NAME ______________________________

DATE ______________________________

Carolina™ Coriolis Effect and Atmospheric Circulation for AP Environmental Science

Background

Introduction

The North American cities of Toronto and Miami are approximately 2,000 km apart, and on a conventional map, Toronto is located due north of Miami. However, a pilot flying from one city to the other cannot simply fly 2,000 km north or south and land in the other city. A plane flying in a straight line south from Toronto would end up somewhere west of Miami; from the perspective of a person in Miami, the plane would seem to have arced to the pilot's right. Why? While the plane is the air, the earth continues to rotate on its axis. For this reason, pilots flying north or south must account for the rotation of the earth, which deflects their path relative to stationary points on the earth's surface. Furthermore, because the earth is a sphere, points near the equator are rotating faster than points near the poles. Air masses are similarly affected by the rotation of the earth, and these global atmospheric circulation patterns in turn significantly influence the planet's climate.

Global Climate Mechanisms

It is easy to take for granted that Arctic and Antarctic regions are quite cold and that areas near the equator are much warmer. We understand that some regions of the earth experience seasons characterized by fluctuating temperatures and varying amounts and types of precipitation, while in other regions these environmental conditions remains relatively constant. However, each of these conditions is the result of numerous factors and influences that collectively determine global climate.

To understand these mechanisms, it is important first to distinguish between weather and climate. "Weather" describes short-term, specific conditions in an area, such as temperature range, wind strength and direction, precipitation type and amount, humidity, and cloud cover in a specific region on a particular day. "Climate" refers to the long-term, collective, cumulative effects of these conditions on the region.

Mechanisms that affect global climate patterns include (1) the tilt of the earth and the rotation of the earth on its axis, (2) uneven heating of the earth's surface due to uneven distribution of radiant solar energy, (3) global air and water circulation and convection currents set in motion by other mechanisms, and (4) the interactions of major air, land, and water masses, including the Coriolis effect.

The Earth in Space

The earth rotates from west to east around a north-south axis. The axis upon which the earth spins is tilted at a 23.5° angle relative to the plane in which the planet orbits the sun. The points on the planet that delineate the axis of rotation are named the North Pole and the South Pole. Viewed from space at the North Pole, the earth rotates counterclockwise. The imaginary line drawn perpendicular to the planet's axis of rotation at an equal distance from the North and South poles is called the equator. Over the course of the earth's annual orbit, due to it's tilt and rotation, the planet receives overall more solar radiation nearer the equator than it does at locations closer to the poles.

Distance from the equator is measured in degrees. Imagine measuring the curve of the earth on a protractor, with the equator at the origin (0°). The Tropic of Cancer lies 23.5° north of the equator, and the

Tropic of Capricorn lies 23.5° south of the equator. The Arctic Circle lies 66.5° north of the equator, and the Antarctic Circle lies 66.5° south of the equator. The poles are, of course, 90° north and south of the equator.

Consider two points on the earth, one at the North Pole (i.e., at the earth's axis of rotation) and another point at the equator. Over the course of one rotation of the planet, the point at the North Pole would rotate once, moving in an exceedingly small circle. In the same amount of time, however, the point on the equator would have traveled, relative to the point at the pole, in a great circle almost 25,000 miles in circumference at a speed of over 1,000 miles per hour! Thus, the earth is moving faster at the equator than it is at the poles, and its speed is proportionally faster or slower at points between these.

