13

EXERCISE

Atmospheric Moisture, Pressure, and Wind

By observing, recording, and analyzing weather conditions, meteorologists attempt to define the principles that control the complex interactions that occur in the atmosphere (Figure 1). No analysis of the atmosphere is complete without an investigation of the remaining variables—humidity, precipitation, pressure, and wind.

This exercise examines the changes of state of water, how the water vapor content of the air is measured, and the sequence of events necessary to cause cloud formation. Global patterns of precipitation, pressure, and wind are also reviewed. Although the elements are presented separately, keep in mind that all are very much interrelated. A change in any one element often brings about changes in the others.

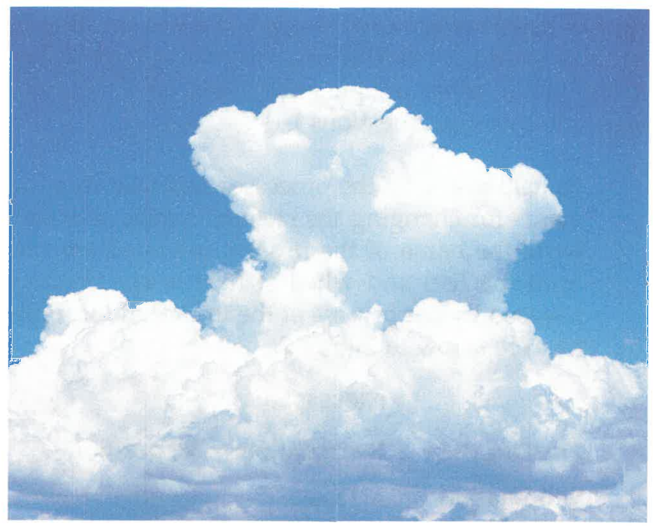

Figure 1 Developing storm clouds. (Photo by E. J. Tarbuck)

Objectives

After you have completed this exercise, you should be able to:

1. Explain the processes involved when water changes state.
2. Use a psychrometer or hygrometer and appropriate tables to determine the relative humidity and dew-point temperature of air.
3. Explain the adiabatic process and its effect on cooling and warming the air.
4. Calculate the temperature and relative humidity changes that take place in air as the result of adiabatic cooling.
5. Describe the relation between pressure and wind.
6. Describe the global patterns of surface pressure and wind.

Materials

calculator
ruler
colored pencils

Materials Supplied by Your Instructor

psychrometer or hygrometer
beaker, ice, thermometer
barometer
atlas
hot plate
thumbtacks
cardboard
tape

Terms

water vapor
evaporation
precipitation
latent heat
dry adiabatic rate
wet adiabatic rate
atmospheric pressure
barometer
isobar
relative humidity
saturated
dew-point temperature
equatorial low
subtropical high
subpolar low
anticyclone
cyclone
wind
psychrometer/hygrometer
condensation nuclei
Coriolis effect
trade winds
westerlies
polar easterlies
monsoon

Atmospheric Moisture and Precipitation

Water vapor, an odorless, colorless gas produced by the **evaporation** of water, comprises only a small percentage of the lower atmosphere. However, it is an important atmospheric gas because it is the source of all **precipitation**, aids in the heating of the atmosphere by absorbing radiation, and is the source of **latent heat** (hidden or stored heat).

Changes of State

The temperatures and pressures that occur at and near Earth's surface allow water to change readily from one state of matter to another. The fact that water can exist as a gas, liquid, or solid within the atmosphere makes it one of the most unique substances on Earth. Use Figure 2 to answer questions 1–4.

1. To help visualize the processes and heat requirements for changing the state of matter of water, write the name of the process involved (choose from the list) and whether heat is absorbed or released by the process at the indicated locations by each arrow in Figure 2.

	PROCESSES	
Freezing	Evaporation	Deposition
Sublimation	Melting	Condensation

2. To melt ice, heat energy must be (absorbed, released) by the water molecules. Circle your answer.
3. The process of condensation requires that water molecules (absorb, release) heat energy. Circle your answer.
4. The energy requirement for the process of deposition is the (same as, less than) the total energy required to condense water vapor and then freeze the water. Circle your answer.

Latent Heat Experiment

This experiment will help you gain a better understanding of the role of heat in changing the state of matter. You are going to heat a beaker that contains a mixture of ice and water (Figure 3). You will record temperature changes *as the ice melts* and continue to record the temperature changes *after the ice melts.* Conduct the experiment by completing the following steps.

Step 1: Write a brief hypothesis as to how you expect the temperature of the ice-water mixture to change as heat energy is added.

____

____

____

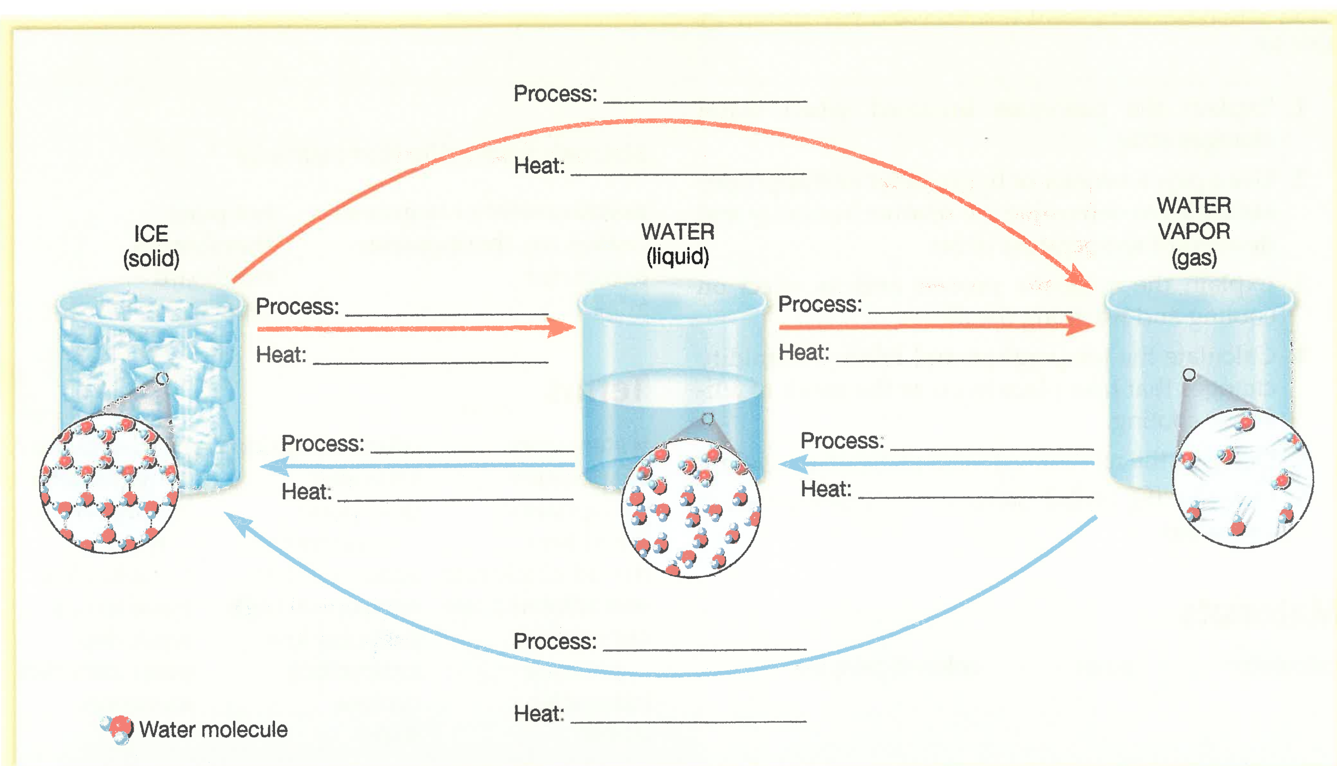

Figure 2 Changes of state of water.

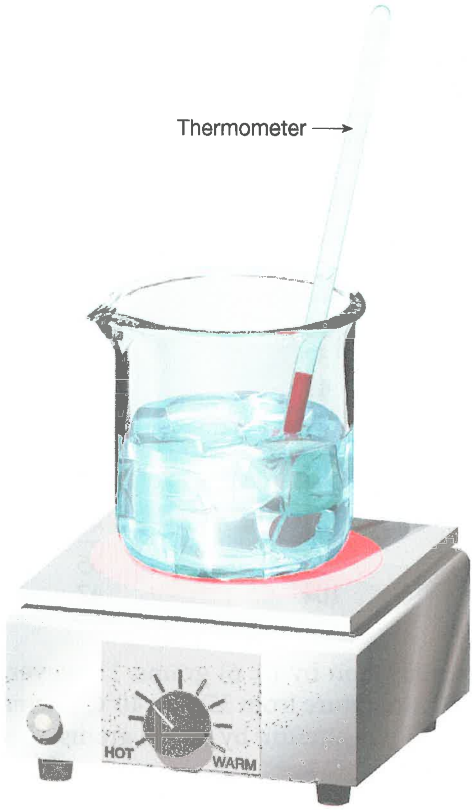

Figure 3 Latent heat experiment equipment.

