

# ACID RAIN

WHAT IS IT AND HOW IS IT MEASURED?

A Series of Five Lesson Plans for Grades 6-8

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## Acid Rain: What is it? How is it measured?

Grade Levels 6 - 8

### 1.0 GOALS

- 1.1 The goal of this lesson plan is to introduce the grade school student to the topic of acid rain and its relevance to Great Smoky Mountains National Park.
- 1.2 Five lessons are included, each building upon the previous one.
- 1.3 There are many high quality environmental education kits on the market concerning acid rain. Teachers are encouraged to use them.
- 1.4 This lesson plan was prepared by the staff of the Uplands Field Research Laboratory and is intended to provide information to the public on current research.

### BACKGROUND INFORMATION

#### 2.0 THE pH SCALE

- 2.1 As mentioned above, the pH scale ranges between 0 and 14, with 7 being neutral (Figure 1). A substance with a pH less than 7 is acidic. If greater than 7, the substance is basic, or alkaline.
- 2.2 Each one-unit change in pH is a tenfold increase or decrease in the strength of the acid or base being measured.
- 2.3 A unit change from pH 5 to pH 3 would be a hundred times ( $10 \times 10$ ) increase in acidity.

#### 3.0 DEFINITION OF ACID RAIN

- 3.1 Robert Angus Smith, an English chemist, first used the phrase "acid rain" in 1852 when he noted the connection between London's polluted skies and the acidity of its rainfall.
- 3.2 Most scientists agree that "normal" rainfall has a pH of 5.6. Rain in the atmosphere reacts with carbon dioxide ( $\text{CO}_2$ ) to form a weak carbonic acid, altering the rain pH to 5.6.
- 3.3 Acid rain is defined as any form of wet precipitation which has a pH less than 5.6 (on a scale of 0 to 14, with 7 being neutral). The "rain" becomes acidic when water molecules ( $\text{H}_2\text{O}$ ) react with gases in the air.
- 3.4 These gases are primarily sulfur dioxide ( $\text{SO}_2$ ) and various nitrous

oxides ( $\text{NO}_x$ ) This combining of gases and water molecules takes place when<sup>x</sup> the water captures (attracts) hydrogen ions ( $\text{H}^+$ ) from the gases (ions are electrically charged particles in molecules).

#### 4.0 HOW ACID RAIN IS MEASURED

- 4.1 The pH test can be done in different ways. Two common methods use either a pH meter or a pH comparator kit.
- 4.2 A pH meter is a piece of equipment which measures the concentration of hydrogen ions in a solution. The pH meter uses a probe called an electrode, and a dial with a pH scale. The electrode and ion meter samples a solution, "calculates" the  $\text{H}^+$  concentration, and records it on the dial. These pH meters are very expensive if highly accurate readings are required.
- 4.3 A pH comparator kit is designed to calculate pH using indicator chemicals.
- 4.4 One type of pH comparator uses acid-base titrations (a titration is a method of measuring the amount of something in a solution; in this case, the amount of acid in rain). With titrations, an indicator chemical (e.g., phenolphthaline) is added drop-by-drop to the sample. The number of drops needed to change the color of the sample are used to calculate the pH of the rain.
- 4.5 Litmus paper uses indicator chemicals which are combined with a special absorbent paper. When this paper comes in contact with anything acid, it will change to a certain color which, when compared with a chart of standard colors, indicates the pH. This litmus paper is made for both acids and bases and is inexpensive (The results will not be as accurate as using a pH meter, however).
- 4.6. The final type of comparator kit uses chemicals which are added to the rain sample. The indicator will change the color of the sample, which is then compared with the appropriate standard color and pH.

#### 5.0 SOURCES OF ACID POLLUTION

- 5.1 From information gathered in the 1930s and 1950s, it appears that the acidity of rainfall in the eastern United States has increased significantly (in Great Smoky Mountains National Park: 1956 - 5.6; 1980 - 4.27). Some scientists dispute this theory, however.
- 5.2 The gases sulfur dioxide ( $\text{SO}_2$ ) and various nitrous oxides ( $\text{NO}_x$ ) are mainly responsible for the increase in acidity.
- 5.3 These gases are primarily created by industrial factories, coal-fired power plants, and car emissions.