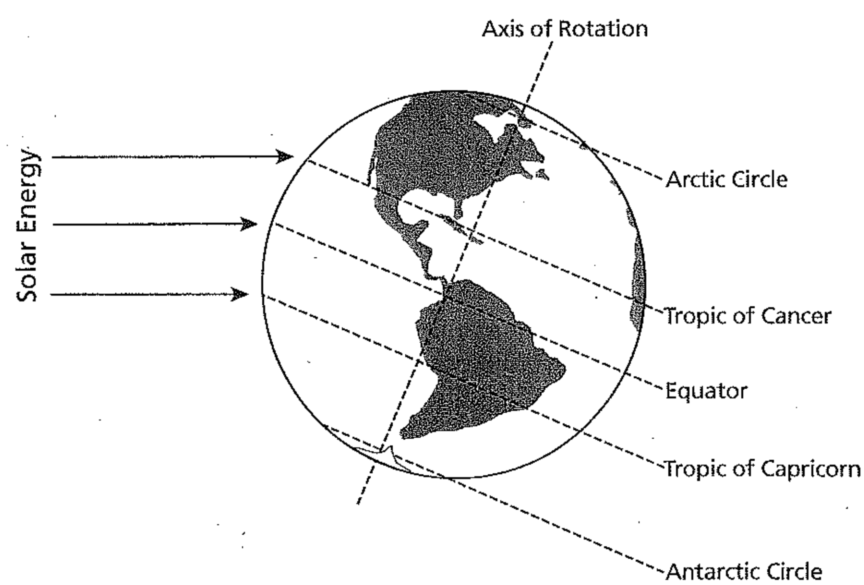
It may also be helpful to keep in mind that as winds move north and south on the earth's spherical surface, they are also moving closer to (moving poleward) or farther from (moving toward the equator) the earth's axis of rotation, due to the curvature of the earth. Furthermore, points on the earth itself move at different speeds relative to its axis of rotation—faster near the equator, slower nearer the poles. Finally, friction caused by earth's irregular surface features causes low-altitude winds to slow, contributing to further divergence of winds near low pressure systems and converging winds near highs.

Solar Energy Distribution

The sun gives off vast amounts of energy, including light and heat, and some of this energy reaches the earth as it orbits the sun. Some of the solar energy is reflected by the ozone layer in the earth's upper atmosphere. The ozone layer's reflective properties help prevent solar rays from damaging and destroying living organisms on the earth's surface. Some solar energy is absorbed by greenhouse gases, such as carbon dioxide, in the earth's atmosphere. Greenhouse gases help warm the atmosphere, and certain amounts of these gases can be beneficial to life. Some solar energy passes through the atmosphere and reaches the earth's surface. Some of the heat is absorbed and some is reflected off the earth's surface back into the atmosphere, where it can be absorbed by greenhouse gases. The amount of solar energy that any particular region on Earth receives is based on the mostly spherical shape of the earth, the tilt of the earth's axis, and the angle of the sun's rays.

Regions close to the equator receive the most solar energy overall because these areas remain closer to the sun over the course of earth's orbit, while the regions near the North and South poles receive less solar energy over the course of a year because these regions remain farther from the sun.

Annual seasonal changes can be attributed to the tilt of the earth. On June 21st, the northern portion of the earth's axis tilts toward the sun, and the regions at the Tropic of Cancer receive the most direct sunlight. Regions of the Northern Hemisphere experience the summer solstice, or the most daylight hours of the year. Conversely, regions of the Southern Hemisphere experience the fewest daylight hours of the year. On this day, the Antarctic Circle receives no sunlight. The opposite occurs on December 21st. On this day, the Tropic of



Winter in the Northern Hemisphere, summer in the Southern Hemisphere

Capricorn receives the most sunlight, and regions of the Southern Hemisphere experience the summer solstice, while regions of the Northern Hemisphere experience winter solstice. On December 21st, the Arctic Circle receives no sunlight.

Convection

An air mass is a body of air that is characterized by a particular temperature and humidity. Air masses usually cover hundreds of thousands of square miles and have temperatures and humidities similar to the area where they originate. Having a lower saturation point, cool air cannot retain as much moisture as warm air. Polar air masses are those originating between the Arctic Circle and the North Pole or between the Antarctic Circle and the South Pole; they are characteristically cold. Tropical air masses are those originating between the Tropic of Cancer and the Tropic of Capricorn; they are warm air masses. Maritime air masses form over the ocean; they are very moist. Continental air masses, as their name implies, form over land; they tend to contain less moisture than maritime air masses. There are, therefore, four basic types of air masses. Their names, abbreviations, and traits are as follows:
continental polar (cP): a cold, dry air mass
continental tropical (cT): a warm, dry air mass
maritime polar (mP): a cold, moist air mass
maritime tropical (mT): a warm, moist air mass

As air molecules are heated, they gain energy and move apart from one another, increasing the volume of the air mass and decreasing its density. As its density decreases, the air mass rises. When air molecules cool, they move closer together, increasing in density. A convection current forms in the atmosphere when cool, dense air moves toward a source of heat, becomes warmer and less dense, then rises and moves away from the heat source, and then cools and sinks again. The differing density of air masses leads to convection currents in the atmosphere. We know these moving currents of air as wind.

