy is added, the order of the crystal is broken and the water returns to a liquid state. If even more heat is added, the motion may be strong enough to cause water molecules to overcome their mutual, attraction and move off into the air, or evaporate. In the following activity, you will investigate the three states of water by removing and adding heat.

Procedure:

1. Set up your equipment as demonstrated by your teacher.

2. When the thermometer has reached 0 degrees C or stops falling, record the value on the **Data Table**.

3. **CAUTION: WEAR YOUR SAFETY GOGGLES!!!** Light the burner and adjust the flame.
   - The burner sho;uld be placed under the beaker and timing begun.
   - Avoid touching the beaker with the thermometer.

4. Record the temperature every minute until the water reaches a full boil.
   - Continue to record the temperature every minute for another 4 minutes.
   - As you are recording the temperature, make a note of the following temperatures:
     - the time at which the ice began to melt;
     - the time at which the ice was completely melted;
     - the time at which the water began to boil;

5. After the water has boiled for 4 minutes, remove the burner from under the beaker.

6. Wait about 30 seconds or until the water has stopped bubbling.
    - Drop two pinches of rock chips into the beaker.
    - Put the beaker burner back under the beaker so that the flame is off to one side of the bottom as demonstrated by your teacher's set up.

7. Observe the motion of the chips in the boiling water.
    - Draw the motion that you observed in the beaker outline provided.

8. Turn off your burner and return all equipment.

9. Graph the temperature readings from your **Data Table** on the graph grid provided, showing Temperature vs. Time.

10. Complete the **Analysis and Conclusions** section.

DATA TABLE

TIME	TEMPERATURE (* CELSIUS)	TIME	TEMPERATURE (* CELSIUS)
0		13	
1		14	
2		15	
3		16	
4		17	
5		18	
6		19	
7		20	
8		21	
9		22	
10		23	
11		24	
12		25	