- 5.4 It has been estimated that approximately 26 million tons of  $\text{SO}_2$  and 22 million tons of  $\text{NO}_x$  were put into the atmosphere in the United States in 1980. (If  $\frac{1}{2}$  ton - 20 students each weighing 100 lbs., how many students = 48 million tons of pollutants? Answer: 960 million, or approximately 1 billion students).
- 5.5 Some scientists believe that natural sources of  $\text{SO}_2$  and  $\text{NO}_x$  (forest fires, lightning, volcanoes, etc.) have an equally important effect on acid rain (pH levels) as manmade sources.
- 5.6 Areas where the soil has been disturbed (mines, forest fires, landslides, construction sites) may be making the water in streams and lakes more acidic. Many soils are already acidic or contain minerals which react with rainwater, snowmelt, etc., to form acids. These acidic waters are carried into streams and lakes.
- 5.7 The gases  $\text{SO}_2$  and  $\text{NO}_x$  are thought to be carried long distances by air currents. Storm systems also move long distances, carrying with them any pollutants they may pick up. The interaction of airborne pollutants and clouds is not well understood.
- 5.8 Understanding the movement of prevailing air currents and storm systems can greatly aid scientists in discovering where acid rain is coming from and, just as importantly, where the rain is returning to earth.
- 5.9 Scientists hope to learn more about the movements of acid rain by studying storm events, high and low pressure movements (high pressure usually is an indication of good, clear weather, whereas low pressure fronts are associated with storms), and occluded fronts. Occluded fronts normally proceed storm events, thus making them a good indicator for tracking storm events.
- 5.10 Researchers are attempting to track where the pollution (gases, fly-ash, soot, dust particles) goes when it leaves the heavy industrial and populated areas by making projections of storm event and air current movements.

## 6.0 POLLUTION CONTROL MEASURES

- 6.1 Currently, there are two primary methods being used by industries and power plants to reduce the amount of pollutants released into the atmosphere.
- 6.2 These two methods consist of installing cleansing devices in the exhaust or "smoke" stacks. The two types currently available are called "scrubbers" and electrostatic precipitators.
- 6.3. Scrubbers are designed to remove the various gases ( $\text{SO}_2$  and  $\text{NO}_x$ ) from the plant emissions. These are considered to be very effective, and many states require that these be installed.

- 6.4 Electrostatic precipitators are less effective than scrubbers. They are designed to remove the visible soot from emissions. This makes the emissions look clean but does not remove the real culprits of acid rain,  $\text{SO}_2$  and  $\text{NO}_x$ .
- 6.5 At this time there are no commercially produced devices for removing  $\text{NO}_x$  from automobile exhaust. Many people think that catalytic converters do this job, but this is not true. Converters are designed to remove hydrocarbons (benzene, for instance) which are thought to cause cancer. Hydrocarbons do not react to form acid rain.

#### 7.0 EFFORTS TO UNDERSTAND THE EFFECTS OF ACID RAIN

- 7.1 The United States government is concerned about the possible problems with acid rain. There are many indications that acid rain is beginning to take its toll of the streams, lakes, forests, and wildlife of the United States.
- 7.2 The Environmental Protection Agency (EPA) has begun a national air quality project which became formally established as the National Atmospheric Deposition Program (NADP) in 1978. The NADP headquarters is located at the University of Illinois in Champaign. Its purpose is to gather data on air quality in this country.
- 7.3 There are 110 NADP collecting stations across the country. These sites are set up to collect precipitation (snow, rain, ice, etc.) and dry fallout (the settling of airborne particles to the ground (dust, soot, dirt). Figure 2 shows the equipment used by NADP to collect these samples.
- 7.4 In order to have data which can be compared in different parts of the country, NADP collects the samples from every site on the same day each week. These samples are then shipped to the headquarters in Illinois for analysis.
- 7.5 Figure 3 is an isopleth map of the United States (an isopleth is a group of similar numbers connected by a line. In this case, the isopleths define pH figures). The diamonds (◆) mark 21 active National Park Service/NADP (NPS/NADP) collecting stations. Great Smoky Mountains National Park (GRSM) is marked with a star (★).
- 7.6 At GRSM, the Uplands Field Research Laboratory is collecting these samples. Before they are sent to Illinois, the Laboratory is testing a portion of the sample for pH and conductivity.

## 8.0 WHY THE NATIONAL PARK SERVICE IS INVOLVED WITH NADP

The National Park Service is charged with the protection of the unique natural resources of our national parks. There is much evidence suggesting damage by acid rain to many of these unique features.

- 8.1 The National Park Service would like to understand more fully the effects of acid rain and ways to minimize these effects.

Activity 1

Time: 1 hour

Behavioral Objectives

At the end of this lesson the student will be able to:

1. Describe the pH scale and its components
2. Explain why a pH measurement must be accurate and why small changes in pH are important.