The Coriolis Effect

The Coriolis effect is the name given to the phenomenon that objects (including air masses and wind) moving in a straight path on an object rotating at a constant speed appear to be deflected to one side of their path when viewed from the frame of reference of the rotating object, due to differences in relative velocity and the turning of the frame of reference. The amount of deflection is determined by both the speed and latitude of the moving object. The greater its speed, the greater the deflection force exerted on the object. This force is named in recognition of the French mathematician and engineer Gaspard Gustave Coriolis (1792–1843), a pioneer in the physics of work, energy, and the forces that affect rotating systems.

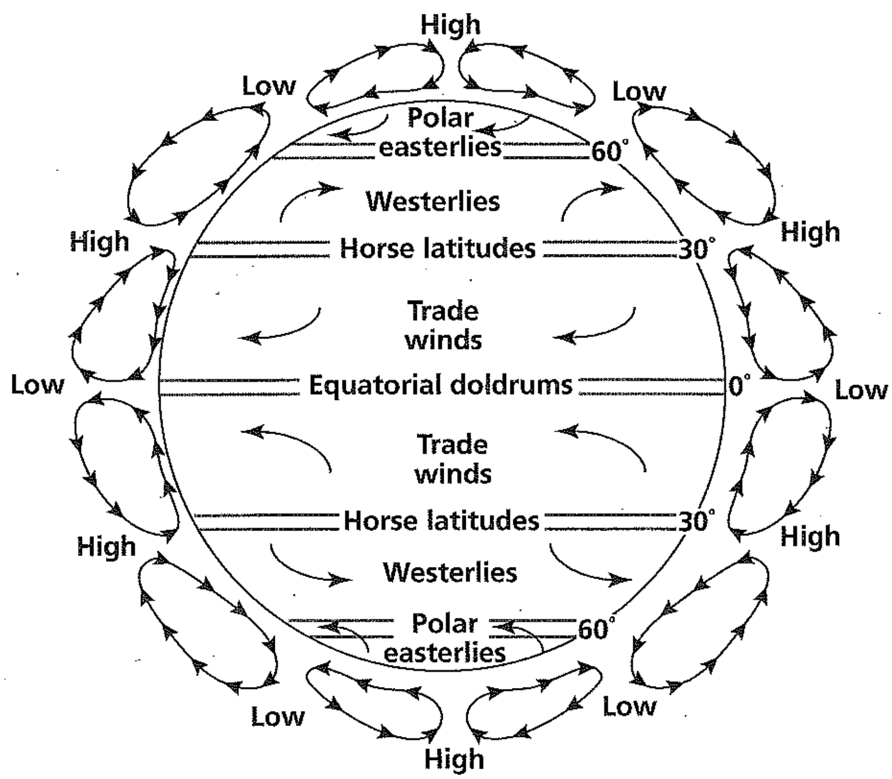
How does this force relate to the other mechanisms that affect global climate? The atmosphere circulates from areas of higher pressure near the poles to areas of lower pressure at the equator, moving essentially from north to south and south to north. This is a result of the pressure gradient force, which works toward achieving atmospheric equilibrium. We know that in the absence of other forces, wind moving in a straight line at a certain speed will continue to do so. However, as we have discussed, many forces are at work. In addition to pressure gradients, convection currents, and other factors, the movement of air across the earth's surface is affected by the planet's rotation—because the globe moves more quickly at the equator than it does at the poles. Due to these conditions, winds in the Northern Hemisphere are deflected to the right of their forward motion, and winds in the Southern Hemisphere are deflected to the left of their forward motion. Viewed from space, however, the path of the wind is a straight line.

The Coriolis effect can be a difficult concept to grasp. Although it is not a perfect representation, a potentially useful exercise is to consider the following examples, where a merry-go-round represents the earth, people represent locations on or above the earth, and a ball represents an air mass moving through the atmosphere. Imagine two people, A and B, sitting opposite one another on a merry-go-round, facing each other. A third individual, person C, looks down on the merry-go-round from above. Person A has a ball and intends to throw it to person B. If the merry-go-round is not rotating when person A throws the ball to person B, the ball will travel in a straight line when viewed from the frames of reference of person A and person B on the merry-go-round, as well as by person C looking down from above.