Step 2: Turn on the hot plate and set the temperature setting to about three-fourths maximum (7 on a scale of 10).

CAUTION: The hot plate will become hot quickly. Do not touch the heating surface.

Step 3: Fill a 400-ml or larger beaker approximately half full with ice and add enough COLD water to cover the ice.

Step 4: Gently stir the ice-water mixture about 15 seconds with the thermometer and record the temperature in the "Starting" temperature space on the data table, Table 1.

Step 5: Place the beaker with the ice-water mixture and thermometer on the hot plate, and while STIRRING THE MIXTURE CONSTANTLY, record the temperature of the mixture at *one-minute intervals* on the data table. Watch the ice closely as it melts. *Note the exact time on the data table when all the ice has melted.*

Step 6: Continue stirring the mixture and recording its temperature for at least 3 or 4 minutes after all the ice has melted.

Step 7: Plot the temperatures from the data table on the graph, Figure 4.

Table 1 Latent Heat Data Table

TIME (MINUTES)	TEMPERATURE (° ____)
Starting	____
1	____
2	____
3	____
4	____
5	____
6	____
7	____
8	____
9	____
10	____
11	____
12	____
13	____
14	____
15	____

Questions 5–8 refer to your latent heat experiment.

5. How did the temperature of the mixture change prior to, and after, the ice had melted?

____

____

6. Calculate the average temperature change per minute of the ice-water mixture prior to the ice

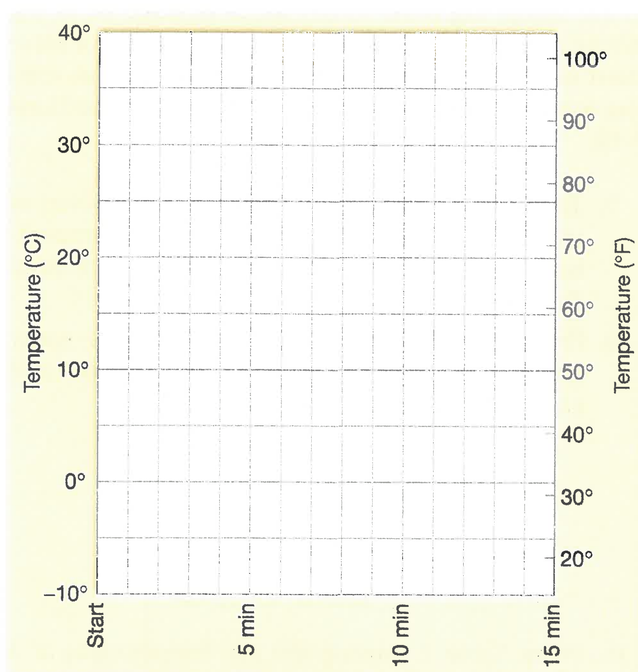

Figure 4 Latent heat experiment graph.

melting and the average rate after the ice had melted.

Average rate prior to melting: ______________

Average rate after melting: ______________

7. With your answers to questions 5 and 6 in mind, write a statement comparing your results to your hypothesis in **Step 1.**

____

____

8. With reference to the absorption or release of latent (hidden) heat, explain why the temperature changed at a different rate after the ice melted as compared to before all the ice had melted.

____

____

____

____

Water-Vapor Capacity of Air

Any measure of water vapor in the air is referred to as *humidity*. The amount of water vapor required for saturation is directly related to temperature.

The mass of water vapor in a unit of air compared to the remaining mass of dry air is referred to as the *mixing ratio*. Table 2 presents the mixing ratios of saturated air (water vapor needed for saturation) at various temperatures. Use the table to answer questions 9–12.

9. To illustrate the relation between the amount of water vapor needed for saturation and temperature, prepare a graph by plotting the data from Table 2 on Figure 5.

10. From Table 2 and/or Figure 5, what is the water vapor content at saturation of a kilogram of air at each of the following temperatures?

40°C: ________ grams/kilogram

68°F: ________ grams/kilogram

0°C: ________ grams/kilogram

−20°C: ________ grams/kilogram

11. From Table 2, raising the air temperature of a kilogram of air 5°C, from 10°C to 15°C, (increases, decreases) the amount of water vapor needed for saturation by (3, 6) grams. However, raising the temperature from 35°C to 40°C (increases, decreases) the amount by (8, 12) grams. Circle your answers.

12. Using Table 2 and/or Figure 5, write a statement that relates the amount of water vapor needed for saturation to temperature.

____

____

____

Table 2 Amount of Water Vapor Needed to Saturate a Kilogram of Air at Various Temperatures, the Saturation Mixing Ratio

TEMPERATURE (°C)	TEMPERATURE (°F)	WATER VAPOR CONTENT AT SATURATION (g/kg)
−40	−40	0.1
−30	−22	0.3
−20	−4	0.75
−10	14	2
0	32	3.5
5	41	5
10	50	7
15	59	10
20	68	14
25	77	20
30	86	26.5
35	95	35
40	104	47

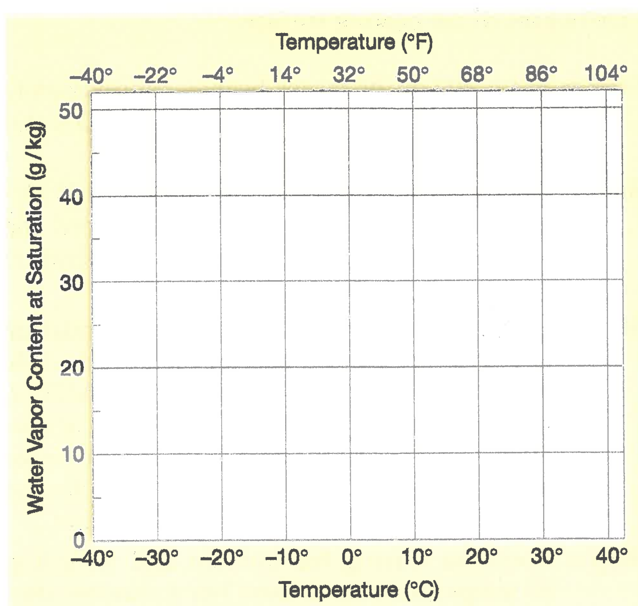

Figure 5 Graph of water vapor content at saturation of a kilogram of air versus temperature.

Measuring Humidity

Relative humidity is the most common measurement used to describe water vapor in the air. In general, it expresses how close the air is to reaching saturation at that temperature. Relative humidity is a *ratio* of the air's actual water vapor *content* (amount actually in the air) compared with the amount of water vapor required for saturation at that temperature (saturation mixing ratio), expressed as a percent. The general formula is

$$\text{Relative humidity (\%)} = \frac{\text{Water vapor content}}{\text{Saturation mixing ratio}} \times 100$$

For example, from Table 2, the saturation mixing ratio of a kilogram of air at 25°C would be 20 grams per kilogram. If the actual amount of water vapor in the air was 5 grams per kilogram (the water vapor content), the relative humidity of the air would be calculated as follows:

$$\text{Relative humidity (\%)} = \frac{5\text{ g/kg}}{20\text{ g/kg}} \times 100 = 25\%$$

13. Use Table 2 and the formula for relative humidity to determine the relative humidity for each of the following situations of identical temperature.

AIR TEMPERATURE	WATER VAPOR CONTENT	RELATIVE HUMIDITY
15°C	2 g/kg	_____%
15°C	5 g/kg	_____%
15°C	7 g/kg	_____%

14. From question 13, if the temperature remains constant, adding water vapor will (raise, lower) the relative humidity, while removing water vapor will (raise, lower) the relative humidity. Circle your answers.

15. Use Table 2 and the formula for relative humidity to determine the relative humidity for each of the following situations of identical water vapor content.

AIR TEMPERATURE	WATER VAPOR CONTENT	RELATIVE HUMIDITY
25°C	5 g/kg	_____%
15°C	5 g/kg	_____%
5°C	5 g/kg	_____%

16. From question 15, if the amount of water vapor in the air remains constant, cooling will (raise, lower) the relative humidity, while warming will (raise, lower) the relative humidity. Circle your answers.

17. In the winter, air is heated in homes. What effect does heating have on the relative humidity inside the home? What can be done to lessen this effect?

____

____

18. Explain why the air in a cool basement is humid (damp) in the summer.

____

____

19. Write brief statements describing each of the two ways that the relative humidity of air can be changed.

1. ____

2. ____

One of the misconceptions concerning relative humidity is that it alone gives an accurate indication of the actual quantity of water vapor in the air. For example, on a winter day if you hear on the radio that the relative humidity is 90%, can you conclude that the air contains more water vapor than on a summer day that records a 40% relative humidity? Completing question 20 will help you find the answer.

