Exercise Seven is suggested as an introductory exercise.

**Exercise Eight**

**Storm Systems**

**Instructor Notes**

**Suggested Correlation of Topics**

Air and its movements, air masses, atmospheres, Coriolis effect, cyclonic storms, geography, meteorology, rotation of planets, weather forecasting, weather satellites, winds

**Purpose**

The objective of this exercise is to demonstrate the fundamentals of atmospheric circulation as they apply to Earth and other planets. Upon completion of this exercise the student should understand the fundamental controls on atmospheric circulation, especially planetary rotation and the Coriolis effect. In addition, the student will be able to make simple weather predictions based on satellite photographs.

**Materials**

World map

**Background**

Earth’s weather patterns are complex, but some basic meteorological concepts can be understood by examining photographs of the Earth taken from space. Furthermore, comparing Earth’s cloud patterns to those of other planets which have very different atmospheres—Mars, Venus, and Jupiter—sheds light on some basic principles of atmospheric circulation.

A fundamental concept of this exercise is that air moves from areas of high pressure toward areas of lower pressure. An analogy can be made to water flowing from a high pressure hose, or dye dissipating in water.

The simple Hadley cell circulation model of Figure 8.1 introduces atmospheric circulation. The pattern is driven by solar energy, which heats the equatorial regions. As the planetary comparisons of this lab indicate, rapid planetary rotation disrupts this simple pattern into multiple circulation cells and turbulent eddies. This occurs on Earth giving rise to cyclonic storms, which are low pressure centers that result in inclement weather. The tilt of a planet can also affect the atmospheric circulation pattern, because the region of maximum solar heating will change with the season of the year. Venus rotates very slowly (once in 243 Earth days) and is tilted only 3° with respect to the plane of its orbit. Thus, Venus has a relatively simple pattern of atmospheric circulation which approximates a Hadley cell.

The Coriolis effect, introduced in the previous laboratory exercise, is an imaginary force that causes deflection of air parcels due to a planet’s rotation (Figure 8.2). On a planet rotating toward the east (such as the Earth and most other planets), this causes rightward deflection and counterclockwise rotation of winds in the northern hemisphere, and the opposite effect in the southern hemisphere (Figure 8.3). The slow rotation of Venus makes the Coriolis effect unimportant there. However, like Earth, Mars has a 24 hour rotation period and the Coriolis effect is important.

To some students it will be readily apparent which way a storm is spiraling. Others may first want to sketch the spiraling clouds. If your pencil moves clockwise as it moves in toward the center of the spiral, then the clouds spiral clockwise, and vice versa. This exercise calls on students to locate and predict the weather in various cities around the world. Using a world map to locate the cities and then finding them on the Earth photo is a good lesson in geography. Additional cities can be added by the instructor if time permits.

Jupiter is a giant gas planet that has no solid surface; instead its atmosphere gets progressively denser with depth. At great depth within the atmosphere the pressure is so tremendous that the gases of the atmosphere are compressed into a liquid, and
below this is the solid core of the planet. Jupiter rotates very rapidly, once in about 9 hours 55 minutes; Jupiter also has a large supply of internal heat. These factors contribute to complex, turbulent flow in the atmosphere. Neighboring bands in Jupiter’s atmosphere typically have winds that blow in opposite directions. Vortices (spots) in the atmosphere are generally not Coriolis-induced; instead they develop along boundaries between bands as a result of the opposing winds. Imagining that a storm rotates like a pinwheel can help to reveal the directions that winds to either side are blowing. Most of Jupiter’s spots are temporary features, appearing and disappearing as winds and eddies shift slightly. The Great Red Spot of Jupiter, observed from Earth for more than 300 years, is a notable exception.

**Science Standards**

- Earth and Space Science
  - Energy in the Earth system
  - Origin and evolution of the Earth system

**Answer Key**

1. **a.** It spirals counterclockwise.
   **b.** The Coriolis effect deflects any northern hemisphere storm into a counterclockwise spiral.

2. **a.** They spiral clockwise.
   **b.** The Coriolis effect deflects any southern hemisphere storm into a clockwise spiral.

3. The feature is a storm front, usually associated with precipitation, wind, and cooler temperatures.

4. **a.** Continued clouds and showers; cool.
   **b.** Continued clear and warm.
   **c.** Partly cloudy and hot.
   **d.** Increasing clouds with rain likely; cooler.
   **e.** Continued clear and cool.