Materials

You will need enough of the following for each student:

1. Dried apricots
2. Grapefruit pieces
3. Lemon pieces
4. Molasses
5. Writing paper, pencils
6. Four paper cups for each child

Instructions to Teacher

1. Write on blackboard:
  - a. Molasses - pH 5
  - b. Dried apricots - pH 4
  - c. Grapefruit - pH 3
  - d. Lemon - pH 2

(Other common substances' pH can be found in Table 1)
2. After the students complete the following experiment, go back over the discussion on pH strengths (5.1 - 5.3).
3. Explain that the molasses the students tried had a pH of 5. The dried apricots had a pH of 4 and are 10 times more acidic than the molasses. Grapefruit (pH 3) is 10 times more acidic than the apricots and 100 times ( $10 \times 10$ ) more acidic than the molasses. The lemons are 1,000 times ( $10 \times 10 \times 10$ ) more acidic than the molasses.

Instructions to Students

1. Sample each item. You may try any one of the four samples first.
2. Record which sample tasted the least bitter, the most bitter. Rank them in that order. Save these answers for discussion later.



Questions to Students

1. How did you rank the four samples, least bitter to most bitter?
2. Why did you rank them this way?
3. Where do you think the following fruits and vegetables would be placed on a pH scale: Apples? Carrots? Spinach? Jams?  
(pH 3, 5, 5, 4, respectively)

Activity 2

Time: 1-2 hours

Behavioral Objectives

At the end of this lesson the students will be able to:

1. Explain the difference between an acid and a base.
2. Understand that an acid can be made more neutral by adding something which is basic or interacting with a natural buffering agent in nature.
3. Become familiar with the pH scale.

Materials

You will need:

1. Vinegar
2. Lemon juice
3. Tomato juice (pure)
4. Distilled water
5. Salt water (3 tbs/1 cup distilled water)
6. Ammonia
7. Milk of Magnesia
8. Alka-Seltzer
9. Blank chart (Figure 4) - one per student or group
10. Enough wide-range (0-14 pH) litmus paper to give each group twenty-one 1-1/2 inch strips
11. Eight 6-8 oz. cups

Because the students will need to use the comparison chart included with the litmus container, you may wish to obtain enough dispensers for each group to have one.

Instructions to Teacher

1. Refer to information in 5.1 and pH scale, Figure 1.
2. Distribute litmus paper and Figure 4 chart to students.
3. Direct supervision is necessary when working with these materials.
4. Put one of the seven samples in a cup and pass these among the students or groups for testing. The students should test each sample three times and arrive at an average pH using the following formula:

Example:

$$\begin{array}{rcl} \text{Test 1} & = & \text{pH } \frac{2}{\phantom{0}} \\ \text{Test 2} & = & \text{pH } \frac{3}{\phantom{0}} \\ \text{Test 3} & = & \text{pH } \frac{2}{\phantom{0}} \\ \hline & & \text{Total } 7 \end{array}$$

Formula:

$$\text{Average pH} = \text{Total} \div 3$$

$$\text{Average pH} = 7 \div 3$$

$$\text{Average pH} = 2.3$$

### Instructions to Students

1. Using the wide-range litmus paper, test each different sample three times.
2. Using these three tests, calculate the average pH of the sample.
3. Record your results on the data sheet, Figure 4. Include the three pH test figures, the sum of these, and the average pH.
4. Repeat this for each of the seven samples.
5. With the help of your teacher, add two Alka-Seltzer tablets to a cup of vinegar. Test this solution for pH.

### Questions for Students

1. How do your results of this test compare with the answers of the rest of the group?
2. What is an acid? A base? Look for answers in reference books such as encyclopedias, science books, etc.
3. Which of the samples are acidic? Neutral? Basic (alkaline)?
4. Did the pH of the vinegar change when you added the Alka-Seltzer tablets? Why? Hint: Make up a cup of Alka-Seltzer and test it for pH. What does this tell you about the pH change in the vinegar - Alka-Seltzer solution?

Activity 3

Time: 1 hour

Behavioral Objectives

At the end of this lesson the students will be able to:

1. Name the two gases which significantly increase acidity in rainfall and give two naturally occurring sources of these gases and two manmade sources of these gases.
2. Tell how surface water (runoff, streams, lakes) may already be acidic, even before any acid rain reaches it.

Materials

You will need:

1. Writing paper
2. Pencils
3. Figure 5a, teacher's copy
4. Figure 5b, one copy per student
5. Markers: Orange, red, green, blue

Instructions to Teacher

1. Describe to students how acid rain is formed and primary control measures. Refer to "Background Information", 3.1 to 3.6 and 4.1 to 4.5.
2. Have students fill in Figure 5b, labeling the illustration as called for in the list below the figure. Color the four major areas: orange for source, red for formation, green for land, and blue for water.
3. Have students write two to three paragraphs on how the United States is cutting down on the amount of  $\text{SO}_2$  and  $\text{NO}_x$  emissions put into the air each year.

Instructions to Students

1. On the picture given to you by your teacher, put the items listed (1 to 12) on the picture in their proper place. Remember where the gases come from, where they mix with water, and where the acid rain returns to earth.
2. Color in these three main areas: where the gases come from, where they mix, and where they return.
3. Write two or three paragraphs on how the United States is cutting down on the amount of  $\text{SO}_2$  and  $\text{NO}_x$  emissions put into the air each year.

