Centripetal Critter Coaster

Students get to see centripetal force in action as it keeps stuffed critters from falling while being swung overhead.

Grade Level
- 4th - 8th

Science Focus
- centripetal force
- centrifugal force
- gravity

Time Required
- 15 minutes

Supplies
There are enough materials in the kit to run up to ten cooperative groups.

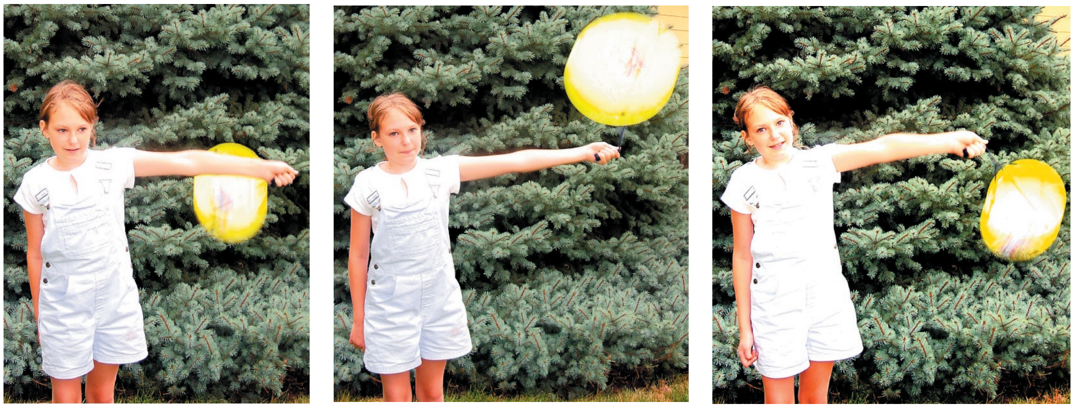
Per Cooperative Group

1 flying disk with three ropes attached

1 stuffed critter

A Special Word About Safety
This activity has students swinging disks over their heads at a pretty good speed. Clearly, this activity needs to be done in an open area, where the students swinging the disks can be well away from each other and from anything the disk might run in to. The disks and the critters are soft, but you should still take care that no one gets hit with a swinging disk! Try the activity yourself first and think about how this will work with your class. If you are uncomfortable with having your students do this - or if you don't have a place that this activity can be done safely - do this as a demonstration activity.

Doing the Activity
- Have the students remember and discuss the "Curve Ball" experiment. They should remember that the ball goes in a straight line unless there is force that keeps it going in a circle. Remind them that the force on the ball pushes it toward the center of the circle; this is the centripetal force.
- Have one student in each cooperative group stand well clear of the other students, hold the knotted end of the ropes, and swing the disk in a vertical circle over his or her head:



The motion will be like an inverted loop in a roller coaster. After one student has done this, each student in the group should try this motion. Have them practice this motion; they will need to do this later.

- Have the students discuss the motion. The motion is a circle, so there is acceleration; the velocity changes. Have them discuss what other experiments involved a change in velocity.
- Now, the students are going to add the stuffed critter to the situation. Have one student in each group hold the knotted end of the ropes so that the disk hangs down. Now, another student should place the critter in the center of the disk. The student holding the ropes should stand well away from the other students, and then swing the disk in a vertical circle. The challenge is this: can they swing the critter in a vertical circle without having the critter fall off the disk? This is just like the loop on a roller coaster, as we mentioned before, but this time with a passenger! If the students are careful, it is pretty easy to keep the critter safely seated on the disk.
- Have every student in each group try this activity; this is an activity that students must feel to be able to understand.
- Discuss what force keeps the critter in place - some suggestions for questions are below.

Active Questioning, Explanation, and Discussion

1. Which force keeps the critter moving in a circle?
2. What force keeps the critter in place? (In this case, we are going to think about the force that the critter feels. We know that since the motion is in a circle, there is a centripetal force. This force is provided by the ropes, which keeps things going in a circle. But the critter feels something else: it feels an outward push, and so will feel pushed into the disk. This apparent force is called the *centrifugal force*. The critter will feel pushed hard into the disk, and so will not fall off - even when it is upside down! Note that the centrifugal force isn't a real force. What the critter really feels is its inertia: it would like to move in a straight line, but it is not. It is this that leads to the feeling of a centrifugal force.)
3. Think about what the critter feels. If you were riding the disk, what would you feel? Why doesn't the critter fall off the disk when the disk is over your head? (As noted, the critter feels a force pushing it into the disk. This is the force that holds it in place.)
4. Why doesn't the critter fall off even when the disk is upside down? Gravity is pulling down... what is pushing it up? Would the critter stay on the disk even if you were swinging

the disk really slowly? (Again, it's the centrifugal force that holds the critter in place. It is the circular motion that causes this force - so if the motion is too slow, the force is too small, and the critter won't stay on the disk! You can try this, if you would like.)

4. Have the students think about relationships to other experiments - such as the cup race. When you turned a corner, what happened to the water? Why? What force made the water want to slosh out? (This experiment is nicely understood as an example of centrifugal force. When you go around a corner, the water wants to keep moving in a straight line. So it will feel a centrifugal force that will make it want to slosh out of the cup. The only way to keep it from sloshing is to tip the tray to compensate, or else to go really slowly!)
5. When have you felt this kind of force? Think about going around a circle in a car. How about a merry-go-round? Roller coasters?