However, if the merry-go-round is rotating when person A throws the ball straight to person B, the ball's path will, from person B's perspective, seem to be deflected and curve away; this is because person B is in motion, rotating along with the merry-go-round. However, to an observer standing on the ground outside the merry-go-round's frame of reference, the ball will appear to travel in a straight line. The ball is in fact moving in a straight line, but by the time the ball arrives where person B was when the ball was thrown, person B (and person A) will have moved to a different location due to the rotation of the merry-go-round. Person C looking down on the merry-go-round from above will still perceive that the ball moved in a straight line.

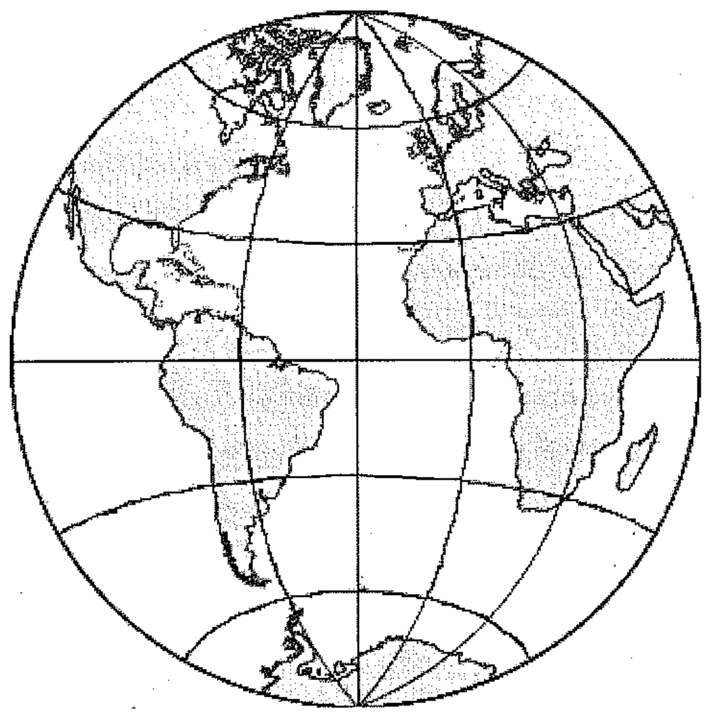
The Coriolis effect is a critical component in the formation of large storm systems, such as hurricanes, cyclones, and typhoons. These storms begin with the heating of tropical waters and air. A heated air mass rises, creating a low-pressure system. Air moves in to fill this low-pressure area, and the farther the mass moves from the equator, the greater its Coriolis deflection, setting in motion the storm's rotation. Because there is no Coriolis force at the equator, tropical cyclones tend to develop at least 500 km away from it, either to the north or south.

The Coriolis effect also influences ocean currents and the global wind belts. The air at the equator is heated, and rises, creating a low-pressure area. Around 30° North and South of the equator, the air has cooled substantially and falls, creating a high-pressure area. The high-pressure area generates the high winds, known as the trade winds, which are deflected to the West due to the rotation of the earth. The overall effect is to create steady bands of wind flow around the globe. The tropical winds are called the trade winds. Other global winds produced by the Coriolis effect and by rising and falling air masses are the subtropical westerlies and the polar easterlies.



Pre-laboratory Questions

1. On the globe:
   a. Draw an arrow indicating the direction that the Coriolis effect would deflect an air mass moving from the North Pole toward the equator. Label the arrow "A."
   b. Draw an arrow indicating the direction that the Coriolis effect would deflect an air mass moving from the South Pole toward the equator. Label the arrow "B."
   c. Indicate the area(s) of the globe that are moving fastest due to the rotation of the earth on its axis. Label the area(s) "C."
   d. Indicate the area(s) of the globe that are moving slowest due to the rotation of the earth on its axis. Label the area(s) "D."
   e. Indicate the area(s) of the globe that typically receive more of the sun's energy. Label the area(s) "E."
   f. Indicate the area(s) of the globe that typically receive less of the sun's energy. Label the area(s) "F."



2. Describe the differences in the seasons between the Northern and Southern Hemispheres due to the tilt of the earth and its orbit around the sun.