20. Use Table 2 to determine the water vapor content for each of the following situations. As you do the calculations, keep in mind the definition of relative humidity.

SUMMER	WINTER
Air temperature = 77°F	Air temperature = 41°F
Relative humidity = 40%	Relative humidity = 90%
Content = _______ g/kg	Content = _______ g/kg

21. Explain why relative humidity does *not* give an accurate indication of the actual amount of water vapor in the air.

____

____

____

Dew-Point Temperature

Air is **saturated** when it contains all the water vapor that it can hold at a particular temperature. The temperature at which saturation occurs is called the **dew-point temperature**. Put another way, the dew point is the temperature at which the relative humidity of the air is 100%.

Previously, in question 15, you determined that a kilogram of air at 25°C, containing 5 grams of water vapor had a relative humidity of 25% and was not saturated. However, when the temperature was lowered to 5°C, the air had a relative humidity of 100% and was saturated. Therefore, 5°C is the dewpoint temperature of the air in that example.

22. By referring to Table 2, what is the dew-point temperature of a kilogram of air that contains 7 grams of water vapor?

    Dew-point temperature = ________°C

23. What is the relative humidity and dew-point temperature of a kilogram of 25°C air that contains 10 grams of water vapor?

    Relative humidity = ________%

    Dew-point temperature = ________°C

Using a Psychrometer or Hygrometer

The relative humidity and dew-point temperature of air can be determined by using a **psychrometer** (Figure 6) or **hygrometer** and appropriate charts. The psychrometer consists of two thermometers mounted side by side. One of the thermometers, the *dry-bulb* thermometer, measures the air temperature. The other thermometer, the *wet-bulb thermometer,* has a piece of wet cloth wrapped around its bulb. As the psychrometer is spun for approximately one minute, water on the wet-bulb thermometer evaporates and cooling results. In dry air, the rate of evaporation will be high, and a low wet-bulb temperature will be recorded. After using the instrument and recording both the dry- and wet-bulb temperatures, the relative humidity and dew-point temperature are determined using Table 3, "Relative Humidity (percent)" and Table 4, "Dew-Point Temperature." With a hygrometer, relative humidity can be read directly, without the use of tables.

24. Use Table 3 to determine the relative humidity for each of the following psychrometer readings.

	READING 1	READING 2
Dry-bulb temperature:	20°C	32°C
Wet-bulb temperature:	18°C	25°C
Difference between dry- and wet-bulb temperatures:	_____	_____
Relative humidity:	_____%	_____%

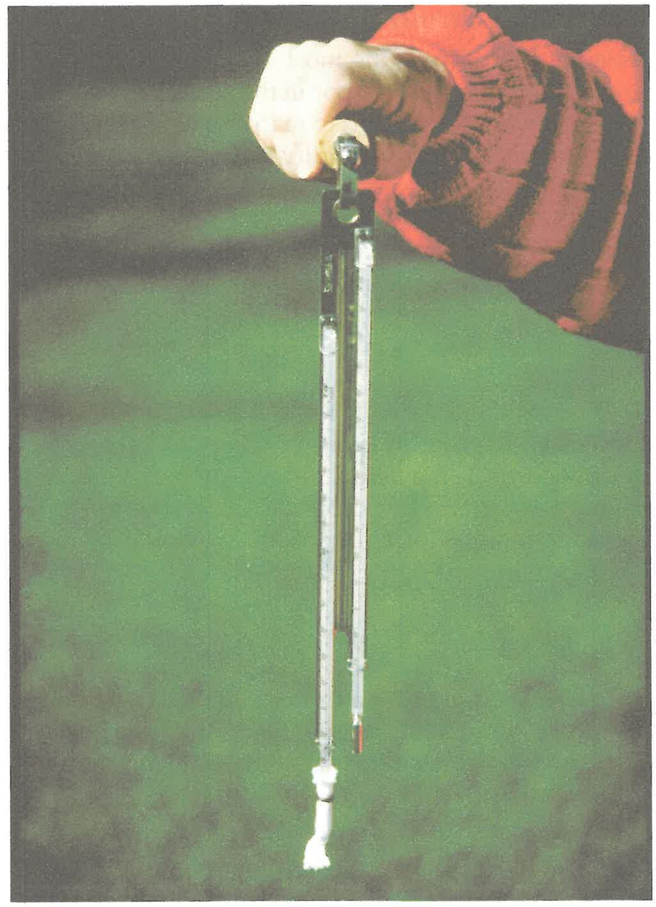

Figure 6 Sling psychrometer. The sling psychrometer is one instrument that is used to determine relative humidity and dew-point temperature. (Photo by E. J. Tarbuck)

25. From question 24, what is the relation between the *difference* in the dry-bulb and wet-bulb temperatures and the relative humidity of the air?

    ____

    ____

26. Use Table 4 to determine the dew-point temperature for each of the following two psychrometer readings.

	READING 1	READING 2
Dry-bulb temperature:	8°C	30°C
Wet-bulb temperature:	6°C	24°C
Difference between dry- and wet-bulb temperatures:	_____	_____
Dew-point temperature:	_____°C	_____°C

Table 3 Relative Humidity (percent)*

Dry-bulb (Air) Temperature — Relative Humidity Values

DRY-BULB TEMPERATURE (°C)	Depression of Wet-bulb Temperature (Dry-bulb Temperature − Wet-bulb Temperature = Depression of the Wet Bulb)																				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
−20	28																					
−18	40																					
−16	48	0																				
−14	55	11																				
−12	61	23																				
−10	66	33	0																			
−8	71	41	13																			
−6	73	48	20	0																		
−4	77	54	43	11																		
−2	79	58	37	20	1																	
0	81	63	45	28	11																	
2	83	67	51	36	20	6																
4	85	70	56	42	27	14																
6	86	72	59	46	35	22	10	0														
8	87	74	62	51	39	28	17	6														
10	88	76	65	54	43	33	24	13	4													
12	88	78	67	57	48	38	28	19	10	2												
14	89	79	69	60	50	41	33	25	16	8	1											
16	90	80	71	62	54	45	37	29	21	14	7	1										
18	91	81	72	64	56	48	40	33	26	19	12	6	0									
20	91	82	74	66	58	51	44	36	30	23	17	11	5	0								
22	92	83	75	68	60	53	46	40	33	27	21	15	10	4	0							
24	92	84	76	69	62	55	49	42	36	30	25	20	14	9	4	0						
26	92	85	77	70	64	57	51	45	39	34	28	23	18	13	9	5						
28	93	86	78	71	65	59	53	47	42	36	31	26	21	17	12	8	2					
30	93	86	79	72	66	61	55	49	44	39	34	29	25	20	16	12	8	4				
32	93	86	80	73	68	62	56	51	46	41	36	32	27	22	19	14	11	8	4			
34	93	86	81	74	69	63	58	52	48	43	38	34	30	26	22	18	14	11	8	5		
36	94	87	81	75	69	64	59	54	50	44	40	36	32	28	24	21	17	13	10	7	4	
38	94	87	82	76	70	66	60	55	51	46	42	38	34	30	26	23	20	16	13	10	7	
40	94	89	82	76	71	67	61	57	52	48	44	40	36	33	29	25	22	19	16	13	10	7

*To determine the relative humidity and dew point, find the air (dry-bulb) temperature on the vertical axis (far left) and the depression of the wet bulb on the horizontal axis (top). Where the two meet, the relative humidity or dew point is found. For example, use a dry-bulb temperature of 20°C and a wet-bulb temperature of 14°C. From Table 3, the relative humidity is 51%, and from Table 4, the dew point is 10°C.

If a psychrometer or hygrometer is available in the laboratory, your instructor will explain the procedure for using the instrument. FOLLOW THE SPECIFIC DIRECTIONS OF YOUR INSTRUCTOR to complete question 27.

27. Use the psychrometer (or hygrometer) to determine the relative humidity and dew-point temperature of the air in the room and outside the building. If you use a psychrometer, record your information in the following spaces.