Other Experiment Extensions To Try

1. This one should be done outside. The students can try the same activity using a cup of water on the tray instead of the critter. Once they master swinging the cup of water around in a circle like a roller coaster (in the vertical plane), have them try swinging it over head like a lasso (in the horizontal plane).
2. The students can also try swinging their arms around in a circle really fast. This will force a lot of blood down into the hand. Make sure the students have plenty of room all around them so they don't swing their arm into a desk or another student. The veins in their hands will swell from the excess blood - it feels a little strange, but looks really cool!
3. Instead of using the tray with a cup of water, they can swing a bucket of water around in a circle.
4. What keeps you in place when you're swinging on the swings in the playground? What would happen if you put a tennis ball loosely in your lap and went on the swings? Do you think the ball will stay in place?
5. Think of other places that centripetal and centrifugal forces can be observed: in a clothes washer or dryer, the water and mud that spins of a bicycle tire, going around a corner in a car.

Activity 3: Waiter Water Challenge

Supplies

There are enough materials in the kit to run up to ten cooperative groups.

Per Cooperative Group

- 1 cup
- 1 tray
- 1 stopwatch
- water
- sidewalk chalk (optional)

Doing the Activity

Special Note*: This activity is best outside as there is a high probability of water spills.*

- Prior to this activity, you'll want to delineate a course for the Waiter Water Challenge. You can use sidewalk chalk to draw a path, or use some other method, such as tape, to mark a a course with both start and finish lines. We recommend that you use two straight parallel paths at first, while students are trying this out. They can race to the end of their path, turn around, and return to the next relay member of their team.
- Explain to students that their teams will use what they have learned about acceleration in the last two activities to compete with other teams in a relay race. Each member of the team will have a chance to act as waiter, carrying a tray with a full water glass on it. The goal is to not spill a drop, but also get to the finish line as quickly as possible.
- Remind students that in the last activity they varied their walking pace to study acceleration. They also tried to move at a constant velocity so the colored liquid in the accelerometer stayed level. Review what happened to the liquid in the accelerometers when they moved forward or stopped quickly.
- Have two teams line up at the starting line.
- Give the first student in each relay team a tray with a cup placed in the center. Fill the cup up to the top with water.
- Use the stopwatch to time the race and challenge each group of students to walk or run the course with the cup on the tray in the least amount of time, spilling the least amount of water.

Active Questioning, Explanation, and Discussion

1. What did you have to while running the course to not spill any water (think about the hand held accelerometers)? (The best is to move at a constant velocity, because once you undergo an acceleration then it causes the water to spill.)
2. Are there other ways you can keep the water from spilling other than adding a lid to the cup? (You can tip the tray in the opposite direction of your movement to keep the water from spilling.)
3. How are velocity and acceleration related? (Acceleration is a change in velocity.)

Other Experiment Extensions To Try

1. Build your own accelerometer using an empty pop bottle. Fill the bottle half way with water and add a couple of drops of your favorite food coloring. Then add baby oil all the way to the top of the bottle. Screw the lid on tightly and seal the cap with tape or hot glue. Tip the bottle sideways and your accelerometer is ready to use. You can use your accelerometer to test acceleration in a car,

airplane, or when you're walking around town.

2. Create or have student groups help you create one or several outdoor courses for students to walk through carrying a tray and a cup of water. The course should have lots of turns and can even involve going around objects and walking backwards. A path could be created in an area with lots of sand, or a path could be drawn on asphalt or sidewalks with the sidewalk chalk.

Why do hurricanes go counterclockwise in the northern hemisphere?

A laboratory experiment from the Little Shop of Physics at Colorado State University

Overview

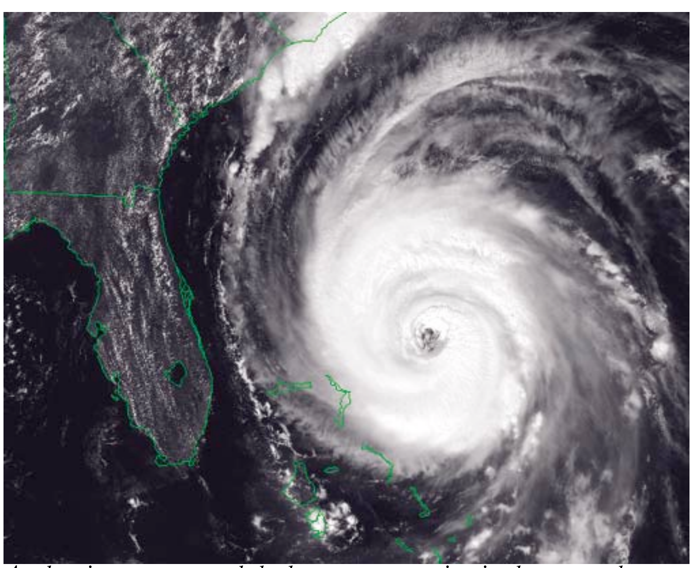
The Coriolis force is part of the reason that hurricanes in the Northern Hemisphere rotate counterclockwise. If the Earth didn't spin, we would have wicked 300 mph winds from the tropics to the poles and back again. The Earth does spin however, and in the mid-latitudes, the Coriolis force causes the wind—and other things—to veer to the right. It is responsible for the rotation of hurricanes.