Questions for Students

1. Where might acids form in the atmosphere? (Fog, smog, clouds)
2. Name two manmade sources and two natural sources of  $\text{SO}_2$  and  $\text{NO}_x$ .

3. Use rain gauge to measure rainfall during collecting period.
4. With the help of your teacher, test the rain sample for pH, using the measurement kit.
5. Record the results of the test on a data sheet provided by your teacher. It will include:
  - a. Class and teacher's name
  - b. Date
  - c. Time information was recorded
  - d. Total rainfall of test period
  - e. Average pH of rain
6. The pH test of the sample should be run three times to get an average figure. Calculate the average directly on the data sheet in the space provided.
7. Using the isopleth map, compare your test results with the pH figure on the map for your locality.

#### Questions for Students

1. What was the average pH of the rain you tested?
2. How does your pH compare with that found in step 7 above? Was yours more or less than the isopleth map figure?
3. Can you think of reasons why your figures may be different from those on the map?
4. How does your figure compare with the average pH figure given for Great Smoky Mountains National Park (pH scale, Figure 1)?

Although one test is enough to demonstrate pH testing, repetition will give a more complete picture of pH levels in your area.

Activity 4

Time: 2 hours

Behavioral Objectives

At the end of this lesson the students will be able to:

1. Explain how acid rain is measured.
2. Explain how acid rain is monitored in the United States.
3. Compare locally measured pH or rain with that of Great Smoky Mountains National Park and national figures as displayed on isopleth (Figure 3) for a specific storm event.

Materials

You will need:

1. Inexpensive pH test kit or comparator kit for water (many scientific supply houses for schools carry these).
2. Clean wide-mouth glass or plastic container for collecting rain samples.
3. Data sheet (Figure 6)
4. Isopleth map (Figure 3)
5. Accurate rain gauge

Instructions to Teacher

1. Describe to the students how the NADP measures acid rain. Refer to "Background Information."
2. Do test for one week or until sufficient rain is collected to run the tests.
3. Whenever the students work with any type of chemicals (pH kit), they should be under direct supervision.

Instructions to Students

1. As a group, you will be monitoring the pH of rainfall in your community. This pH test can be run once or many times. You will then be able to compare your local pH with the pH indicated on the isopleth map your teacher has.
2. Place the collection container in an open area away from buildings or trees that might block the rain.

Activity 5

Time: Run by events; two to three storm events in 30 days

Behavioral Objectives

At the end of this lesson the student will be able to:

1. Explain how storm tracking is important to understanding sources of acid rain pollution.
2. Read and understand a weather map.

Materials

You will need:

1. National weather maps (these should be saved for the 30-day period of this activity. This will allow for tracking all storm events during the 30-day period). Collect them from your local newspaper.
2. Inexpensive pH test kit for water (or comparator kit). Many scientific supply houses for schools carry these.
3. Clean wide-mouth glass or plastic container for collecting rain samples.
4. Accurate rain gauge
5. Data sheet (Figure 7)
6. Blank United States map (make as many copies as necessary; Figure 8)

Instructions to Teacher

1. Refer to "Background Information," 3.0 to 3.10, 6.0 to 7.7.
2. Instruct the students to collect national weather maps for a 30-day period. These maps will be used continually throughout the lesson.
3. Figure 9 is an example of the National Weather Service map for Friday, March 11, 1983, (Knoxville Journal, March 10, 1983. Knoxville, Tennessee).



4. Using a copy of the U.S. map (Figure 8), have the students track each storm event as it moves toward them (using a separate map for each event) during the 30-day period.
5. Have the students collect all precipitation for the 30-day period, keeping track of total rainfall with a rain gauge and also recording the total rain per storm event.
6. At the end of the storm event collection period, assist students in measuring pH. Have them record information on data sheets (Figure 7).