	ROOM	OUTSIDE
Dry-bulb temperature:	______	______
Wet-bulb temperature:	______	______
Difference between dry- and wet-bulb temperatures:	______	______
Relative humidity:	______%	______%
Dew-point temperature:	______	______

Table 4 Dew-Point Temperature (°C)*

DRY-BULB TEMPERATURE (°C)	*Depression of Wet-bulb Temperature* (Dry-bulb Temperature − Wet-bulb Temperature = Depression of the Wet Bulb)																					
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**
−20	−33																					
−18	−28																					
−16	−24																					
−14	−21	−36																				
−12	−18	−28																				
−10	−14	−22																				
−8	−12	−18	−29																			
−6	−10	−14	−22																			
−4	−7	−22	−17	−29																		
−2	−5	−8	−13	−20																		
0	−3	−6	−9	−15	−24																	
2	−1	−3	−6	−11	−17																	
4	1	−1	−4	−7	−11	−19																
6	4	1	−1	−4	−7	−13	−21															
8	6	3	1	−2	−5	−9	−14															
10	8	6	4	1	−2	−5	−9	−14														
12	10	8	6	4	1	−2	−5	−9	−16													
14	12	11	9	6	4	1	−2	−5	−10	−17												
16	14	13	11	9	7	4	1	−1	−6	−10	−17											
18	16	15	13	11	9	7	4	2	−2	−5	−10	−19										
20	19	17	15	14	12	10	7	4	2	−2	−5	−10	−19									
22	21	19	17	16	14	12	10	8	5	3	−1	−5	−10	−19								
24	23	21	20	18	16	14	12	10	8	6	2	−1	−5	−10	−18							
26	25	23	22	20	18	17	15	13	11	9	6	3	0	−4	−9	−18						
28	27	25	24	22	21	19	17	16	14	11	9	7	4	1	−3	−9	−16					
30	29	27	26	24	23	21	19	18	16	14	12	10	8	5	1	−2	−8	−15				
32	31	29	28	27	25	24	22	21	19	17	15	13	11	8	5	2	−2	−7	−14			
34	33	31	30	29	27	26	24	23	21	20	18	16	14	12	9	6	3	−1	−5	−12	−29	
36	35	33	32	31	29	28	27	25	24	22	20	19	17	15	13	10	7	4	0	−4	−10	
38	37	35	34	33	32	30	29	28	26	25	23	21	19	17	15	13	11	8	5	1	−3	−9
40	39	37	36	35	34	32	31	30	28	27	25	24	22	20	18	16	14	12	9	6	2	−2

Dew-Point Temperature Values

*See footnote to Table 3

Condensation

If air is cooled below the dew-point temperature, water will condense (change from vapor to liquid) on available surfaces. In the atmosphere, the particles on which water condenses are called **condensation nuclei**. Condensation may result in the formation of dew or frost on the ground and clouds or fog in the atmosphere.

28. Examine the process of condensation by gradually adding ice to a beaker approximately one-third full of water. As you add the ice, stir the water-ice mixture gently with a thermometer. Note the temperature at the moment water begins to condense on the outside surface of the beaker. After you complete your observations, answer questions 28a and 28b.

    a. The temperature at which water began condensing on the outside surface of the beaker was ______.

    b. How does the temperature at which water began to condense compare to the dew-point temperature of the air in the room you determined using the psychrometer (or hygrometer)?

    ____

29. Refer to Table 2. How many grams of water vapor will condense on a surface if a kilogram of 50°F air with a relative humidity of 100% is cooled to 41°F?

    ______ grams of water will condense

30. Assume a kilogram of 25°C air that contains 10 grams of water vapor. Use Table 2. How many grams of water will condense if the air's temperature is lowered to each of the following temperatures?

    5°C: ______ grams of condensed water

    −10°C: ______ grams of condensed water

31. Considering your answers to the previous questions, what relation exists between the altitude of the base of a cloud, which consists of very small droplets of water, and the dew-point temperature of the air at that altitude?

___

Daily Temperature and Relative Humidity

Figure 7 shows the typical daily variations in air temperature, relative humidity, and dew-point temperature during two consecutive spring days at a middle latitude city. Use the figure to answer questions 32–36.

32. Relative humidity is at its maximum at (6 A.M., 3 P.M.) on day (1, 2). Circle your answers.
33. The lowest temperature over the two-day period occurs at (6 A.M., noon, 3 P.M.) on day (1, 2).
34. The lowest relative humidity occurs at (6 A.M., noon, 4 P.M.) on day (1, 2).
35. Write a general statement describing the relation between temperature and relative humidity throughout the time period shown in the figure.

___

___

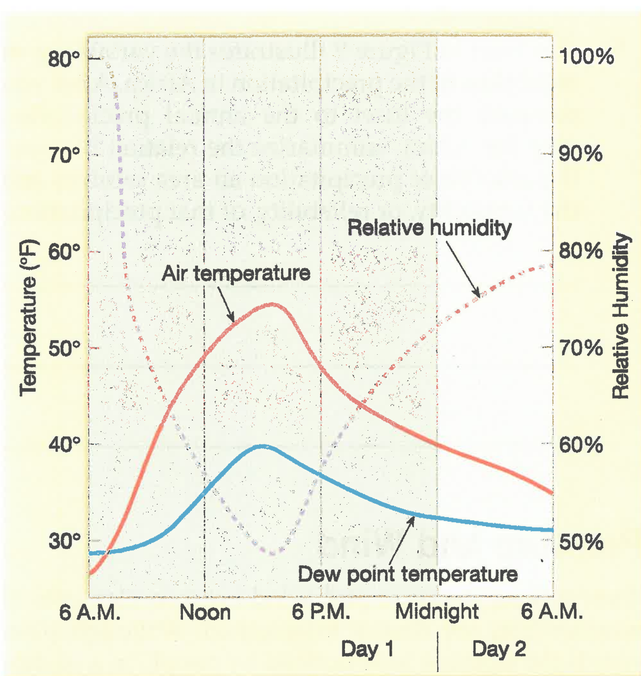

Figure 7 Typical variations in air temperatures, relative humidity, and dew-point temperature during two consecutive spring days at a middle latitude city.

36. Did a dew or frost occur on either of the two days represented in the figure? If so, list when and explain how you arrived at your answer.

___

___

Adiabatic Processes

As you have seen, the key to causing water vapor to condense, which is necessary before precipitation can occur, is to reach the dew-point temperature. In nature, when air rises and experiences a decrease in pressure, the air expands and cools. The reverse is also true. Air that is compressed will warm. Temperature changes brought about solely by expansion or compression are called *adiabatic temperature changes*. Air with a temperature above its dew point (unsaturated air) cools by expansion or warms by compression at a rate of 10°C per 1000 meters (1°C per 100 meters) of changing altitude—the **dry adiabatic rate.** After the dew-point temperature is reached, and as condensation occurs, latent heat that has been stored in the water vapor will be liberated. The heat being released by the condensing water slows down the rate of cooling of the air. Rising saturated air will continue to cool by expansion, but at a lesser rate of about 5°C per 1,000 meters (0.5°C per 100 meters) of changing altitude—the **wet adiabatic rate.**

Figure 8 illustrates a kilogram of air at sea level with a temperature of 25°C and a relative humidity of 50%. The air is forced to rise over a 5,000-meter mountain and descend to a plateau 2,000 meters above sea level on the opposite (leeward) side. To help understand the adiabatic process, answer questions 37–49 by referring to Figure 8.

37. What is the saturation mixing ratio, content, and dew-point temperature of the air at sea level?

    Saturation mixing ratio: _____g/kg of air

    Content: _____g/kg of air

    Dew-point temperature: _____°C

38. The air at sea level is (saturated, unsaturated). Circle your answer.
39. The air will initially (warm, cool) as it rises over the windward side of the mountain at the (wet, dry) adiabatic rate, which is (1, 0.5)°C per 100 meters. Circle the correct responses.
40. What will be the air's temperature at 500 meters?

    _____°C at 500 meters

41. Condensation (will, will not) take place at 500 meters. Circle your answer.
42. The rising air will reach its dew-point temperature at _____ meters and water vapor will begin to (condense, evaporate). Circle your answer.

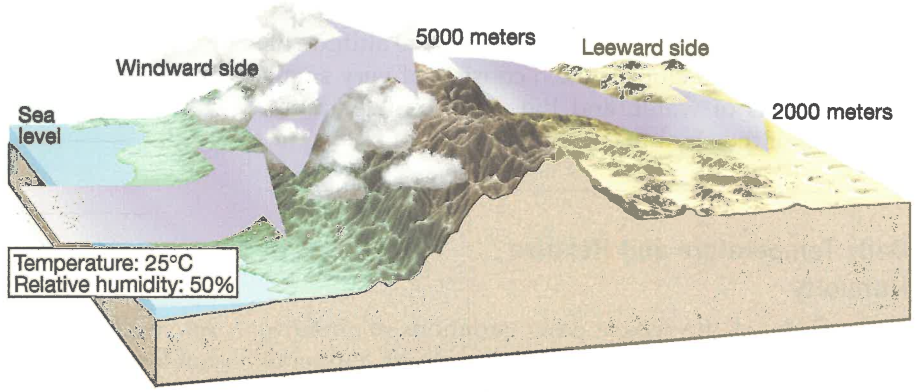

Figure 8 Adiabatic processes associated with a mountain barrier.