Guided Activity

Overview

In this activity, you will complete three exercises to learn about the Coriolis effect. In the first, your group will use a turntable to observe the effect of apparent motion due to rotation. Then, you will observe fluid convection using warm and cold water. In the third exercise, your group will use a model globe to chart the direction of air masses affected by the Coriolis effect.

Materials

- turntable
- wet-erase marker
- inflatable globe
- aluminum pie pan
- 2 100-mL beakers
- bottle of chilled food coloring
- room-temperature water
- ice water
- warm water
- paper towels
- scissors
- Turntable Template

Procedure

Turntable

1. Cut out the circle from the Turntable Template.
2. Place the paper circle on the turntable.
3. Hold the turntable stationary, and have one member of your group use the marker to draw a straight line on the paper from the edge to the center of the turntable. At the edge, label this line "R." This is your reference line.
4. Have one person in your group slowly rotate the turntable **counterclockwise** at a constant speed.
5. While the turntable is being rotated, have another person use the marker to draw a straight line on the paper from the edge to the center of the turntable.
6. Stop the turntable and observe the path of the marker. Label this line "1CCW" (first trial, counterclockwise). Place an arrowhead at the endpoint of the line to indicate the direction the marker was moving.
7. Have one person in your group slowly rotate the turntable **counterclockwise** at a constant speed.
8. While the turntable is being rotated, have another person use the marker to draw a straight line on the paper from the center of the turntable to the edge of the paper.
9. Stop the turntable and observe the path of the marker. Label this line "2CCW" (for second trial, counterclockwise). Place an arrowhead at the endpoint of the line to indicate the direction the marker was moving.
10. Have one person in your group slowly rotate the turntable **clockwise** at a constant speed.
11. While the turntable is being rotated, have another person use the marker to draw a straight line on the paper from the edge to the center of the turntable. Have the other members of your group observe the path of the marker.
12. Stop the turntable and observe the path of the marker. Label this line "1CW" (first trial, clockwise). Place an arrowhead at the endpoint of the line to indicate the direction the marker was moving.

13. Have one person in your group slowly rotate the turntable **clockwise** at a constant speed.
14. While the turntable is being rotated, have another person use the marker to draw a straight line on the paper from the center of the turntable to the edge of the paper.
15. Stop the turntable and observe the path of the marker. Label this line "2CW" (for second trial, clockwise). Place an arrowhead at the endpoint of the line to indicate the direction the marker was moving.
16. Note the differences between the counterclockwise arrows and the clockwise arrows, and consider how rotation affects the apparent path of an object, such as the pen, traveling in a straight line.

Fluid Convection

1. Place a small amount of ice in one of the 100-mL beakers. Fill the beaker with room-temperature water to the 80-mL mark. **Tip:** To make sure that the bottle of food coloring remains chilled, place the bottle in the beaker of ice water while you are preparing the other materials.
2. Pour about three-fourths of an inch of room-temperature water into the aluminum pie pan.
3. Pour 80 mL of warm water into the other 100-mL beaker.
4. Place the beaker of ice water in the pie pan, off to one side. Place the beaker of warm water on the opposite side of the pie pan.
5. Place 1 or 2 drops of chilled food coloring in the water in the pie pan, at the base of the beaker of ice water.
6. Observe the movement of the food coloring through the water of the pie pan, and observe the convection currents.

Globe

1. Locate the following lines of latitude on the globe:
   a. the Tropic of Cancer (23.5° N)
   b. the Tropic of Capricorn (23.5° S)
   c. the Arctic Circle (66.5° N)
   d. the Antarctic Circle (66.5° S)
2. Have one team member hold the globe and rotate it at a constant speed counterclockwise, as viewed from the North Pole. While the globe is rotating, have another team member use the wet-erase marker to draw an arrow from the North Pole to the Arctic Circle.
3. Continue to rotate the globe counterclockwise. While the globe is rotating, have a team member use the wet-erase marker to draw an arrow from the Tropic of Cancer to the Arctic Circle.
4. Continue to rotate the globe counterclockwise. While the globe is rotating, have a team member use the wet-erase marker to draw an arrow from the Tropic of Cancer to the equator.
5. Continue to rotate the globe counterclockwise. While the globe is rotating, have a team member use the wet-erase marker to draw an arrow from the Tropic of Capricorn to the equator.
6. Continue to rotate the globe counterclockwise. While the globe is rotating, have a team member use the wet-erase marker to draw an arrow from the Tropic of Capricorn to the Antarctic Circle.
7. Continue to rotate the globe counterclockwise. While the globe is rotating, have a team member use the wet-erase marker to draw an arrow from the South Pole to the Antarctic Circle.
8. Answer the Laboratory Questions.
9. After completing this activity, use glass cleaner or whiteboard cleaner to wipe the ink off the globe.