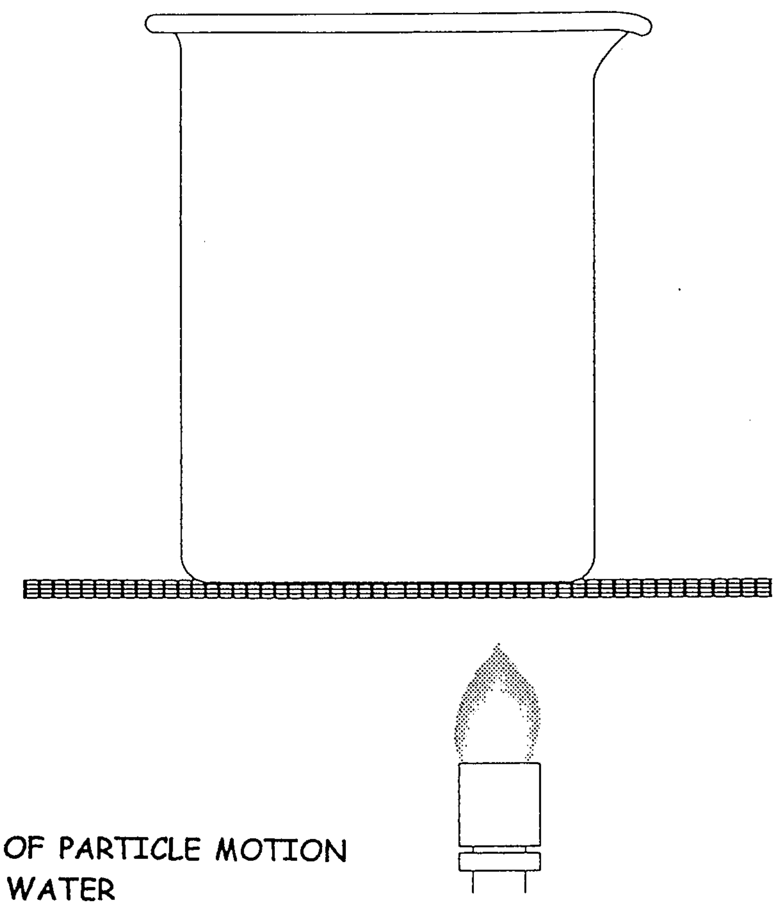
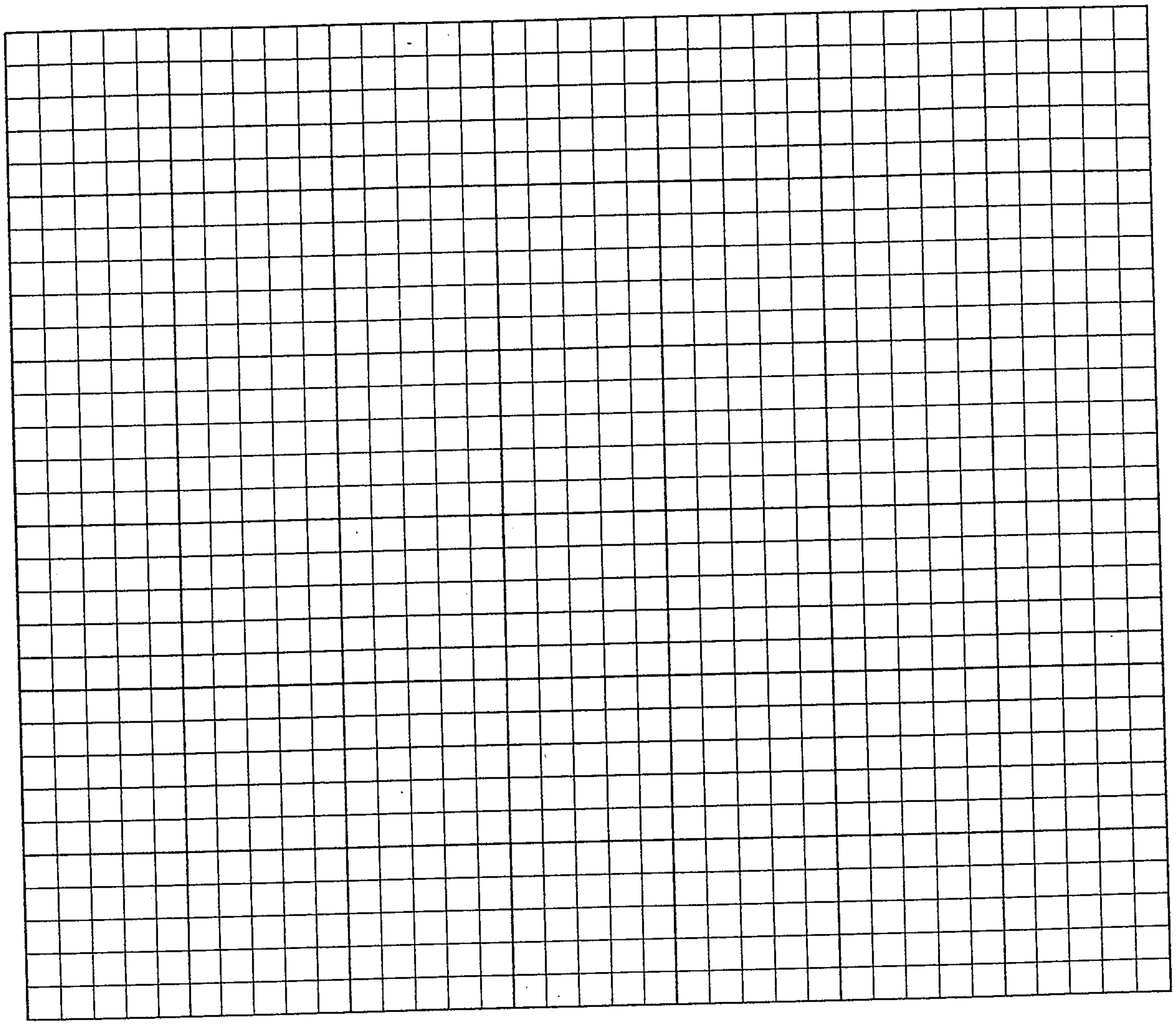


DIAGRAM OF DIRECTION OF PARTICLE MOTION
IN BOILING WATER

GRAPH OF TEMPERATURE READINGS:



Analysis and Conclusions:

1. Describe the rate of temperature change shown by your graph.

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2. How are the various states, or phases of the water related to the rate of temperature change?