43. From the altitude where condensation begins to occur, to the summit of the mountain, the rising air will continue to expand and will (warm, cool) at the (wet, dry) adiabatic rate of about _____ °C per 100 meters.
44. The temperature of the rising air at the summit of the mountain will be _____ °C.
45. Assuming the air begins to descend on the leeward side of the mountain, it will be compressed and its temperature will (increase, decrease).
46. Assume the relative humidity of the air is below 100% during its entire descent to the plateau. The air will be (saturated, unsaturated) and will warm at the (wet, dry) adiabatic rate of about _____ °C per 100 meters.
47. As the air descends and warms on the leeward side of the mountain, its relative humidity will (increase, decrease).
48. The air's temperature when it reaches the plateau at 2,000 meters will be _____ °C.
49. Explain why mountains might cause dry conditions on their leeward sides.

____

____

Global Patterns of Precipitation

Use Figure 9 to answer questions 50–54.

50. List at least four areas of the world that receive the greatest average annual (over 160 cm) precipitation.

____

____

51. The polar regions of Earth have (high, low) average annual precipitation. Circle your answer.
52. What is the average annual precipitation at your location?

_____ centimeters per year, which is equivalent to _____ inches per year.

53. Describe the pattern of average annual precipitation in North America.

____

____

____

54. The inset in Figure 9 illustrates the variability, or reliability, of the precipitation in Africa. After you compare the inset to the annual precipitation map for Africa, summarize the relation between the amount of precipitation an area receives and the variability, or reliability, of that precipitation.

____

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Pressure and Wind

Atmospheric pressure and wind are two elements of weather that are closely interrelated. Although pressure is the element least noticed by people in a weather report, it is pressure differences in the atmosphere that drive the winds that often bring changes in temperature and moisture.

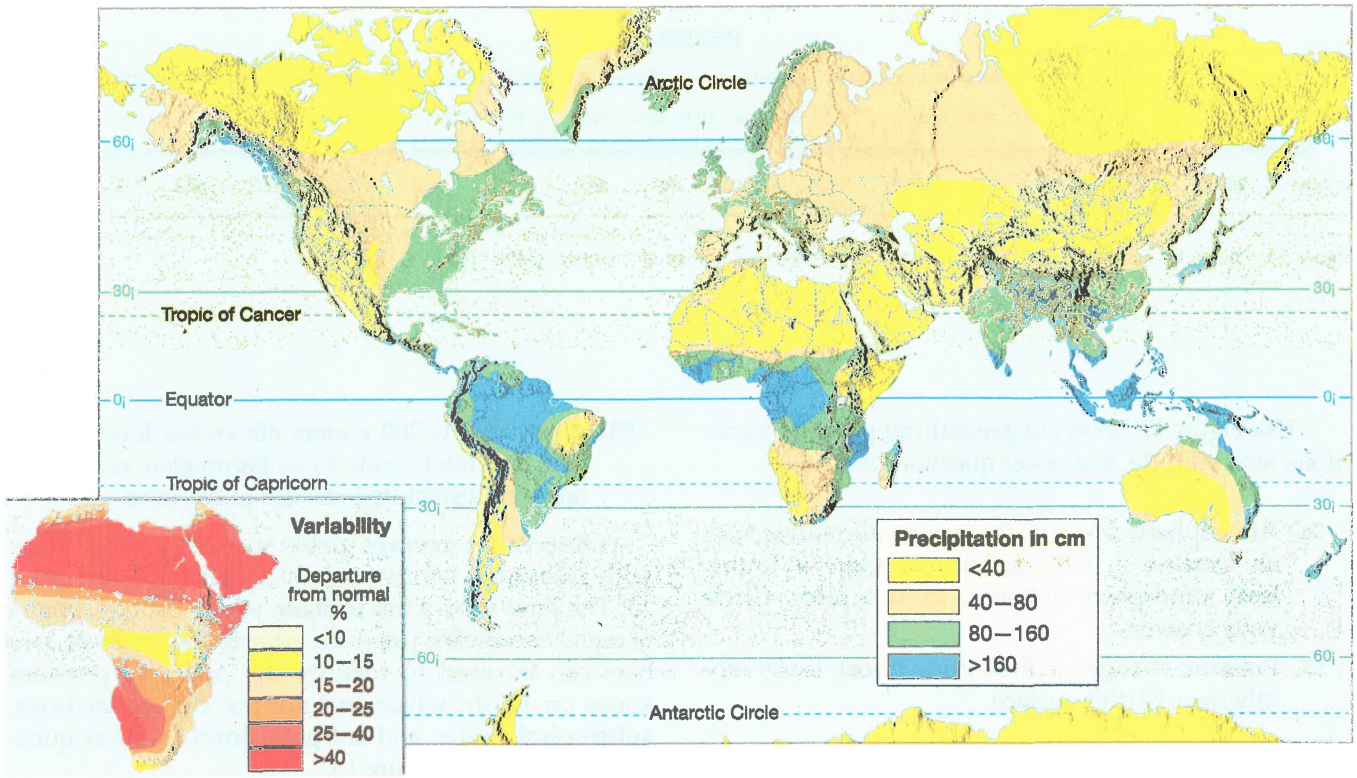

Figure 9 Average annual precipitation in centimeters.

Atmospheric Pressure

Atmospheric pressure is the force exerted by the weight of the atmosphere. It varies over the face of Earth, primarily because of temperature differences. Typically, warm air is less dense than cool air and, therefore, exerts less pressure. Cold, dense air is often associated with higher pressures. Pressure also changes with altitude.

The instrument used to determine atmospheric pressure is the **barometer** (Figure 10). Two units that can be used to measure air pressure are *inches of mercury* and *millibars*. Inches of mercury refers to the height to which a column of mercury will rise in a glass tube that has been inverted into a reservoir of mercury. The millibar is a unit that measures the actual force of the atmosphere pushing down on a surface. Standard pressure at sea level is 29.92 inches of mercury or 1,013.2 millibars (Figure 11). A pressure greater than 29.92 inches or 1,013.2 millibars is called *high pressure*. A pressure less than the standards is called *low pressure*.

55. If a barometer is located in the laboratory, record the current atmospheric pressure in both inches of mercury and millibars. If necessary, use Figure 11 to convert the units.

Inches of mercury: __________ inches of mercury

Millibars: ____________________ millibars (mb)

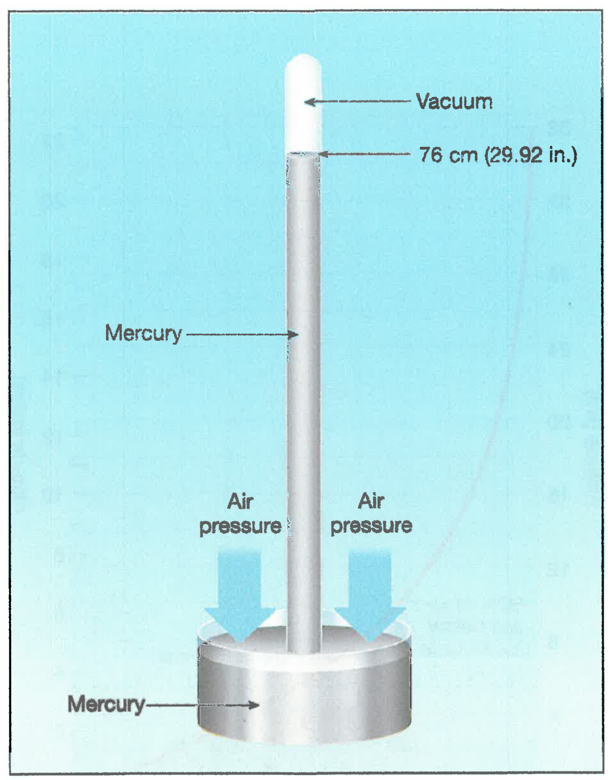

Figure 10 Simple mercury barometer. The weight of the column of mercury is balanced by the pressure exerted on the dish of mercury by the air above. If the pressure decreases, the column of mercury falls; if the pressure increases, the column rises.

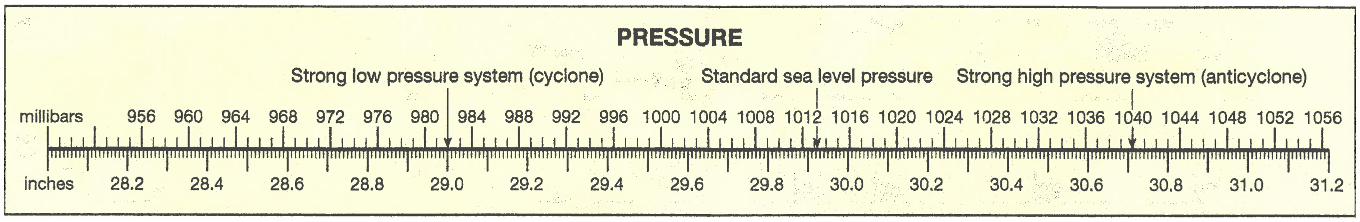

Figure 11 Scale for comparing pressure readings in millibars and inches of mercury. (After NOAA)

Use Figure 12, showing generalized pressure variations with altitude, to answer questions 56 and 57.