Necessary materials:

- One foam ball
- A large area to form a circle with your students
- An even number of participants

You may want to demonstrate with just 2 to 6 people in the circle before attempting this with your class. It is also helpful to have a few adults participating in the circle. This activity will be successful if students understand the directions and also are dexterous enough to catch a ball. We know! We tried this with 4th graders and eventually they caught on to how this worked and what was happening.

But the Coriolis force on earth only works on very large scales. It doesn't affect such small things as toilets and sinks. You may have heard of people claiming that toilets and sinks swirl counterclockwise in the Northern Hemisphere and clockwise in the Southern Hemisphere due to this force. As cool as that would be, it's just not true. It turns out that the way the water swirls has to do with a number of conditions such as the shape of the bowl and the way the water enters the bowl. Alistair B. Fraser lists other goofy examples people attribute to the Coriolis force in the different hemispheres, including, the way dogs circle before lying down, and the way women's ringlets curl. The website is called Bad Coriolis and can be found at www.ems.psu.edu.



As the air moves toward the low pressure region in the center, the Coriolis force causes a rightward deflection—leading to the counterclockwise rotation of the hurricane.

Theory

So what is the Coriolis force? Let's look at a scenario before discussing it further.

Imagine two people playing catch. They are running in a straight line, parallel to each other and tossing the ball back and forth. The ball is easy to catch because they are always directly across from each other. Now, let's make this game more complicated. Our two players opt to continue their game of catch, but decide to run in a circle where they are still across from each other. As they circle counterclockwise, the ball is tossed. Rather than go directly to the catcher, the ball appears to veer to the right. They try it again and the same thing happens. They think something mysterious is pushing the ball to the right. When they ask their friends who have been watching the game, the friends say the ball went straight and the two players just missed it. What is going on?

Why did the players think the ball veered to the right, yet their friends watching from the sidelines, clearly saw that the ball traveled a straight path. It all has to do with frame of reference and Newton's 1st Law: All objects in motion stay in motion unless acted upon by an outside force. The ball does travel in a straight line... but the players don't!

The Coriolis force is an example of a ficitious force, and can be compared to another such force, the centrifugal force. You most likely have felt this while riding in a car. You are traveling straight ahead in a car, when suddenly the driver has to make a sharp left turn. Your body continues to travel forward, but it feels as if your body is pushing out on the car door. Actually, the car door is pushing in on you!

Doing the Experiment

- Have your group form a circle. Have each person point to their partner directly across from them, so they know whom they will toss the ball to.
- Have them take turns tossing the ball underhanded to their partners, so they get a feel for how hard they need to toss the ball to get it across the circle.
- Explain to the class that they will now turn their bodies to the right and start circling to the east, just like the Earth in its orbit. They will continue to toss toward their partner, but the ball can only be caught if it comes directly to an individual. The partner is not supposed to reach across and grab it from someone else.
- Students will soon see that the ball starts out aimed at the partner, but by the time it reaches the other side, is caught by the person to the right of the partner.
- It should appear as if the ball is veering to the right, by the participants in the circle.

Summing Up

The Coriolis force is a complicated concept that is difficult for many to grasp. Be patient and give your students as many experiences as you can with this concept. You may want to show them video clips to reinforce this activity. If you can find a merry-go-round in your area, use it with your students to reinforce this concept.

For More Information

CMMAP, the Center for Multi-Scale Modeling of Atmospheric Processes: http://cmmap.colostate.edu

Little Shop of Physics: http://littleshop.physics.colostate.edu

Why doesn't the wind blow from high pressure to low?

A laboratory experiment from the
Little Shop of Physics at
Colorado State University

Overview

The wind blows because of differences in air pressure caused by uneven heating of the earth's surface -- the equator is hot, and the poles are cold. So why doesn't wind blow directly from areas of high pressure (the poles) to areas of low pressure (the equator)? This would happen, but for one fact: The earth rotates. The spin of the earth causes the air to spin, and we call this the Coriolis effect.

Necessary materials:

- A clear area such as an open field or gym
- Students

This works best in smaller groups but can be done with 30 - 40 people at once if you have a large enough space.

Theory

The sun heats up the equator and the poles unequally. Air at the equator warms and rises, moves toward the poles, and finally cools and sinks, as in Figure 1. However, the earth is rotating, complicating the otherwise easy flow of air to balance the energy between the equator and the poles. This "sideways" motion of the earth causes air to deflect to the right as it moves in the Northern Hemisphere. In the Southern Hemisphere air is deflected to the left. This deflection of air produces the jet stream that travels east-west in direction! Storms and fronts are left to finish the job of transporting energy from the equator to the poles.