Inquiry Activity

Now that you have modeled the Coriolis effect and fluid convection, work with your group to design a model that demonstrates the movement of oceans, global air masses, or storm systems. Follow the procedure below and use the Experimental Design Template to plan your hypothesis, materials, and procedure. Seek teacher approval before beginning the activity.

Materials

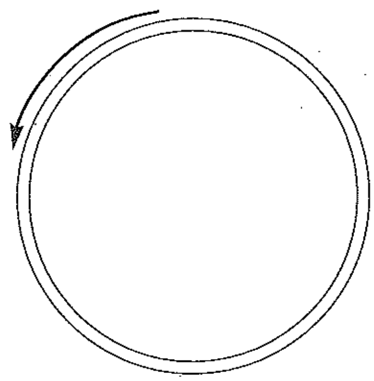
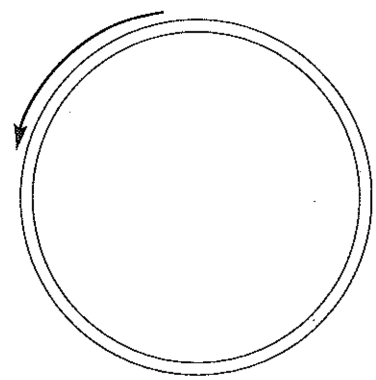
turntable
wet-erase marker
inflatable globe
aluminum pie pan
2 100-mL beakers
bottle of chilled food coloring
room-temperature water
ice water
warm water
paper towels
Other materials might be available. Consult your instructor.

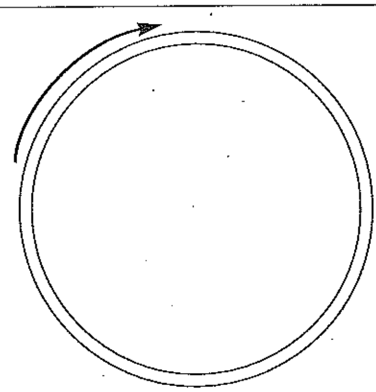
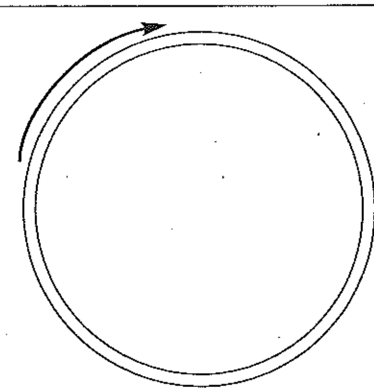
Procedure

1. Collaborate with your group to come up with a testable question about the Coriolis effect or about fluid convection in air masses, the ocean, or storm systems. If you have trouble, ask your teacher for guidance.
2. Design an experiment to test your question. Consider the following as you frame your experiment:
   - **Question** - What are you testing in your experiment? What are you trying to find out?
   - **Hypothesis** - What do you think will happen? Why do you think so? What do you already know that helps support your hypothesis?
   - **Materials** - What materials, tools, or instruments are you going to use to find the answer to the question?
   - **Procedure** - What are you going to do? How are you going to do it? What are you measuring? How can you make sure the data you collect are accurate? What are the independent and dependent variables in this experiment? What is/are your control(s)? What safety practices do you need to use?
   - **Data Collection** - What data will you record, and how will you collect and present it? Show and explain any data tables and graphs that you plan to use.
3. Have your teacher approve your experimental plan before you begin the experiment.
4. After you perform the experiment, analyze your data:
   - **Data Analysis** - What happened? Did you observe anything that surprised you? Show and explain any tables and graphs that support your data.
   - **Conclusion** - What conclusions can you draw from the results of your experiment? How does this compare with your initial hypothesis? Identify some possible sources of error in your experiment. If given the opportunity, how might you conduct the experiment differently?
5. Be prepared to present the findings of your experiment to the class according to your instructor's specification.