56. Atmospheric pressure (increases, decreases) with an increase in altitude because there is (more, less) atmosphere above to exert a force. Circle your answers.

57. Pressure changes with altitude (most, least) rapidly near Earth's surface.

Since surface elevations vary, barometric readings are adjusted to indicate what the pressure would be if the barometer was located at sea level. This provides a common standard for mapping pressure, regardless of elevation.

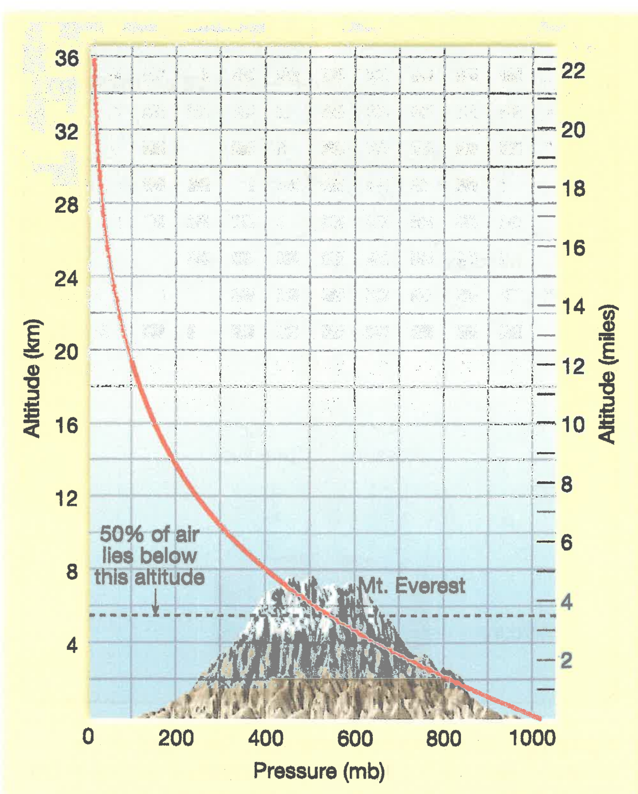

Figure 12 Pressure variations with altitude.

58. A city that is 200 meters above sea level would (add, subtract) units to its barometric reading in order to correct its pressure to sea level.

Observe the average global surface pressure maps with associated winds for January and July in Figure 13. The lines shown are **isobars**, which connect points of equal barometric pressure, adjusted to sea level. Isobars can be used to identify the principal pressure zones on Earth, which include the **equatorial lows**, **subtropical highs**, and **subpolar lows**. Answer questions 59–65 using Figure 13.

59. The units used on the maps to indicate pressure are (inches of mercury, millibars). Circle your answer.

60. By writing the word "HIGH" or "LOW," indicate on the maps the general pressure at each of the following latitudes: 60°N, 30°N, 0°, 30°S, 60°S.

61. Write on the maps the names (equatorial low, subtropical high, or subpolar low) of each of the pressure zones you identified in question 60.

62. During the summer months, January in the Southern Hemisphere and July in the Northern Hemisphere, (high, low) pressure is more common over land. Circle your answer.

63. (High, Low) pressure is most associated with the land in the winter months.

64. Considering what you know about the unequal heating of land and water and the influence of air temperature on pressure, why does the pressure over continents change with the seasons?

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65. Why does the air over the oceans maintain a more uniform pressure throughout the year?

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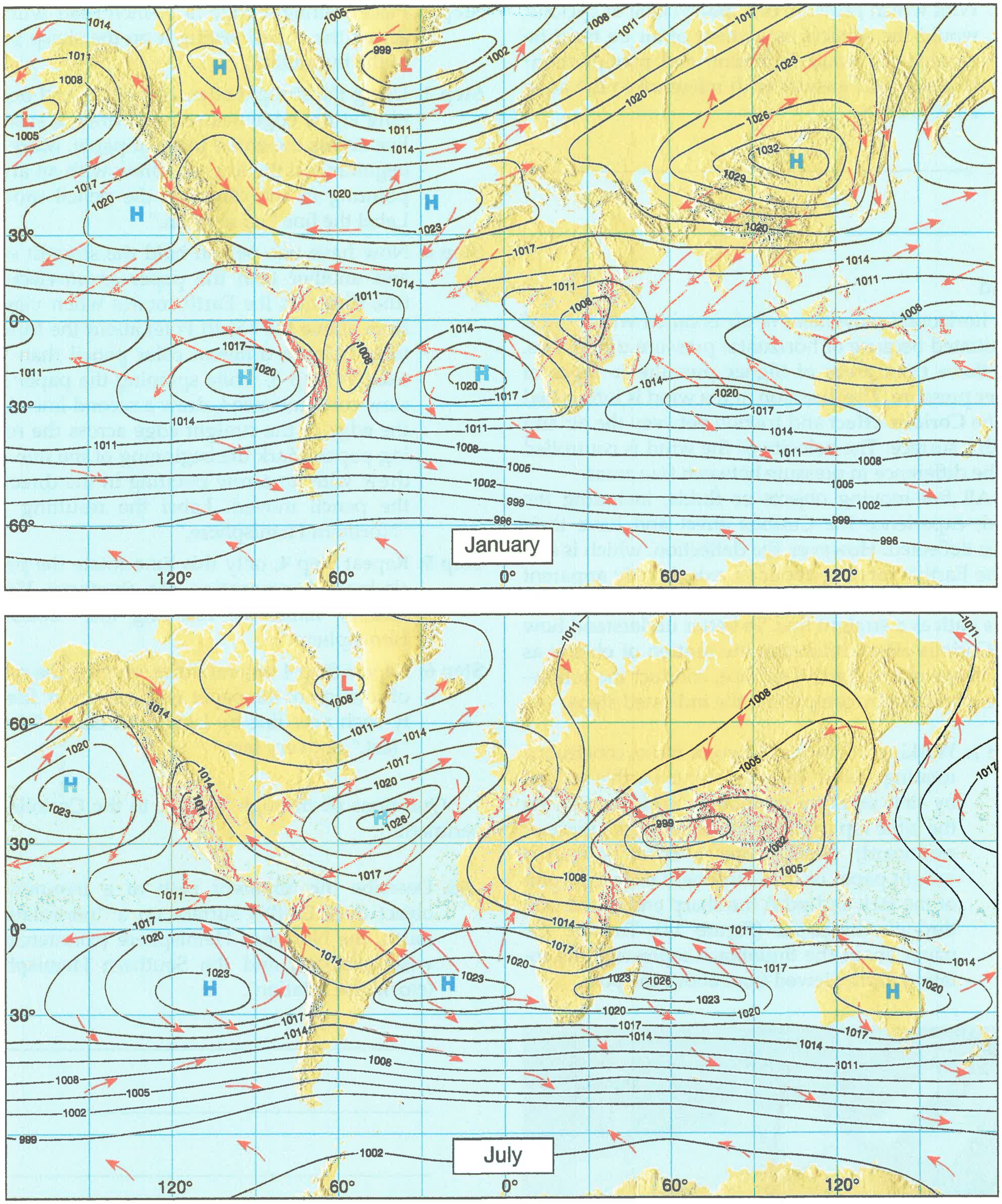

Figure 13 Average surface barometric pressure in millibars for January and July with associated winds.

The differential heating and cooling of land and water over most of Earth causes the zones of pressure to be broken into cells of pressure. Pressure cells are shown on a map as a system of closed, concentric isobars. **High pressure cells**, called **anticyclones**, are typically associated with descending (subsiding) air. **Low pressure cells**, called **cyclones**, have rising air in their centers. Locate and examine some of the pressure cells on the maps in Figure 13. Then answer questions 66 and 67.

66. In an anticyclone, the (highest, lowest) pressure occurs at the center of the cell. In a cyclone, the (highest, lowest) pressure occurs at the center. Circle your answers.

67. With which pressure cell, anticyclone or cyclone, would the vertical movement of air be most favorable for cloud formation and precipitation? Explain your answer with reference to the adiabatic process.

____

____

Wind

The horizontal movement of air is called **wind**. Wind is initiated because of horizontal pressure differences. Air flows from areas of higher pressure to areas of lower pressure. The direction of the wind is influenced by the **Coriolis effect** and friction between the air and Earth's surface. The velocity of the wind is controlled by the difference in pressure between two areas.

All free-moving objects or fluids, including the wind, experience the Coriolis effect and have their paths deflected. However, the deflection, which is due to the Earth's rotation about an axis, is only apparent as an observer watching from space would see the object's path as a straight line. To better understand how the Coriolis effect influences the motion of objects as they move across Earth's surface, conduct the following experiment by completing the indicated steps.

Step 1: Working in groups of two or more, construct a rotating "table" that represents Earth's surface by first taping a thumbtack upside down on the table top (or inserting it through a piece of cardboard). Next, center a sheet of heavy-weight paper or thin cardboard over the point of the tack and push the sharp end of the tack through the paper (Figure 14). Turning the paper about the thumbtack represents the rotating Earth viewed from above the pole.