#### Instructions to Students

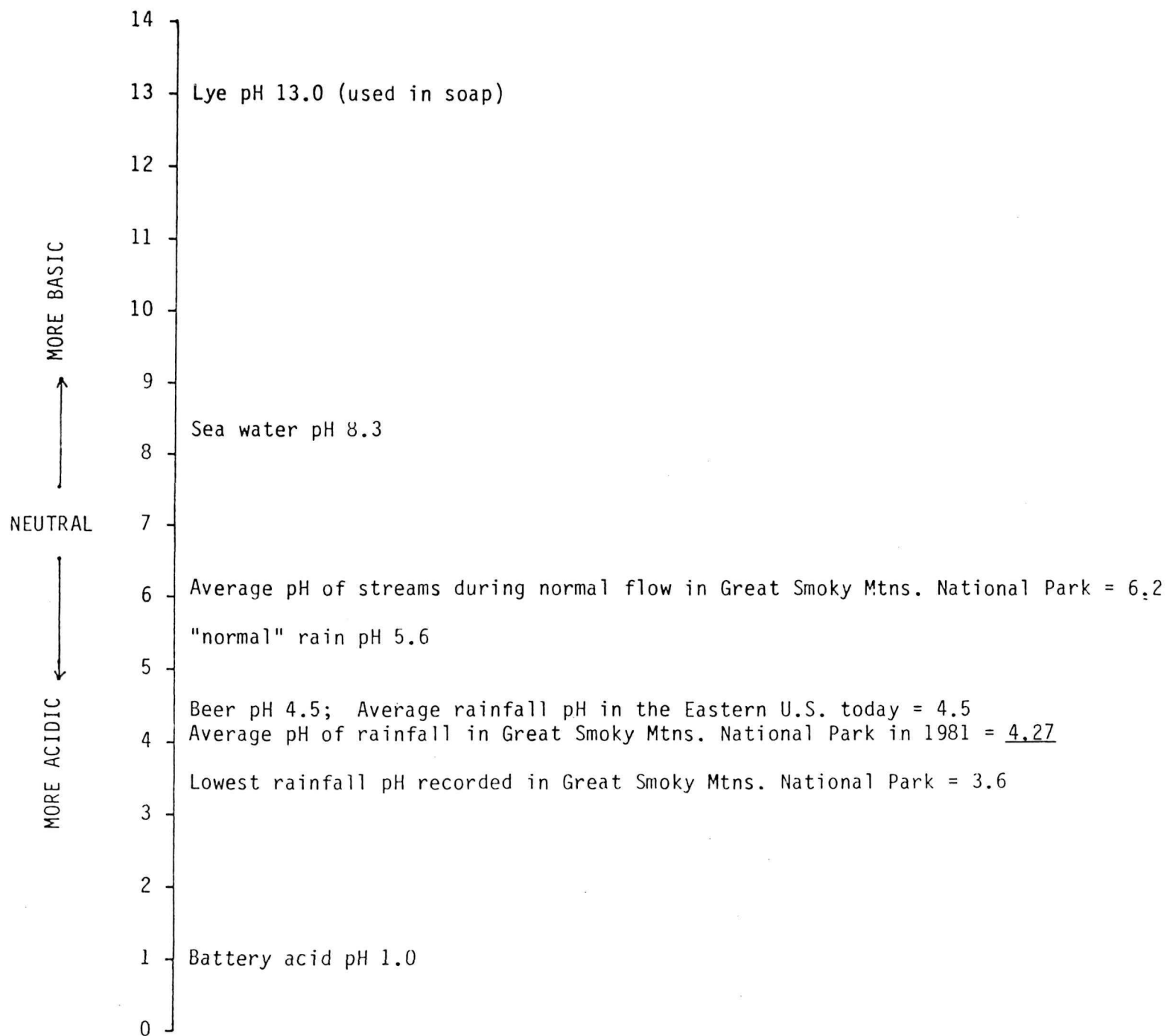
1. Set up the plastic or glass collection container for rain in an open area away from buildings and trees. This will be left out for a 30-day period. The rain is measured after each storm event and recorded. Also, the total amount for the 30-day period is recorded.
2. Each symbol on a weather map is important. The ones you should be mainly concerned with for this activity are:
  - a. Warm fronts and movement -
  - b. Cold fronts and movement -
  - c. Occluded fronts and movement -
  - d. Rain, snow, showers, flurries -
3. You should know the direction of heavily populated areas, industrial areas, coal-fired power plants, etc., in your area. Plot these on the blank U.S. maps provided by your teacher.
4. Each day of the activity, record the national weather on one of the U.S. maps. (The same map should be used during the whole storm event.) On the map, write in the days in which the event occurred.
5. A storm front normally precedes what is termed an occluded front (this is when a cold front overtakes a warm front, forcing the warm air up and over the cold front).
6. At the end of each storm event in the 30-day period, collect the rain gauge and rain collector with all of the rain for the test period. With the help of your teacher, test the sample three separate times for pH and get an average pH figure. Record this and the total rainfall for the storm event on the data sheet (Figure 7).

Questions for Students

1. During the 30-day test period, were there any storm events? Which direction did they come from?
2. Are there any large sources of pollution (No. 3 above) in this direction? How far did the storm travel from the pollution sources to your area?
3. Was there any difference between the pH calculated in this activity with the pH calculated for Activity 4? How much of a difference? How did this activity pH compare with GRSM pH?
4. Why might there be a difference between Activities 4 and 5? GRSM and Activity 4?