Laboratory Questions

1. Draw the arrows that were made on the turntable for each of the following scenarios:

Turntable Rotated Counterclockwise	
 A. From the edge toward the center	 B. From the center toward the edge

Turntable Rotated Clockwise	
 C. From the edge toward the center	 D. From the center toward the edge

2. If you were viewing the marker from the surface of the turntable as the turntable rotated counterclockwise, how would the marker appear to move? How does this apparent path compare with the path of the marker as observed by your group?

3. Record your observations of the movement of the food coloring in the water in the pie pan. Be as detailed as possible.

4. Why did most of the chilled food coloring initially sink to the bottom of the pie pan?

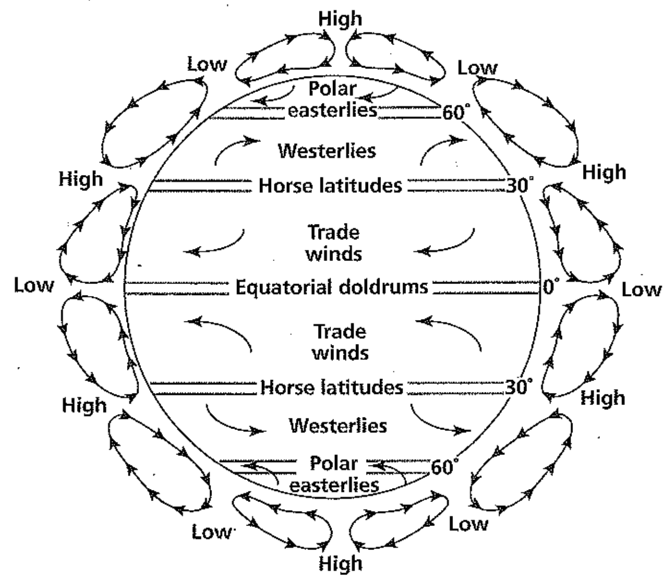
5. What happened to the food coloring after it reached the beaker of warm water?

6. Air, like water, is characterized by fluid motion. Predict what happens to air masses as they are heated and cooled.

7. As surface air masses move in the Northern Hemisphere, in which direction are they deflected from their linear trajectory? As air masses move in the Southern Hemisphere, in which direction are they deflected from their linear trajectory?

Discussion Questions

1. How does the rotation of the earth affect global air circulation? Examine this simplified diagram of the earth's major wind belts, and explain how the Coriolis effect influences the direction of the polar easterlies, the westerlies, and the trade winds.



2. Which other geographical region or continent is most likely to be affected by industrial air pollution originating in Europe? Use your knowledge of atmospheric circulation to support your answer.

3. Refer to the diagram in Discussion Question 1. The series of oblong circuits surrounding the globe represent the general direction that air masses travel at different latitudes and elevations. For example, air masses rise at the equator and descend as they approach the tropics. Explain the mechanism by which air masses rise and fall, and how this mechanism might contribute to stratospheric ozone deterioration.

4. Refer to the diagram in Discussion Question 1. Why do you think many of the world's deserts are located at approximately 30° North or South latitude?

Experimental Design Template

Part A: To be completed and approved before beginning the investigation

What question will you explore? ____________________

____

On the basis of your previous laboratory exercise, background knowledge, and research, what is the hypothesis that you will test? ____________________

____

____

What will be the independent and dependent variables? ____________________

____

What will be the control group(s)? ____________________

____

What equipment and materials will you need (list items and quantity)? ____________________

____

____

What procedure (step-by-step) will you follow? ____________________

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What safety steps will you follow (equipment and procedures)? ____________________

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How will you collect data? ____________________

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How will you analyze data? ____________________

____

Teacher approval to begin your investigation: ____________________

Part B: To be completed during or after your investigation

What changes or modifications have you made to the investigation? ______________________

Attach any data collection or analysis as instructed by your teacher.

What results did you see in the experiment? ______________________

Was the hypothesis accepted or rejected? What conclusions can you draw on the basis of the data and analysis?

What sources of error may have existed, and how might the experiment have been conducted differently? What additional questions arose from the experiment?

Turntable Template

Cut around the edge of the circle below and use the paper circle according to the instructions in the Turntable activity.