5. The air pressure will decrease as the cyclonic storm over the eastern United States, a center of low pressure, passes through.

6. **a.** It is a cyclonic storm.
   **b.** It must be in the northern hemisphere because the clouds spiral counterclockwise.

7. **a.** No.

8. **a.** Jupiter rotates quickly. It shows well-defined banding and a turbulent, complex pattern of atmospheric circulation.
   **b.** The GRS lies in Jupiter’s southern hemisphere.
   **c.** Counterclockwise.
   **d.** No; the rotation is incorrect.

9. **b.** Venus has a more simple circulation pattern.
   **c.** Venus must rotate more slowly than the Earth, because it does not show evidence for Coriolis-induced storms. Also, its simple cloud banding reflects a single equator-to-pole circulation cell.
Purpose

By examining photographs of Earth, Mars, Venus, and Jupiter, you will recognize wind circulation patterns and the influence of rotation and the Coriolis effect on planetary atmospheres.

Materials

World map.

Introduction

Our lives are affected every day by the weather—on some days more than others! Being able to predict the weather is a convenience, but being able to predict severe weather is important to public safety. Furthermore, understanding the Earth’s weather patterns is critical to agriculture, transportation, and the military. To gain insight into Earth’s weather and circulation patterns, it is useful to examine the atmospheres of other planets, comparing them to each other and to Earth.

Atmospheric circulation is caused by differences in heating, primarily between the poles and equator. On an ideal non-rotating planet (Figure 8.1), warm air would rise over the equatorial regions, lowering the air pressure there. Air in each hemisphere would then circulate to the cool polar regions where it would sink, increasing air pressure there. To complete the cycle, the cold high-pressure air would travel at ground level back toward the equator. This simplified pattern of circulation is called a Hadley cell, named after the British scientist who first proposed the model. On a real planet, the pattern of atmospheric circulation is complicated by rotation, which breaks the circulation into several cells from pole to equator and results in an ever-changing pattern of turbulent swirling clouds, called eddies. Also, if a planet is tilted with respect to its orbit around the Sun, the latitude of maximum solar heating changes as the planet goes through its yearly cycle of seasons.

Air moves from regions of high pressure to regions of low pressure. The pressure difference, or gradient, is the driving force for atmospheric circulation. However, other effects prevent the direct motion of a given air mass from high to low pressure. Friction between the ground and the atmosphere modifies air motion, as does the presence of mountains or other topography. Furthermore, the Coriolis effect deflects air masses as they move. On a planet that rotates in the normal sense (toward the east), a parcel of air is deflected to the right of its direction of motion in the northern hemisphere and to the left in the southern hemisphere. Figure 8.2 shows this effect.

Cyclonic storms are the fundamental mechanism
for turbulent, inclement weather on Earth. These are huge, well-organized centers of low pressure which develop along the boundaries between air masses. As a cyclone intensifies, so does weather activity along the boundary, or **front**. In addition to its clouds, a storm front commonly brings with it precipitation, wind, and cooler temperatures.

The motion of air parcels on Earth generates such low pressure centers. Air parcels can approach low pressure cells from all directions. Because of the Coriolis deflection, a circulation of winds is set up around the low pressure centers (Figure 8.3). The result is a counterclockwise spiral of air into a low center in the northern hemisphere, and a clockwise spiral in the southern hemisphere.

### Procedure and Questions

Examine Figure 8.4, using the world map to help identify the land masses that are visible.

1. Notice the well-defined spiral pattern of clouds southwest of the Baja peninsula, Mexico.
   a. Which way is this cloud pattern spiraling, clockwise or counterclockwise?

   b. Why?

2. Now examine the two cloud spirals over the southern Pacific Ocean.
   a. Which way are these clouds spiraling, clockwise or counterclockwise?

   b. Why?

3. Notice the long line of clouds stretching over the southern Pacific Ocean. What is this feature and what kind of weather is likely associated with it?