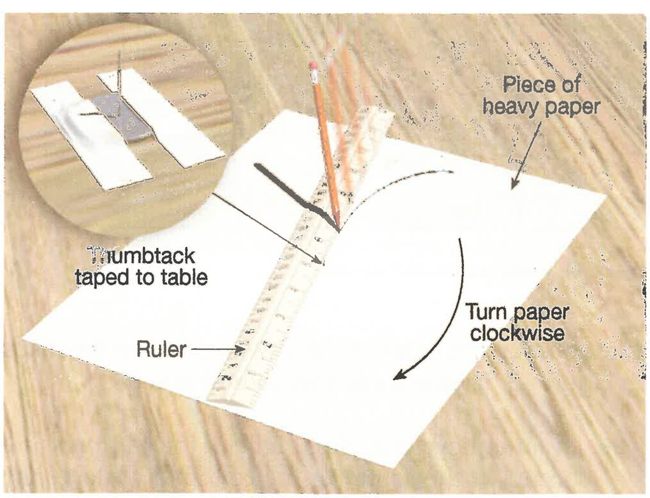

Figure 14 Coriolis experiment setup—Southern Hemisphere.

Step 2: Place a straight edge (a 12-inch ruler will do) across the paper, resting it on the sharp point of the thumbtack.

Step 3: Using the straight edge as a guide and beginning at the edge nearest you, draw a straight line across the entire piece of paper. Mark the beginning of the line you drew with an arrow pointing in the direction the pencil moved. Label the line "no rotation."

Step 4: Now have one person hold the straight edge and another turn the paper *counterclockwise* (the direction the Earth rotates when viewed from above the North Pole) about the thumbtack. Using a different color pencil than you used in Step 3, while spinning the paper at a slow constant speed, draw a second line along the edge of the straight edge across the rotating paper. Mark the beginning of the line you drew with an arrow pointing in the direction the pencil moved. Label the resulting line "Northern Hemisphere."

Step 5: Repeat Step 4, only this time rotate the paper *clockwise* (representing the Southern Hemisphere). Label the resulting line "Southern Hemisphere."

Step 6: Repeat Step 4 several times, varying the speed of rotation of the paper with each trial. Identify each new line by labeling it either "slow," "fast," or "very fast."

Questions 68 through 70 refer to the Coriolis experiment.

68. Describe the apparent path of a free-moving object over Earth's surface on a "nonrotating" Earth, the Northern Hemisphere (counterclockwise rotation), and the Southern Hemisphere (clockwise rotation).

____

____

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____

69. In the Northern Hemisphere, the deflection of objects is to the (right, left), while in the Southern Hemisphere it is to the (right, left). Circle your answers.

70. Summarize your observations of the relation between speed of rotation and magnitude of the Coriolis effect you observed in **Step 6.**

____

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From your observations in **Step 6,** you would suspect that the deflection in the path of a free-moving object would be maximized near the equator where Earth's rotational velocity is greatest. However, it is NOT. Vector motion on the surface of a sphere is complex; however, the Coriolis effect is controlled primarily by rotation about a VERTICAL axis. In your experiment, all points on the paper were rotating about a vertical axis, the thumbtack. However, the flat paper does not represent the "real" spherical Earth. On Earth, the vertical axis of rotation is a line connecting the geographic poles that is only vertical to Earth's surface at each pole. On the Equator, the axis is *parallel* to the surface; therefore, there is no rotation about a vertical axis. As a consequence, the Coriolis effect is strongest at the poles and weakens equatorward, becoming nonexistent at the equator. (To help visualize this changing orientation, obtain a globe and hold a pencil parallel to Earth's axis at the North Pole. Notice the axis is vertical to the surface, just as in the experiment. Now, *while keeping the pencil parallel to Earth's axis of rotation,* slowly move it over the surface to the equator. Notice how the orientation of the pencil changes relative to the surface as it is moved. At the equator, the pencil is now parallel to the surface and rotation about the pencil is directed toward and away from Earth's center, not over the surface.)

71. Considering what you have learned about the Coriolis effect, write a brief statement describing the Coriolis effect on the atmosphere of the planet Venus, about the same size as Earth, but with a period of rotation of 244 Earth days. What about on Jupiter, a planet much larger than Earth, with a 10-hour day?

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Examine the global wind pattern (shown with arrows) that is associated with the global pattern of pressure in Figure 13. The wind arrows can be used to identify the global wind belts, which include the **trade winds**, **westerlies**, and **polar easterlies**. Then answer questions 72–75.

72. Examine the pressure cells in Figure 13. Then, on Figure 15, complete the diagrams of the indicated pressure cells for each hemisphere. Label the isobars with appropriate pressures *and* use arrows to indicate the surface air movement in each pressure cell.

73. In the following spaces, indicate the movements of air in high and low pressure cells for each hemisphere. Write one of the two choices given in italics for each blank.

	NORTHERN HEMISPHERE		SOUTHERN HEMISPHERE	
	HIGH	LOW	HIGH	LOW
Surface air moves *into* or *out of:*	____	____	____	____
Surface air will *rise* or *subside* in the center:	____	____	____	____
Surface air motion is *clockwise* or *counterclockwise:*	____	____	____	____

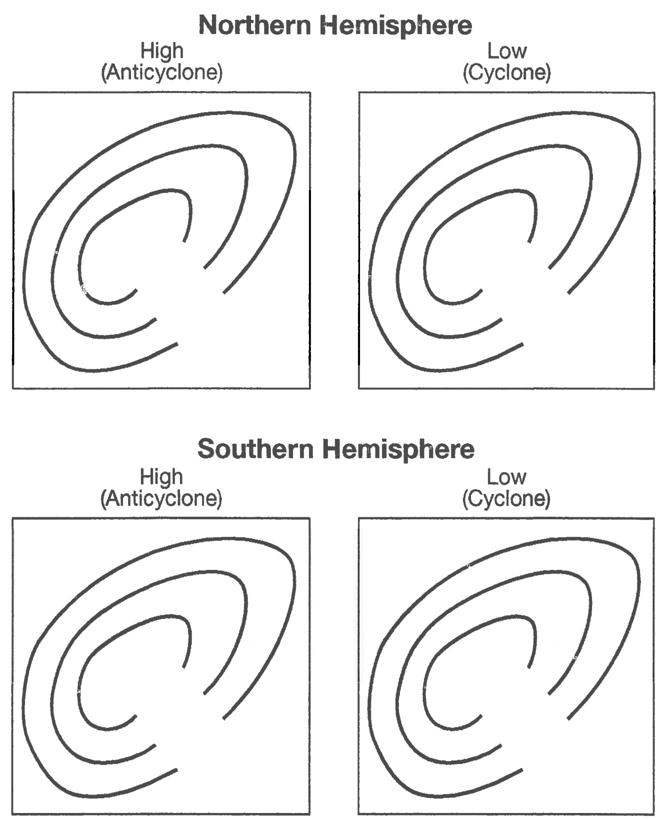
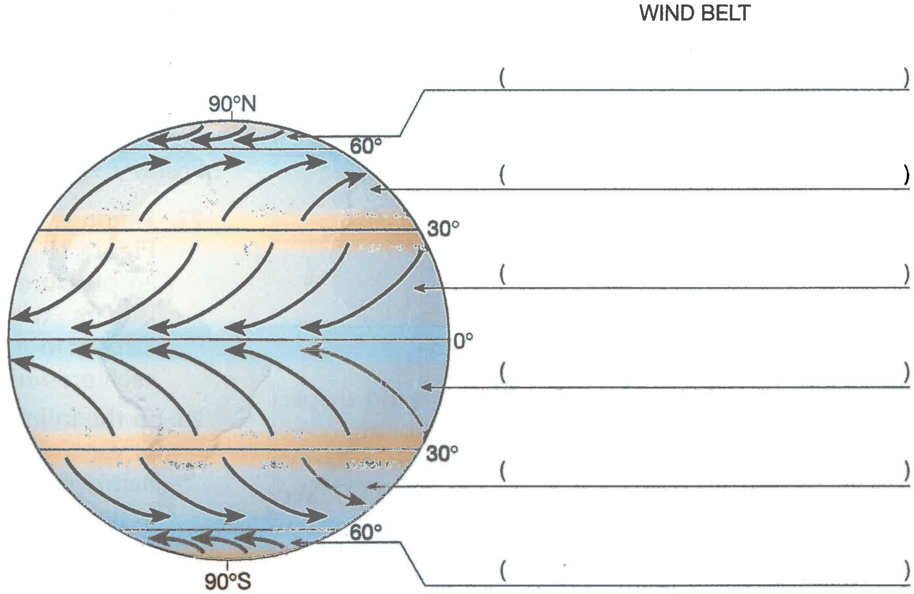


Figure 15 Northern and Southern Hemisphere pressure cells.

Figure 16 Global winds (generalized).