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3. Did the constant energy input produce a constant temperature increase? Why?

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4. Some of the heat energy absorbed by the water during this investigation is converted to potential energy known as latent heat. How does this "hidden energy" return?

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5. Describe the motion of the small rock chips placed in the boiling water that you recorded in your drawing. What form of heat transfer (convection, conduction or radiation) produced this pattern of motion?

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Part II: A Simulation of the Hydrologic Cycle

Introduction: The processes in the hydrologic cycle continuously move water between the Earth's surface and the atmosphere. In this activity students will observe the basic processes that form the hydrologic cycle: evaporation, condensation and precipitation.

Materials (Per pair of students): 2 same-sized jars (such as baby food jars), one of which has a lid, 2 same-sized flat containers such as pie pans, measuring cup or 250 mL beaker, medium sized sauce pan (about 2.5 L or 2 qt), hot plate or stove, small saucepan with long heat-proof handle (about 1.5 L or 1 qt), ice, oven mitt or heat-proof glove;

Procedure:

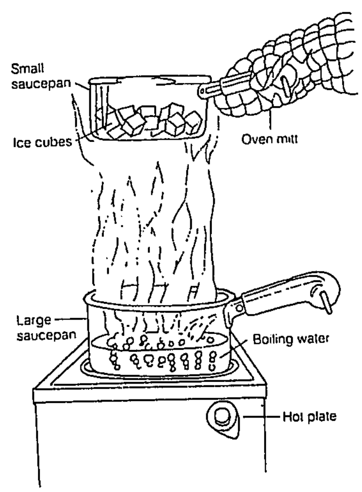
1. Students should measure 100 mL of water into each jar and flat container.
   - Each jar should be securely covered with a lid.
   - Both jars and one of the flat containers should be placed ion a sunny place.
   - The other flat container should be placed in a dark closet.

2. Jars and containers should be left to stand for about 1 day, and then examined.
   - The measuring cup should be used to remove any water remaining in the jars and containers. Students should note the amount remaining.
   - Observations should be recorded on the LAB sheet.

3. Students should then fill the saucepan about $\frac{1}{4}$ full with water.
   - The pan should be placed on the hot plate and brought to a boil,
   - Any observation should be recorded on the LAB sheet.

CAUTION: Students need to be very careful when working with a heat source!!!

4. Students should then fill the small saucepan with ice cubes.
   - Wearing an oven mitt, students should then hold the saucepan with the ice in it above the saucepan with the boiling water.
   - The saucepan should be held so that the main part of the pan, and not the handle are over the boiling water. **(See below.)**



5. Students should observe what happens to the bottom of the small saucepan.
   - Observations should be recorded on the LAB sheet.

6. Students should turn off the hot plate and clean up after the equipment has cooled off.

7. Students should complete all activities /questions in the **Observations** and **Analysis and Conclusions** sections.

Part III: Quantifying the Global Water Cycle:

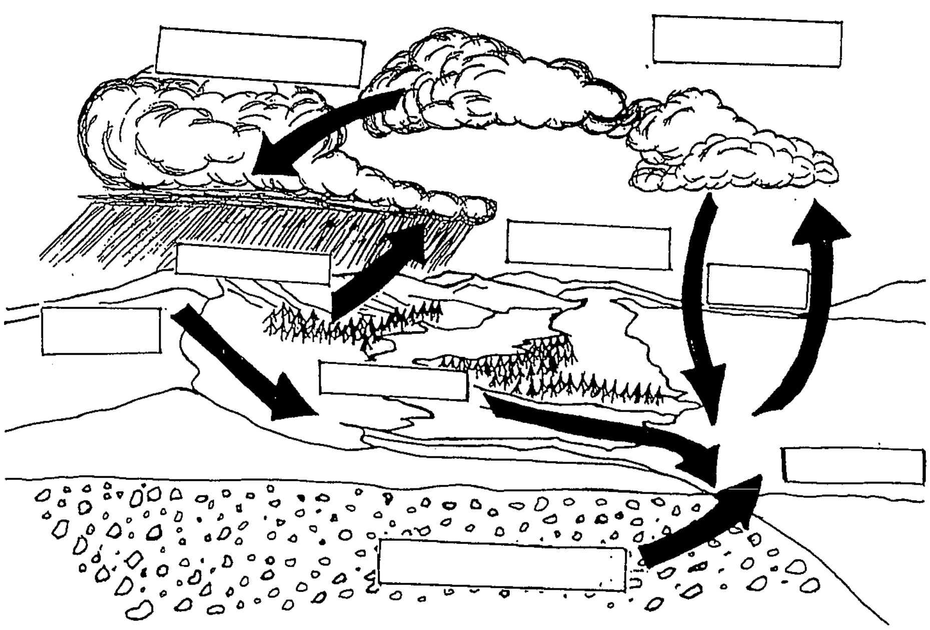
Introduction: Since the quantities of water in global water cycle are so large, it is traditional to describe the pools (reservoirs) and transfers (fluxes) in units of 1000 km^3. Remember that each cubic meter of water weighs 1 ton, so 1000 km^3 weighs 10^{18} g. The flux of water in the water cycle is also expressed in units of depth. For example, if all the rainfall on land were spread evenly over the surface, each weather station would record a depth of about 70 cm/yr. Units of depth can just as easily be used to express evaporation. The annual evaporation from the ocean removes the equivalent of 100 cm of water each year from the surface area of the sea. The data table and diagram that follow represent the fluxes and pools in the global water cycle and illustrate the enormous quantities of water that move through the atmosphere each year.

DATA TABLE: Pools (km^3) AND Fluxes (km^3/yr) in the Global Hydrologic Cycle

Pool (km^3) or Flux (km^3/yr)	AMOUNT
*SNOW AND ICE	27,500,000
*GROUNDWATER	8,200,000
RIVERFLOW AND RUNOFF	40,000
*OCEANS	1,350,000,000
EVAPORATION FROM OCEAN	425,000
EVAPORATION FROM SOIL/PLANTS	71,000
PRECIPITATION TO OCEANS	385,000
PRECIPITATION TO LAND	111,000
WATER VAPOR TRANSPORT TO LAND	40,000
*ATMOSPHERE	13,000

* **Indicates a Pool**

THE GLOBAL WATER CYCLE



Procedure:

1. Review and discuss the data table and diagram of the water cycle with students.
2. Instruct students to complete the diagram by labeling the blanks with the correct title and amount of water involved.

   Example: **Atmosphere 13,000 Km^3**

3. Students should then complete the **Analysis and Comprehension** section.

Student LAB Sheet: A Simulation of the Hydrologic Cycle

Introduction: The processes in the hydrologic cycle continuously move water between the Earth's surface and the atmosphere. In this activity you8 will observe the basic processes that form the hydrologic cycle: evaporation, condensation and precipitation.

Procedure:

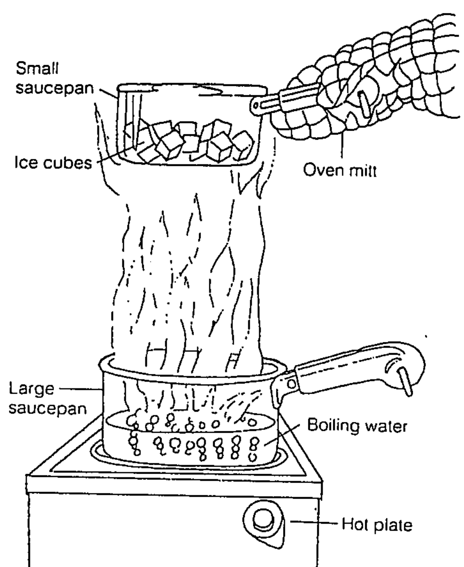
1. Measure 100 mL of water into each jar and flat container.
    - Secure each jar and container with a lid.
    - Place both jars and one of the flat containers in a sunny place.
    - Place the other flat container in a dark closet.

2. Let the jars and containers stand untouched for 1 day. Then examine them.
    - Use the measuring cup to take out any water remaining in the jars and containers. Note the amount of water remaining.
    - Observations should be recorded in your LAB sheet.