Figure 1. pH SCALE

On the pH scale illustrated below, you will find some common substances listed with their pH's, and some pH figures from Great Smoky Mountains National Park.



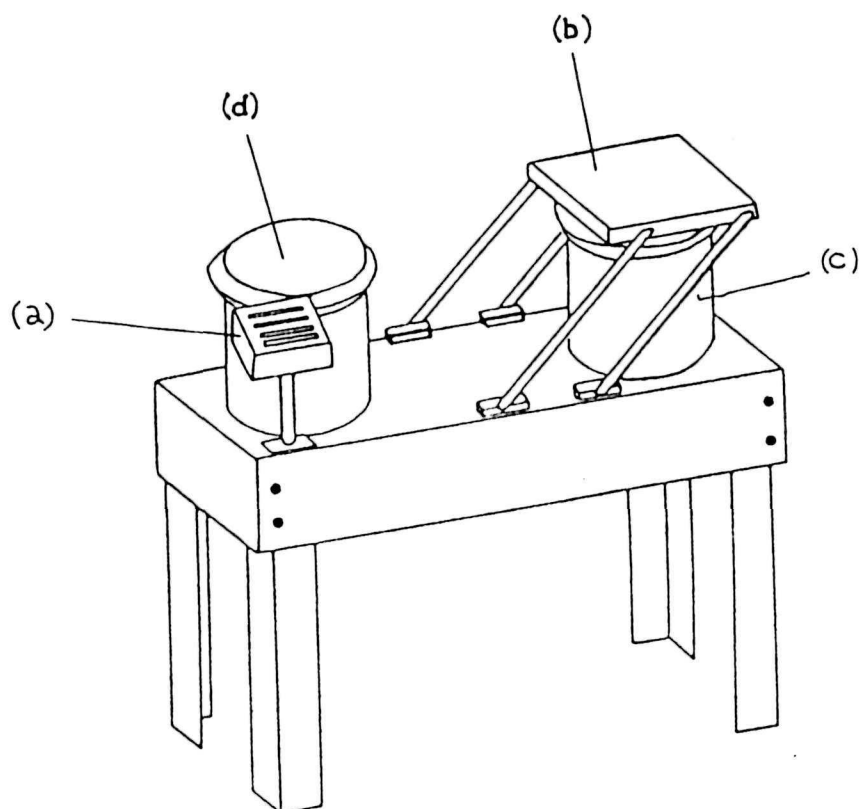


Figure 2. Standard wet material - dry material catchment container for collecting wet and dry fallout. The sensor (a) is triggered through rain falling on its grid. This in turn operates the motor for the lid (b), which swings it off of the wet bucket (c), and onto the dry bucket (d), thus protecting the dry bucket from the rain and opening the wet bucket. This remains open until the storm event is over. The lid returns to its original position over the wet bucket (adapted from Lippincott et al. 1982).