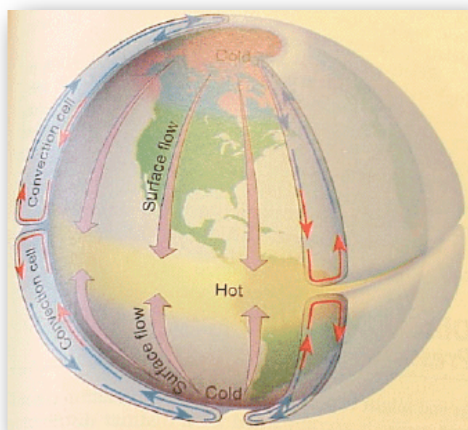


Figure 1: If Earth did not rotate, energy would travel directly from equator toward poles.

Doing the Experiment

Show students weather maps portraying air traveling clockwise around a high pressure system, and counter-clockwise around a low pressure system. Ask them to hypothesize about why air would behave differently around these two systems, and whether there are there any situations in which this wouldn't be the case.

To start, explain to your class that they will be taking part in a kinesthetic activity to demonstrate why air doesn't blow directly from high to low pressure in macroscopic situations, where the rotation of the Earth must be considered.

Have the students form a large circle facing inward. Explain that person is going to pretend to be a parcel of air able to be influenced by differences in air pressure and the Coriolis effect.

Start by telling the class to pretend that there is low pressure at the center of the circle, and high pressure outside the circle (at their backs). If pressure difference was the only factor in wind direction, the low pressure system would collapse, with students all congregating at the center, and that would be the end of it. However, we have the Coriolis effect to consider, so as students start moving toward the center of the circle, they are also deflected to the right, as the Coriolis effect always deflects objects 90 degrees to the right of the direction of travel. They'll end up walking in a counter-clockwise circle (as seen from the top), showing the Coriolis effect balances with the pressure force.

Try several scenarios. Tell them that now there is high pressure at the center of the circle and low pressure outside the circle. (Have them turn around to face outward so they're not walking backwards). Ask them how they should move. (Clockwise!) Have them act this out for storms in the Southern Hemisphere. What would be different? (The Coriolis effect would now act 90 degrees to the *left*!) What would be the same? Have them act this out. In each case, keep track of the direction of movement.

Participants rotating clockwise around a high pressure system.

Summing Up

This is a great way to illustrate how wind direction, on a macroscopic model, varies not only with pressure but also the direction of the Coriolis effect. Once students have done this, they will be able to visualize more readily the reason why high pressure systems spin in opposite directions of low pressure systems.

For More Information

CMMAP, the Center for Multi-Scale Modeling of Atmospheric Processes: http://cmmap.colostate.edu

Little Shop of Physics: http://littleshop.physics.colostate.edu

How does the spin of the earth lead to the spin of a storm?

A laboratory experiment from the Little Shop of Physics at Colorado State University

Overview

The equator is hot; the poles are cold. So why doesn't cold air at the poles just slide down to the equator, and warm air here move to the poles?

This would happen, but for one fact: The earth rotates. This rotation complicates what would otherwise be a very simple motion, and it leads to bands of climate regions that circle the globe, and to the spin of large-scale storms.

Such phenomena are difficult to visualize since they occur on such a large scale. This activity will allow your students to bring these concepts down to a more manageable size as they watch weather phenomena develop on the table-top in a very simple system that is complex enough to simulate much of the complex behavior of moving air in the earth's atmosphere.

Necessary materials:

- Lightweight container with deep sides. We use a pan for casting stepping stones which we found at Hobby Lobby. We painted the inside white.
- Water (about 1 liter of warm liquid water and a cup of ice)
- Red and blue food coloring
- Heat lamp
- Turntable that rotates at approximately 3 rpm. We purchased this from Hobby Town. It's intended for models.
- Something to keep the ice from turning into icebergs that is a good thermal conductor. We used a small metal can.
- Level. The pan must be as level as possible; this is very important.

Necessary equipment for this experiment.

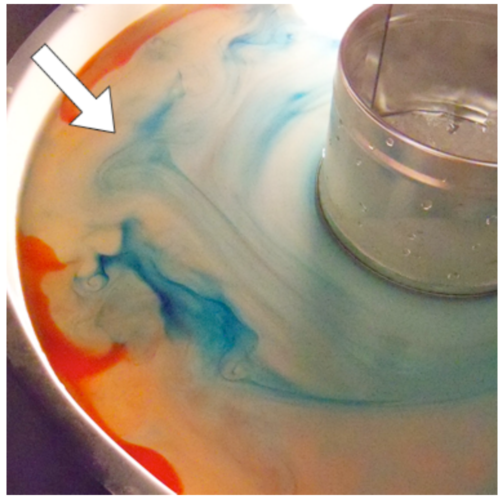
Theory

The thin blanket of atmosphere that envelops our planet has a big job to do—moving energy around. The sun heats the equator and the poles unequally. The gases that make up the atmosphere have the lofty responsibility of transporting the energy from the equator to the poles. Air warms and rises, moves toward the poles, and finally cools and sinks. Easy enough, but there's a catch. The earth is spinning. At the equator, the spin is pretty fast; it corresponds to a motion to the east at 1600 kilometers per hour. At the poles, the motion is much more gentle; a single rotation in 24 hours.