74. Write a brief statement that describes the difference in surface air movement between a Northern Hemisphere and Southern Hemisphere anticyclone.

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75. Write the name of each global wind belt (trade winds, westerlies, or polar easterlies) at the appropriate location on Figure 16. Also indicate by name each global wind belt on the world maps in Figure 13.

In Figure 13, notice the seasonal changes in wind direction, called **monsoons**, over continents.

76. During the (summer, winter) season, the air is moving from the continent to the ocean. Circle your answer.

77. During the (summer, winter) season, the air is moving from the ocean to the continent.

78. In what way is the seasonal change in wind direction over continents related to pressure?

____

____

79. What effect will the seasonal reversal of wind have on moisture in the air and the potential for precipitation over the continents during the following seasons?

Summer season: _______________

____

Winter season: _______________

____

By examining Figure 13, you should notice that the systems of pressure belts and global winds change latitude with the seasons.

80. In what manner is the seasonal shift in pressure belts and global winds related to the movement of the overhead noon Sun throughout the year?

____

Atmospheric Moisture, Pressure, and Wind on the Internet

Using what you have learned in this exercise, investigate the current weather conditions at your location and in North America by completing the corresponding online activity on the *Applications & Investigations in Earth Science* website at http://prenhall.com/earthsciencelab

Atmospheric Moisture, Pressure, and Wind

Date Due: ______________________

Name: ______________________

Date: ______________________

Class: ______________________

After you have finished this exercise, complete the following questions. You may have to refer to the exercise for assistance or to locate specific answers. Be prepared to submit this summary/report to your instructor at the designated time.

1. Answer the following by circling the correct response.
   a. Liquid water changes to water vapor by the process called (condensation, evaporation, deposition).
   b. (Warm, Cold) air has the greatest saturation mixing ratio.
   c. Lowering the air temperature will (increase, decrease) the relative humidity.
   d. At the dew-point temperature, the relative humidity is (25%, 50%, 75%, 100%).
   e. When condensation occurs, heat is (absorbed, released) by water vapor.
   f. Rising air (warms, cools) by (expansion, compression).
   g. In the early morning hours when the daily air temperature is often coolest, relative humidity is generally at its (lowest, highest).
2. What is the dew-point temperature of a kilogram of air when a psychrometer measures an 8°C dry-bulb temperature and a 6°C wet-bulb reading?

   Dew-point temperature = ________ °C
3. Explain the principle that governs the operation of a psychrometer for determining relative humidity.

   ____

   ____

   ____
4. Describe the adiabatic process and how it is responsible for causing condensation in the atmosphere.

   ____

   ____

   ____
5. In the section of the exercise "Adiabatic Processes," question 42, what was the altitude where condensation occurred as the air was rising over the mountain?

   ______________ meters
6. Place each of the following statements in proper sequence (1 for the first) leading to the development of clouds.

   ______: dew-point temperature reached

   ______: air begins to rise

   ______: condensation occurs

   ______: adiabatic cooling
7. Assume a parcel of air on the surface with a temperature of 29°C and a relative humidity of 50%. If the parcel rises, at what altitude should clouds form?

   ____
8. Describe the Coriolis effect and its influence in both the Northern and Southern Hemispheres.

   ____

   ____

   ____

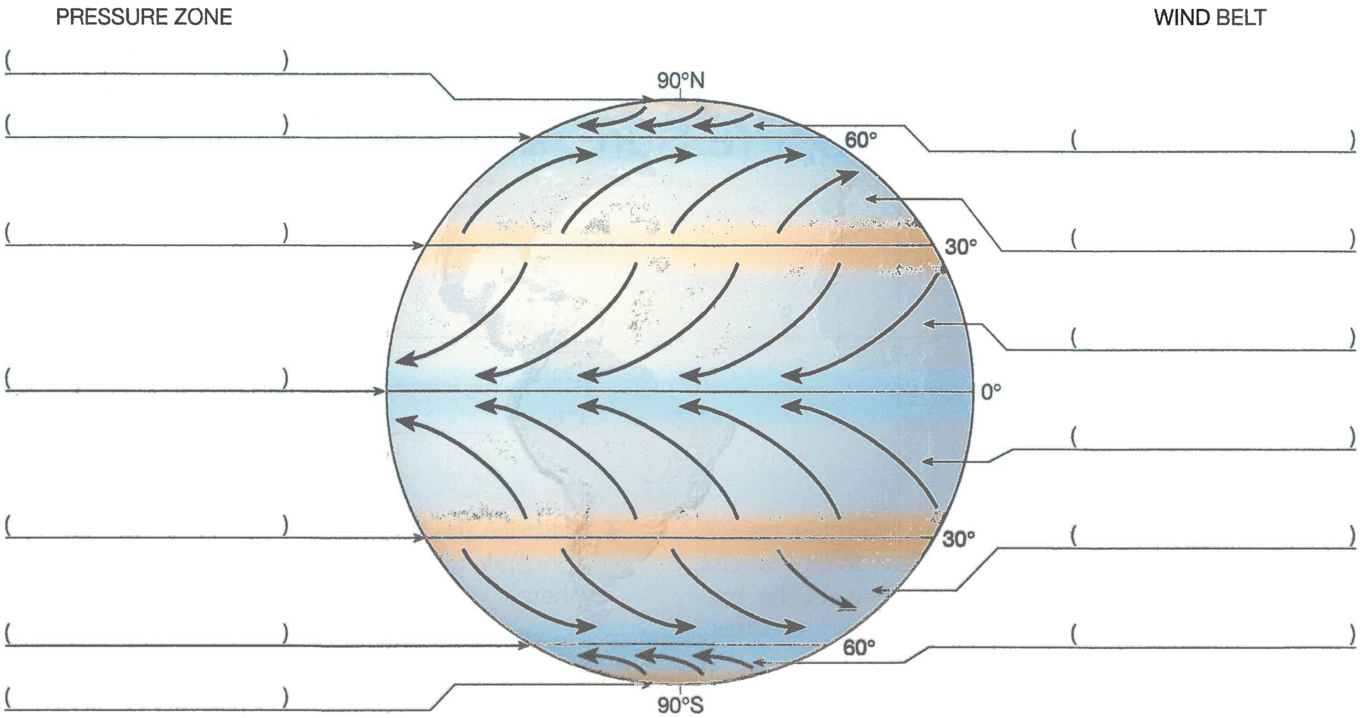

Figure 17 Global pressures and winds (generalized).

9. Refer to Figure 17. Use the indicated parallels of latitude as a guide to write the names of the global pressure zones and wind belts at their proper locations.

10. On Figure 18, illustrate, by labeling the isobars, a typical Northern Hemisphere cyclone and anticyclone. Use arrows to indicate the movement of surface air associated with each pressure cell.

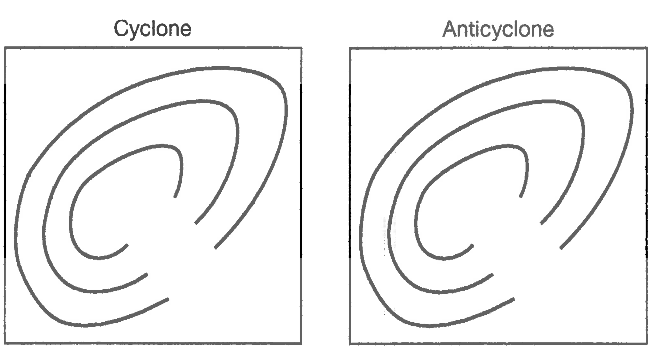

Figure 18 Pressures and winds in a typical Northern Hemisphere cyclone and anticyclone.

11. Complete Figure 19 by using the indicated surface barometric pressures to assist in drawing appropriate isobars. Begin with the 988 mb isobar and use a 4 mb interval between successive isobars.

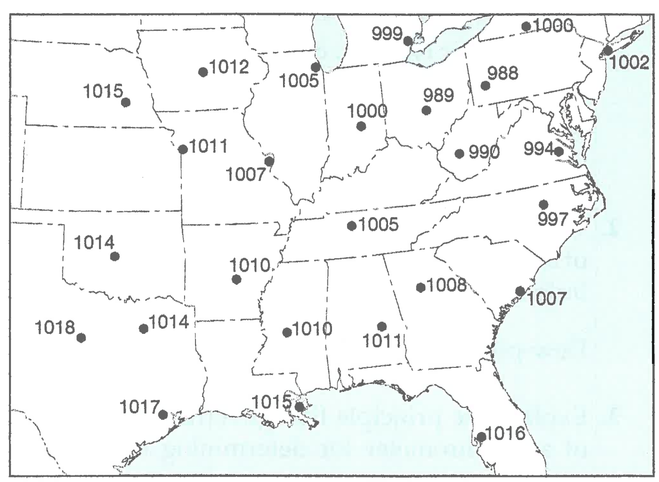

Figure 19 Atmospheric pressures for select cities.