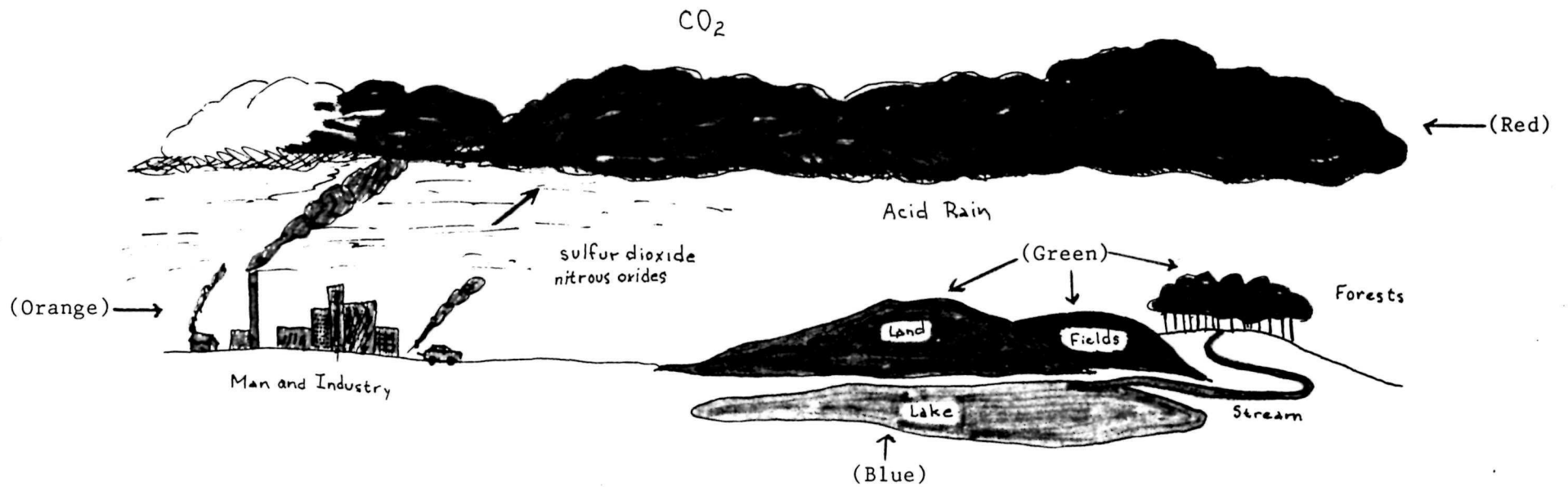


Figure 3. Isopleth of the United States showing the distribution in rainfall pH for the year 1981. Diamonds represent NPS/NADP sites. (NADP, 1982)

Figure 4. Data Sheet for Activity 2.

Test Number	Vinegar	Lemon Juice	Tomato Juice	Distilled Water	Salt Water	Ammonia	Milk of Magnesia
1							
2							
3							
Average pH							

Figure 5a.



1. Sulfur dioxide

2. CO<sub>2</sub>

3. Stream

4. Acid rain

5. Lake

6. Forests

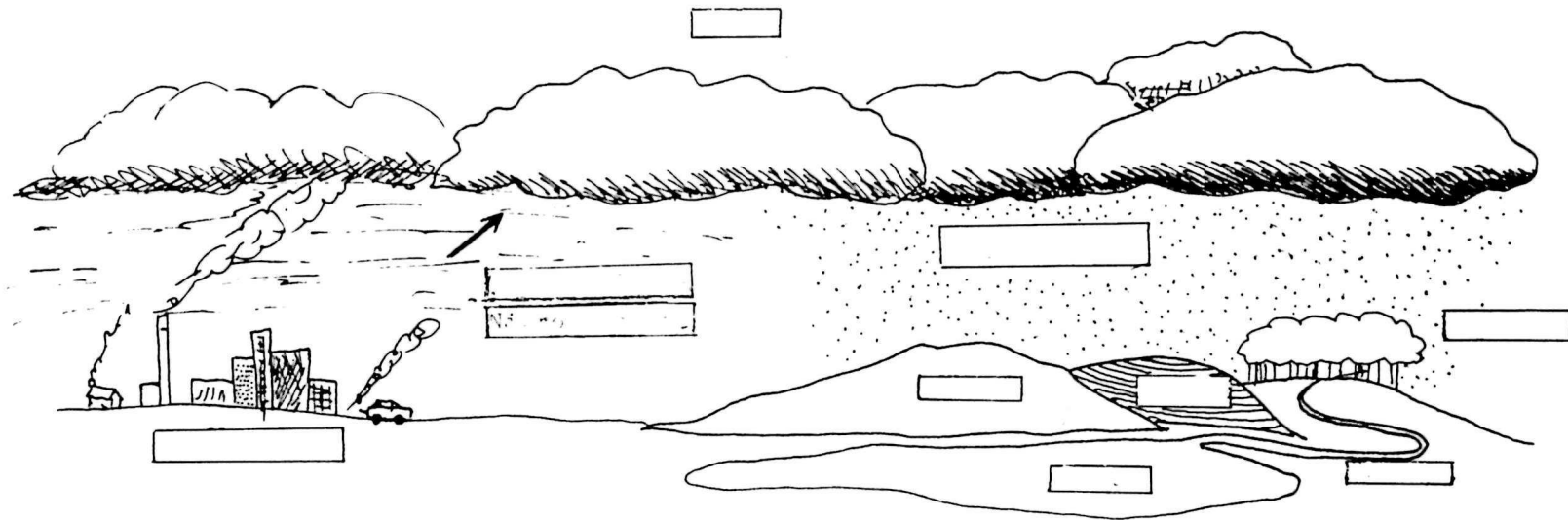
7. Man and Industry

8. Nitrous oxides

9. Fields

10. Land

Figure 5b.



1. Sulfur dioxide
2. CO<sub>2</sub>
3. Stream
4. Acid rain
5. Lake

6. Forests
7. Man and Industry
8. Nitrous oxides
9. Fields
10. Land



Figure 6. Sample pH Monitoring Data Sheet

TEACHERS NAME _____		CLASS _____	DATE _____
TIME RECORDED _____		ADDITIONAL COMMENTS (notes on weather, trouble with pH test, etc.)	
TOTAL RAINFALL FOR WEEK _____			
pH OF RAIN FOR WEEK _____		Test 1: _____ Test 2: _____ Test 3: _____ Total = _____ average = Total ÷ 3	