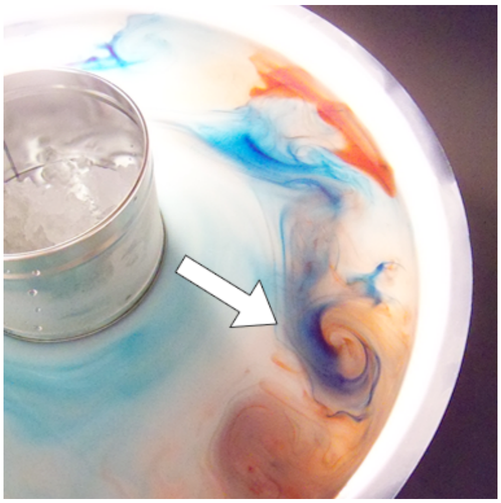
As the air moves from the equator toward the poles, it's this "sideways" motion that complicates things. Imagine an air mass at the equator. It's moving to the east at 1600 kilometer per hour—faster than the speed of sound! As it moves north, this motion continues, but the earth below it is moving more slowly. Net result: The moving air will turn to the right. We, who ride with the earth, term this apparent force the Coriolis force. This subtle force and is a key player in the weather patterns we experience every day.

Doing the Experiment

Proper set up is extremely important in this experiment, as is patience. You'll need a flat, extremely level surface where it won't get bumped or jostled. It is also important to note the locations of any air vents as they can cause problems. Make sure the pan is centered on the turntable and the ice container is centered in the pan. We find it useful to secure the ice container to the pan with glue or a suction saucer so that it won't sabotage the calm of the water. Fill the pan as deep as you can while still allowing it to spin smoothly on the turntable. We found that one liter of warm water works best. Position the heat lamp to shine on the outer edge. Reserve the ice for now. After you have your equipment set up, let it spin undisturbed for about two minutes, allowing perturbations to damp out.



Cold water from the "poles" is moving toward the equator, following a curving path as it trav-



A spinning "storm" forms.

Ask your students to gather around and observe. Gently fill the ice container and place a few drops of blue food coloring at its edges. Add a few drops of red along the outer edge of the pan. The food coloring will allow your students to see the motion of the fluid: red for the warm "air" at the equator and blue for the cold "air" at the North pole. Watch the simulation begin to develop and point out anything of note to your students. You will notice that the hot and cold "air" don't tend to mix but instead travel under or over one another.. If set up carefully, this simulation can run for several minutes and simulate many different atmospheric phenomenon: the jet stream, the doldrums, the trade winds, warm and cold fronts as well as hurricanes.

You will notice smooth lines of blue encircling the "North pole." As time goes on, this smooth line will develop waves that dip toward the "equator." You might see a wave dip very far down, as we see at times when cold Arctic air dips down to our latitude. If this piece dips far enough, it might separate and begin to swirl, forming into a "storm", which spins in the same sense as the turntable.

Summing Up

This experiment is a great way to step outside our planet and give ourselves a better perspective on a concept that is too large to tackle with conventional methods. A great extension to this activity would be relating what they are seeing (did see or will see) in the Spin Tank to actual weather maps. Interestingly, after the experiment has run its course, you can further enforce the importance of our spinning planet by turning the turntable off. Your students will see, almost instantly, how the dyes mix and the beautiful and complex system they had been watching fades into purple-grey nothingness.

For More Information

CMMAP, the Center for Multiscale Modeling of Atmospheric Processes: http://cmmap.colostate.edu

Little Shop of Physics: http://littleshop.physics.colostate.edu

Lesson II: How does the general circulation of the atmosphere describe earth's climate zones?

Overview:

What causes the general circulation of the atmosphere? How does the general circulation of the atmosphere describe earth's climate zones? This exercise will help explain the mechanisms behind the general circulation of the atmosphere and provide a better understanding of earth's climate zones.

Necessary Materials:

- Internet access (for obtaining maps etc.)
- Printers for making hard copies
- Practice wind sheet
- Map of the world
- A cross section along a longitude line (North Pole to South Pole)
- Four colored pencils (red, green, blue, and **black**)
- Analysis sheet

Theory:

The three cell convection (Hadley cell, Ferrel cell, and Polar cell) model of earth's general circulation divides the earth into different climate zones. A climate zone is a region of the earth's surface that shares a climatic classification. The climate zones that succeed each other from the pole to the equator are polar, temperate, subtropical, and tropical or equatorial climate.

The **polar** climate zone (also frost climate or snow climate) is located in the polar latitudes where conditions are too harsh to support vegetation. The **temperate** climate zone describes the middle latitudes between the polar climate and subtropical climate zones, and is characterized by a lack of temperature and precipitation extremes. The **subtropical** climate zone is located between the tropical climate and temperate climate zones and is described by warm temperatures and little precipitation. The **tropical** or **equatorial** climate zone is located in the tropics and is characterized by a climate typical of the equatorial and tropical regions.