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**Figure 8.2.** As a small mass of air, called an air parcel, moves under the influence of a pressure gradient, its path is not a direct one from high to low pressure. The curved lines around the low pressure centers (L) are contours of equal pressure, or isobars. The low pressure center can be considered a “well” or sink for air, and the high pressure center (H) can be considered a “ridge” or source of air. If you were riding along an air parcel in the northern hemisphere, you would be deflected to the right of your direction of motion as the air parcel drifts from high pressure toward lower pressure. Thus, the final motion is nearly parallel to the isobars, rather than across them. In the southern hemisphere, the mirror image of the diagram is observed, with the Coriolis “force” causing air parcels to deflect toward their left.
Figure 8.3. A simplified illustration of how low pressure cells (cyclones) develop. Air parcels heading toward lows are deflected by the Coriolis effect to set up a counterclockwise circulation pattern in the northern hemisphere, and a clockwise pattern in the southern hemisphere.

4. As Earth rotates from west to east, frictional drag pulls the atmosphere along more slowly in the same direction. Assuming that the storm system off of southern Chile will reach the coast by tomorrow, and noting that this photo was taken in September, determine a likely weather forecast (temperature, clouds, and precipitation) for the next 24 hours in each of the following locations:

a. Indianapolis (40°N, 86°W)

b. El Paso (32°N, 106°W)

c. The Galápagos Islands (0°N, 91°W)

d. Tierra del Fuego (54°S, 68°W)

e. Buenos Aires (34°S, 58°W)

5. Will the air pressure become higher or lower in Bermuda during the next 24 hours? Explain.

6. Look at Figure 8.5, taken by a spacecraft in orbit over Mars. Like Earth, Mars rotates west to east.

a. What do you think this cloud feature is?

b. In what hemisphere is the feature? How do you know?
7. Examine the atmosphere of Venus as seen in Figure 8.6.
   a. Can you identify any obvious spiraling clouds that might be due to the Coriolis Effect?

   b. Compare the photos of Venus and Earth, and recall the simple Hadley cell circulation model of Figure 8.1. Does Venus appear to have a more simple or more complex pattern of atmospheric circulation than Earth?

   c. How does the circulation pattern support the proposition that Venus rotates slowly?

Jupiter is a gaseous planet, having no solid surface (but likely possessing a solid core). Although the planet is composed mostly of hydrogen and some helium, its visible clouds probably consist of ammonia (NH₄), ammonium hydrosulfide (NH₄HS), and water (H₂O). The Great Red Spot (GRS) is a great storm in the clouds of Jupiter.

8. Base your answers to the following questions on the Voyager photos of Jupiter shown in Figures 8.7 and 8.8.
   a. Does Jupiter rotate quickly or slowly? Justify your answer.

   b. Does the GRS lie in the northern or southern hemisphere of Jupiter?

   c. In which direction do winds around the GRS rotate?

   d. Is the GRS a Coriolis-induced storm? Support your answer.

9. The winds of Jupiter commonly blow in opposite directions in neighboring bands. That is, winds blow to the east in one band and to the west in the neighboring band. These opposing winds can act to create swirling eddies and storms. Draw a sketch of the GRS. Indicate with arrows the directions that winds along its northern and southern edges are blowing.
Figure 8.4. Earth as seen from the Geostationary Operational Environmental Satellite, GOES-7. The picture was taken at 6 p.m. Greenwich Mean Time on September 25, 1994, soon after the start of northern hemisphere autumn. The north pole is toward the top.
Figure 8.5. Viking Orbiter image 78A42, showing a water frost cloud pattern over the surface of Mars. North is toward the top.
Figure 8.6. Patterns of cloud motion on Venus are revealed in this ultraviolet image, taken by the Pioneer Venus orbiter in 1979. Venus is unusual in that the planet and its atmosphere rotate from east to west. The surface of Venus cannot be seen through the thick clouds. North is toward the top; the horizontal black line is missing data. Pioneer Venus image 0202-79-046-0830, courtesy of Larry Travis.
Figure 8.7. Jupiter as seen by the Voyager 1 spacecraft from a distance of 54 million km (34 million miles), as it approached the planet on January 9, 1979. The Great Red Spot (GRS) is a large vortex just below center. North is toward the top.

Figure 8.8. Closeup of the Great Red Spot (GRS) seen by Voyager 1 on February 25, 1979 from a distance of 9.2 million km (5.7 million miles). The spot is about 25,000 km (16,000 miles) across, and could hold two Earths side-by-side. White ovals and turbulent, swirling eddies are also visible.