TEACHERS NAME _____		CLASS _____	DATE _____
TIME RECORDED _____		ADDITIONAL COMMENTS (notes on weather, trouble with pH test, etc.)	
TOTAL RAINFALL FOR _____			
pH OF RAIN FOR _____	Test 1: _____		
	Test 2: _____		
	Test 3: _____		
	Total = _____		
	$\text{average} = \text{Total} \div 3$		

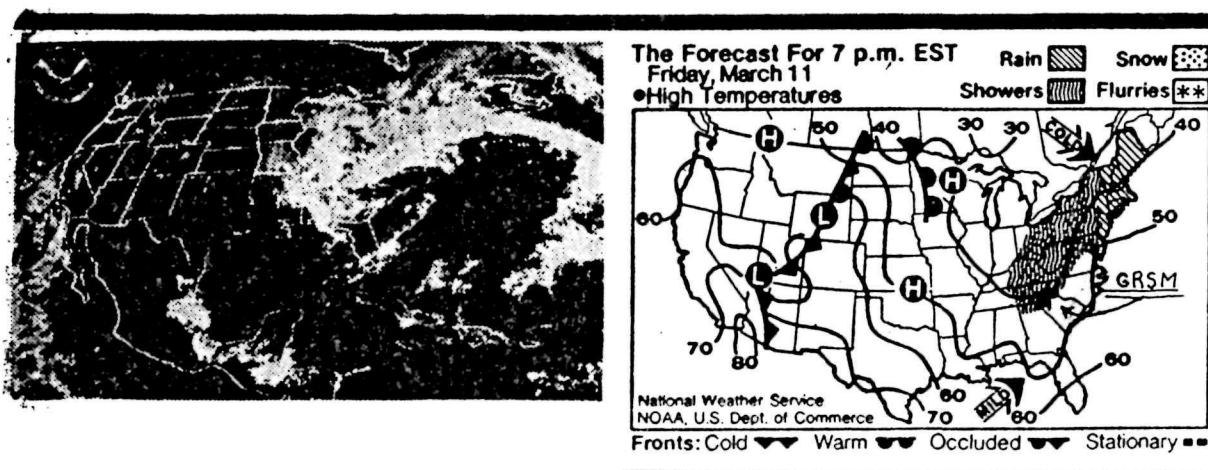


Figure 8. National Weather Map

Table 1. Approximate pH of some common substances.

Apppples	2.9 - 3.3	Limes	1.3 - 2.0
Asparagus	5.4 - 5.7	Magnesia, Milk of	10.5
Battery Acid	1.0	Milk, Cows	6.4 - 6.8
Beans	5.0 - 6.0	Olives	3.6 - 3.8
Beets	4.9 - 5.6	Oranges	3.0 - 4.0
Bread, White	5.0 - 6.0	Peas	5.8 - 6.0
Beers	4.0 - 5.0	Peaches	3.4 - 3.6
Blackberries	3.2 - 3.6	Pears	3.6 - 4.0
Cider	2.9 - 3.3	Pickles, Dill	3.2 - 3.5
Crackers	7.0 - 8.5	Pickles, Sour	3.0 - 3.5
Cabbage	5.2 - 5.4	Pimento	4.7 - 5.2
Carrots	4.9 - 5.2	Plums	2.8 - 3.0
Corn	6.0 - 6.5	Pumpkin	4.8 - 5.2
Cherries	3.2 - 4.1	Raspberries	3.2 - 3.7
Dates	6.2 - 6.4	Rhubarb	3.1 - 3.2
Flour, Wheat	6.0 - 6.5	Sauerkraut	3.4 - 3.6
Grapes	3.5 - 4.5	Salmon	6.1 - 6.3
Gooseberries	2.8 - 3.1	Shrimp	6.8 - 7.0
Ginger Ale	2.0 - 4.0	Spinach	5.1 - 5.7
Hominy (Lye)	6.9 - 7.9	Squash	5.0 - 5.3
Human Blood Plasma	7.3 - 7.5	Strawberries	3.1 - 3.5
Human Duodenal Contents	4.8 - 8.2	Sweet Potatoes	5.3 - 5.6
Human Feces	4.6 - 8.4	Tomatoes	4.1 - 4.4
Human Gastric Contents	1.0 - 3.0	Tuna	5.9 - 6.1
Human Milk	6.6 - 7.6	Turnips	5.2 - 5.5
Human Saliva	6.0 - 7.6	Vinegar	2.4 - 3.4
Human Spinal Fluid	7.3 - 7.5	Water, Mineral	6.2 - 9.4
Human Urine	4.8 - 8.4	Water, Sea	8.0 - 8.4
Jams, Fruit	3.5 - 4.0	Water, Distilled (equil. with air)	5.8
Jellies, Fruit	3.0 - 3.5	Water, Distilled (CO <sub>2</sub> free)	6.8 - 7.0
Lemons	2.2 - 2.4	Wines	2.8 - 3.8