The **Hadley cell** is thermally driven along the equator where the sun shines directly throughout the year. As you know, when air is heated, it expands becoming less dense and more buoyant. Since pressure in the atmosphere decreases with height, the rising warm bubble of air expands adiabatically, doing work to push away surrounding air and therefore cooling as it rises and leaving low pressure behind. The **Hadley cell** consists of equator-ward motion near the surface and pole-ward motion aloft between about 30° and the equator in both hemispheres. The **Ferrel cell** has pole-ward movement near the surface and equator-ward movement aloft. The **Ferrel cell** has sinking motion in the same latitudes as the **Hadley cell** (~30°), but has rising motion at subpolar latitudes (~60°) in both hemispheres. The **Polar cell** is characterized by pole-ward motion aloft and equator-ward motion near the surface. Rising motion occurs at subpolar latitudes (~60°) and sinking motion occurs at the poles in both hemispheres. Using the Hadley, Ferrel and Polar cells, we can examine air motion and subdivide the globe into the appropriate climate zones.

Doing the experiment:

Part I: Wind force diagrams

- Using the **wind** force balance diagram practice sheet and colored pencils, apply the principles learned from the previous lesson and draw the resulting **wind** vectors. Assume the diagram is at the surface and remember that the Coriolis "force" affects the wind direction differently in the Northern and Southern Hemispheres.

Part II: Prevailing wind and surface pressure bands

- Using the world map and colored pencils, mark the locations of the ITCZ, subtropical high, subpolar low and polar high (low (L) and high (H)) pressure bands beginning with the ITCZ. Knowledge of the pressure bands should be presented prior to this experiment.
- Applying the principles learned from the previous lesson and using the sheet from part I as a guide, draw the resulting **wind** vectors in **black**.

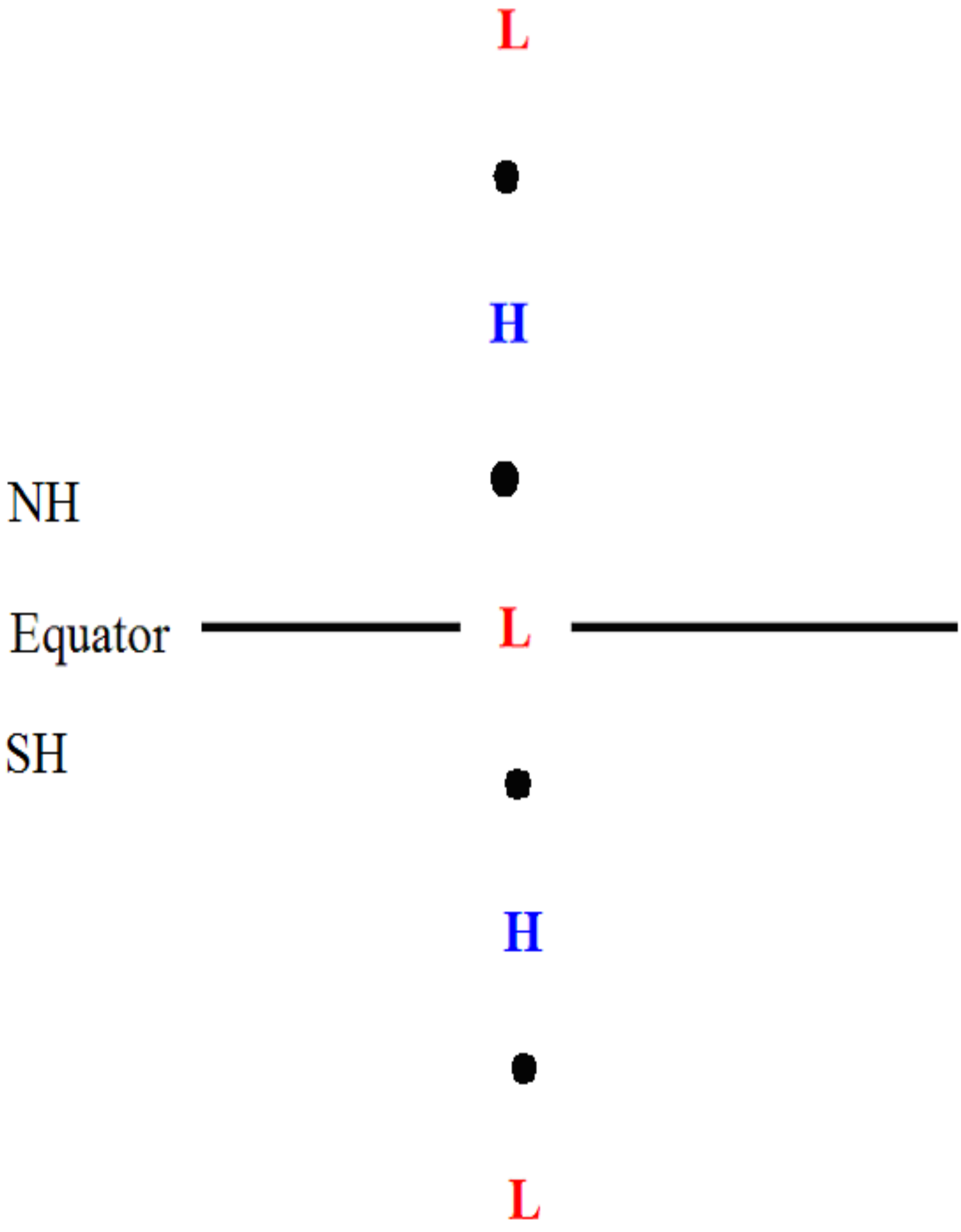
Part III: Cross section along a line of longitude