3. Fill the saucepan about $\frac{1}{4}$ full with water.
    - Put the pan on the hotplate and bring it to a full boil.
    - Record any observations you make on your LAB sheet.

    CAUTION: BE careful when working with the heat source!!!

4. Fill the small saucepan with ice cubes.
    - Wearing an oven mitt, hold the saucepan with the ice in it above the saucepan with the boiling water,
    - Hold the saucepan so that the main part of the pan and not the handle are over the boiling water. **(See below.)**



5. Observe what happens to the bottom of the small saucepan.
    - Record you observations on your LAB sheet.

6. Turn off the hot plate and clean up when the equipment has cooled.

7. Complete all activities / questions in the **Observation** and **Analysis and Conclusions** sections.

Student LAB Sheet: A Simulation of the Hydrologic Cycle

Observation:

1. What happened to the water in the jars and the container? ________________
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2. Describe what you observed about the boiling water. ________________
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3. What happened to the bottom of the small saucepan? ________________
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4. How much water remained in the jars and container after 1 day? ____________
   How much was lost? ____________________

Analysis and Conclusions:

1. What hydrologic cycle process caused the results in step 2. ________________
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2. Using the results from step 2, compare the amount of water in the two jars, in the two flat containers and in the open jar and flat container that were in the sunny location. What can you conclude about evaporation from these results?
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3. Identify the hydrologic cycle process that you observed in step 5. Explain your answer. ____
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4. Compare your results with those of your classmates. Are they the same or different? Why? ________________________________
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5. On a hot, sticky day, you notice water collecting on the outside of your glass of ice water. One of your friends says that the hot weather has caused the pores in the glass to open up so that the water leaks out. You suspect that the water got on the outside of the glass another way. What is your hypothesis? How might you go about testing your hypothesis? ____________________

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6. Cold air can hold less water than warm air. The loss of enough heat energy causes water vapor to condense into liquid water. Use this information to explain the following events.

   a. Steam condenses on a pan that contains ice. ________________

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   b. Dew forms on grass during the night. ____________________

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   c. Morning fog disappears as the day gets warmer. ______________

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How do these events relate to the hydrologic cycle? ________________

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Student Activity Sheet: Part III: Quantifying the Global Water Cycle

Introduction: Since the quantities of water in the global water cycle are so large, it is traditional to describe the pools (reservoirs) and transfers (fluxes) in units of 1000 km^3. Remember that each cubic meter of water weighs 1 ton, so 1000 km^3 weighs 10^{18} g. The flux of water in the water cycle is also expressed in units of depth. For example, if all the rainfall were spread evenly over the surface, each weather station would record a depth of about 70 cm/yr. Units of depth can just as easily be used to express evaporation. The annual evaporation from the ocean removes the equivalent of 100 cm of water each year from the surface area of the sea. The data table and the diagram that are attached represent the fluxes and pools in the global water cycle and illustrate the enormous quantities of water that move through the atmosphere each year.

Procedure:

1. Review and discuss the data table and the diagram with your teacher.
2. Complete the diagram by labeling the blanks with the correct title and amount of water involved.
   Example: **Atmosphere 13,000 km^3**
3. Complete the Analysis and Comprehension section.