- This cross section is from the North Pole to the South Pole along a longitude line.
- Using your map from part II as a guide, label high and low pressure at the surface and aloft (surface low pressure has upper level high pressure and surface high pressure has upper level low pressure). When labeling pressure aloft, remember that the height of the tropopause is maximized at the equator (~17km) and decreases towards the poles (~8km) in both hemispheres.
- Starting at the ITCZ, draw and label the Hadley, Ferrel, and Polar cell.
- If you are having trouble with rising and sinking motion associated with low and high pressure at the *surface*, use the right hand rule.
- For the right hand rule, curl your right hand fingers following the direction of flow around high or low pressure. If your thumb points up, you have vertical motion (low pressure), and if your thumb points down, you have sinking motion (high pressure).
- For the upper levels, low pressure convergence forces air towards the surface, and high-pressure divergence forces air away from the surface.
- Once you are satisfied with your work, proceed to the analysis sheet.

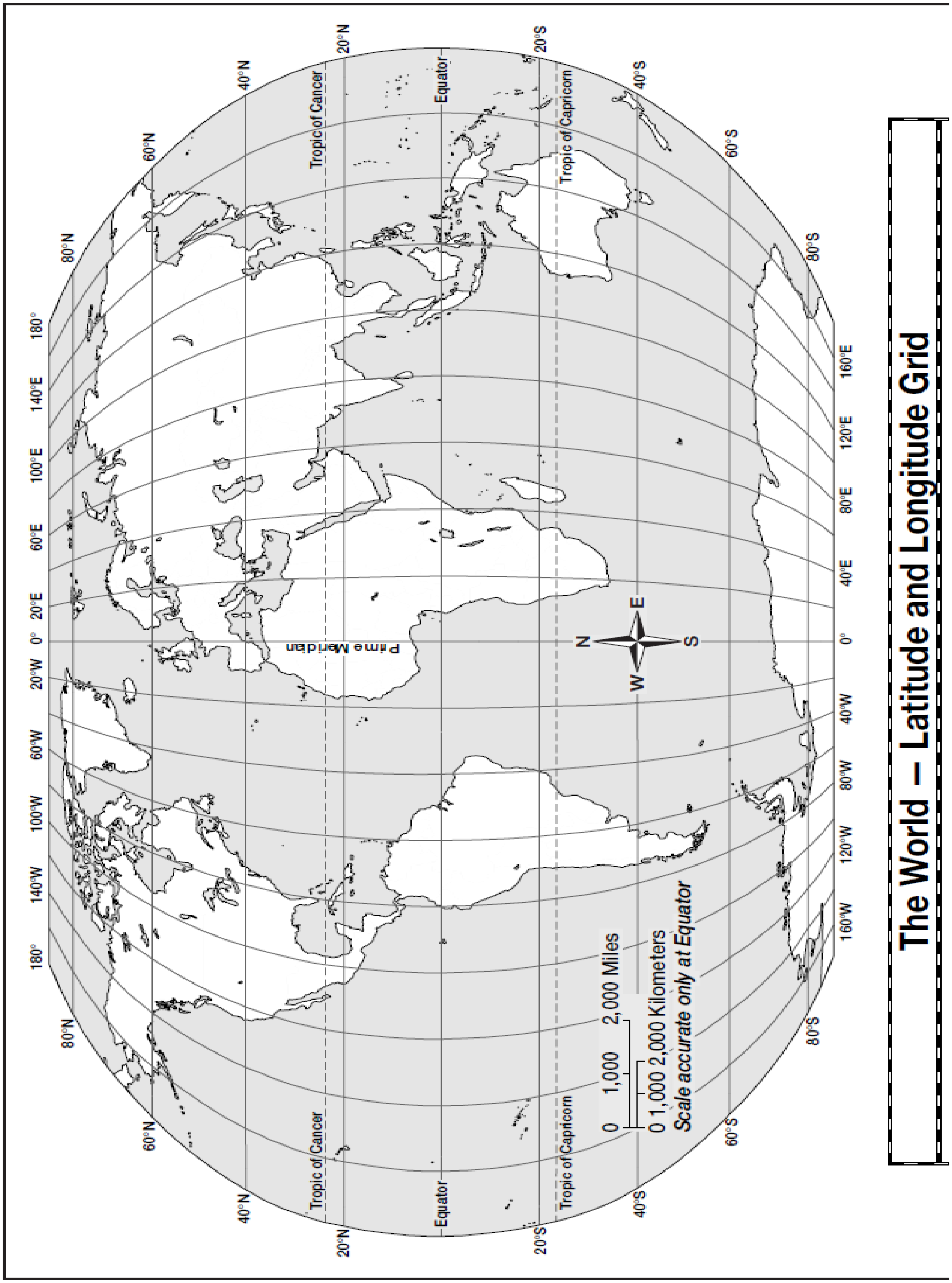
Summary:

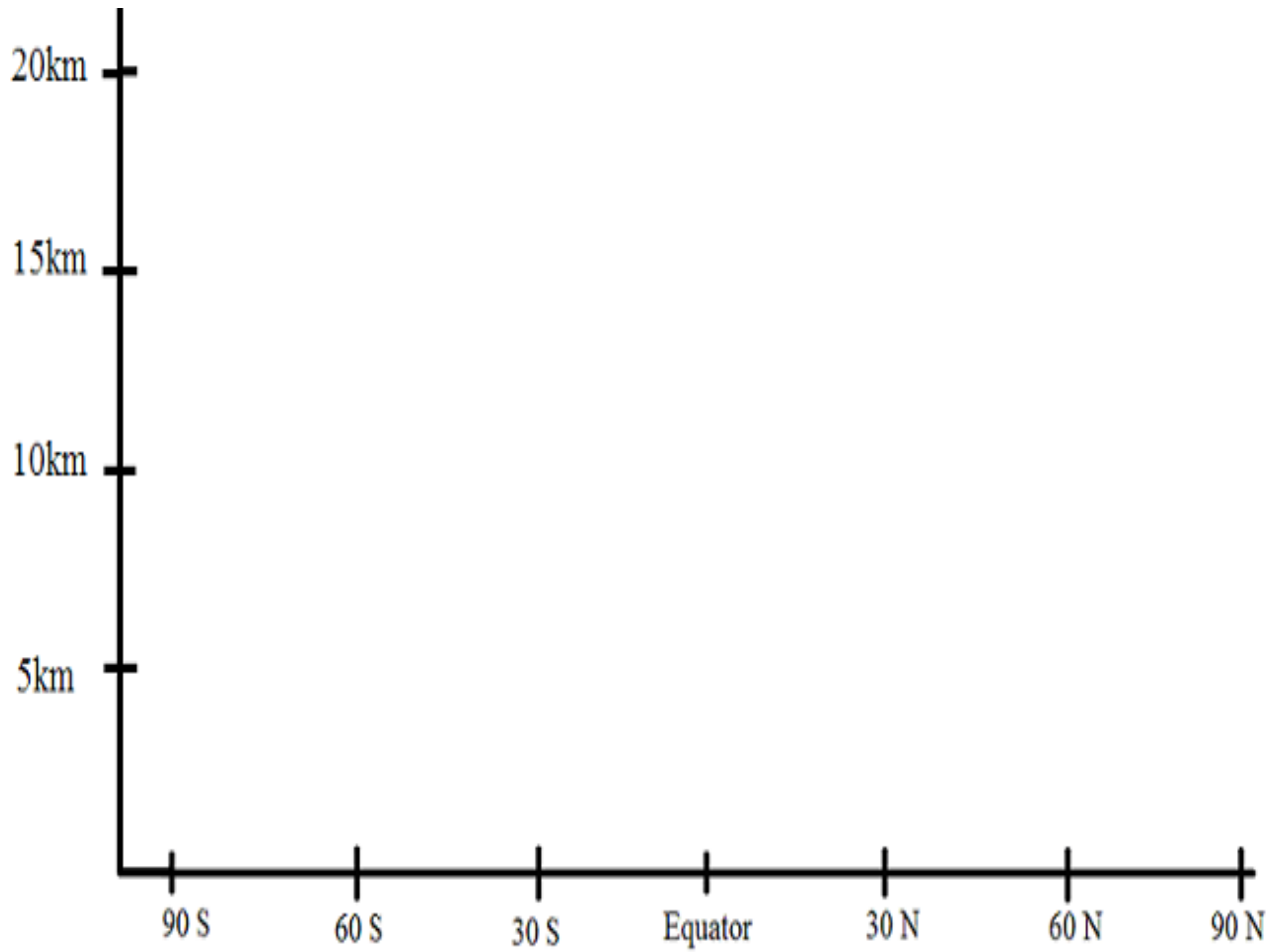
Clearly, an understanding of the general circulation of the atmosphere is essential for determining earth's climate zones. After completing this lesson, students should have a good feel for how the rainforests stay green and why the deserts are located where they are, having drawn it out for themselves. It is important to remember that a discussion of the general circulation of the atmosphere prior to this lesson is necessary.

Practice wind sheet



The World — Latitude and Longitude Grid




20km
15km
10km
5km
90 S
60 S
30 S
Equator
30 N
60 N
90 N

Analysis Sheet

1. What type of climate is expected where the near surface winds diverge? Why?

2. What type of climate is expected where the near surface winds converge? Why?

3. Match each location to its corresponding general circulation cell.

   A. Hadley Cell
   B. Ferrel Cell
   C. Polar Cell

   Caracas, Venezuela ~(10.5°N, 67°W) :

   Colombo, Sri Lanka ~(7°N, 80°E) :

   Timbuktu, Mali ~(16.8°N, 3°W) :

   Svalbard, Norway ~(66°N, 14°E) :

   Fort Collins, Colorado ~(40.5°N, 105°W) :

4. Describe the general climatic conditions and prevailing winds for the following locations:

   Caracas, Venezuela:

   Colombo, Sri Lanka:

   Timbuktu, Mali:

   Svalbard, Norway:

   Fort Collins, Colorado:

5. What does the seasonal motion of the ITCZ mean for January and July climates in India and the Amazon?