DATA TABLE: Pools (km^3) AND Fluxes (km^3/yr) in the Global Hydrologic Cycle

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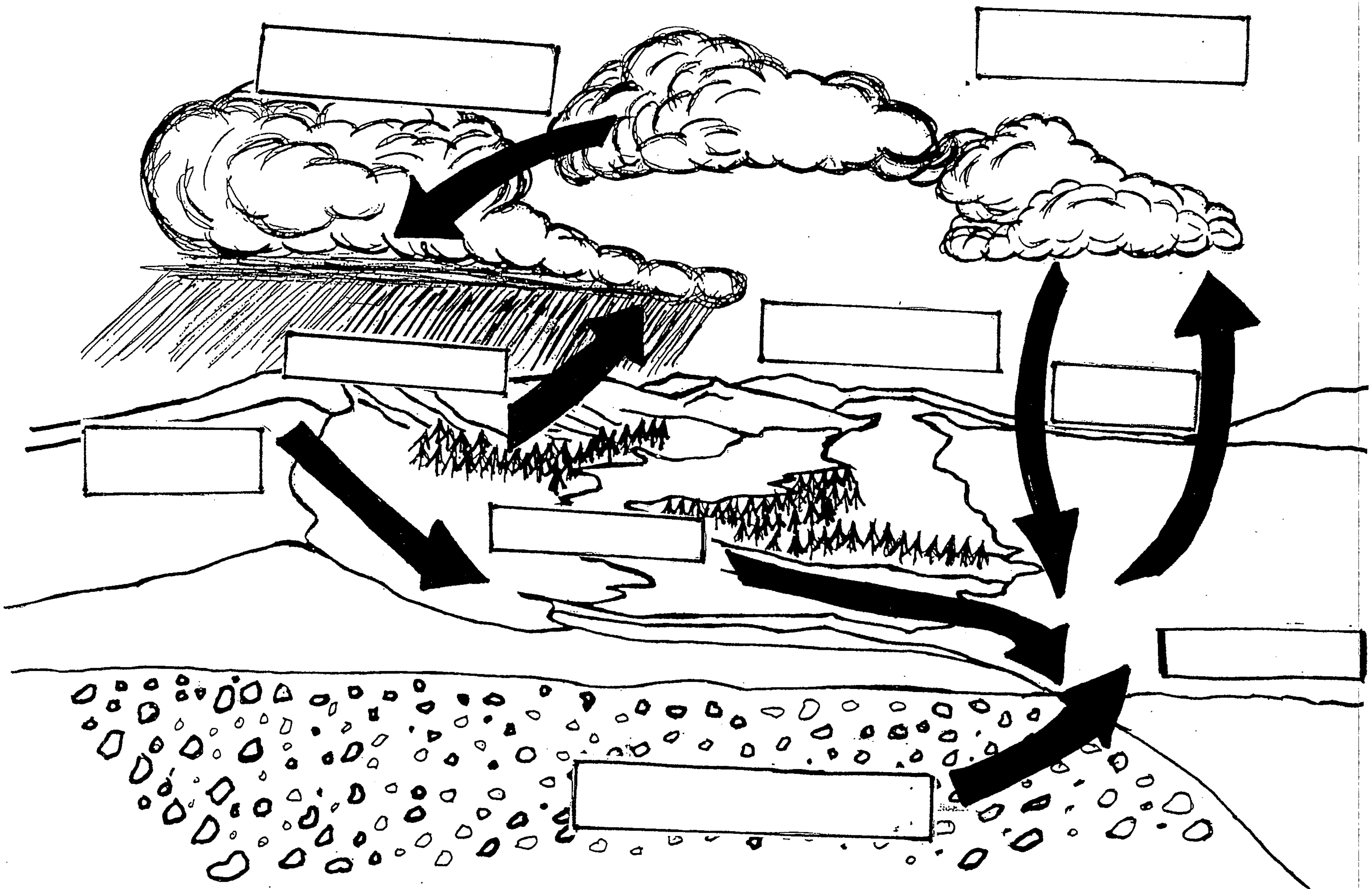
THE GLOBAL WATER CYCLE



Analysis and Comprehension:

1. What are the 4 reservoirs of water in the hydrologic cycle?

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2. List the fluxes involved in the hydrologic cycle from greatest to least.

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3. What is the total amount of water involved in the hydrologic cycle?

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4. What is the largest of the 4 reservoirs?____________________

5. How much water is lost to the atmosphere through evaporation ?

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6. How much water is returned to the surface through precipitation?

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7. What do these numbers tell you about the cycling of water through the Earth's system? ________________________________

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8. When precipitation falls to the Earth's surface three things can happen to it can run off, evaporate or soak into the ground. What happens to the water that soaks into the ground? ____________________

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9. What percent of the total amount of water that falls to Earth evaporates? ______________________________

10. About 99% of the Earth's water supply is in the oceans or locked in the ice caps. Because of this, it is not available for use by humans. Explain how the water cycle helps to provide a constant supply of useful freshwater. __________________________________

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11. Using the information from the Data Table, compute the lifetime of a molecule of water in the atmosphere. HINT: Look at evaporation amounts and the atmospheric pool. ______________________