

# The Coriolis Effect

Does water drain in different directions in the northern and southern hemispheres?

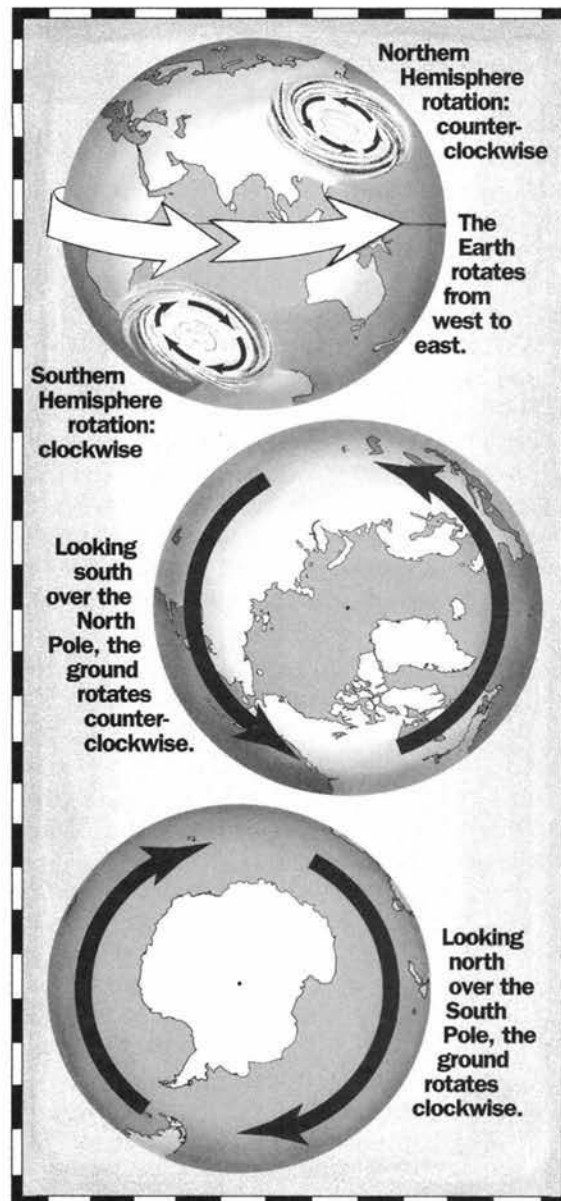
W I L L I A M D . S T A N S F I E L D

ON THE EQUATOR, NEAR THE TOWN OF Nanyuki, Kenya, a local man named Peter McLeary makes a living by showing tourists the so-called "Coriolis force":

He takes them to a line drawn on the ground (the putative location of the equator) and drains a pan of water on either side of it. The water flows clockwise when the pan is north of the line, and counterclockwise when the pan is south of the line. McLeary explains that this is due to Earth's rotation, and then collects tips from the tourists.<sup>1</sup>

In reality, the Coriolis phenomenon is not detectable for many miles on either side of the equator. When it is detectable, moving objects tend to be deflected counterclockwise in the Northern Hemisphere and clockwise in the Southern Hemisphere. The Coriolis effect is named for the French engineer/mathematician Gaspard Gustav de Coriolis (1792-1843) who first described it in 1835. There really is no such thing as a Coriolis "force". The Coriolis "effect" or "phenomenon" results from the fact that the observer on the ground is spinning along with the rotating Earth. A rotating observer will think there is a mysterious "force" apparently deflecting moving objects. Why? The surface of the Earth moves from west to east. Looking south from space along the Earth's rotational axis in the Northern Hemisphere, the ground is rotating counterclockwise. Looking north from space along the Earth's axis in the Southern Hemisphere, the ground is rotating clockwise.<sup>2</sup>

While the angular speed is identical at each point on the Earth (they all make a 360° rotation in 24 hours), the linear speed decreases from the equator with increasing latitude (i.e., approaching the poles). The Earth's surface rotational speed



(eastward linear velocity) around its axis is greatest on the equator (approximately 0.46 km/sec), diminishing at successively higher latitudes (e.g., 0.33 km/sec at latitude 45°N).

The Earth's rotation does tend to divert moving objects in opposite directions in the two hemispheres, but its effects are most obvious on moving objects high above the Earth that are not greatly affected by the forces of terrestrial friction (such as airplanes, rockets, artillery shells), or on large air masses developed over extended time periods and over long distances such as storms or major oceanic currents. Stationary objects on the Earth's surface have an angular momentum due to the rotation of the Earth, but they are not affected by the Coriolis force.

The Coriolis force is directed eastward to the direction of a moving object at any instant over the curvature of the Earth's surface, as seen from a fixed point in space. In the Northern Hemisphere, the Coriolis effect tends to deflect a mass moving north or south to the right of its path; in the Southern Hemisphere it tends to deflect a mass moving north or south to the left of its path. Slowly moving objects tend to be deflected less than rapidly moving ones, while a moving mass closer to the poles would be deflected more than a mass of the same speed closer to the equator.<sup>3</sup>

The Coriolis effect is far too weak in small bodies of water to be detectable by the kind of demonstrations that McLeary performs, especially at or near the equator where the Coriolis force is zero. Thus, Mr. McLeary's demonstration of the Coriolis effect on or near the equator is bogus. However, under carefully controlled conditions, it is claimed that scientists at the Massachusetts Institute of Technology have demonstrated the Coriolis effect in the Northern Hemisphere by using a perfectly symmetrical vessel with a small drain hole exactly in the middle of the bottom, and by allowing the water to become as still as possible over several days prior to the tests. After the plug is pulled, the water in the bowl moves toward the drain hole and is deflected slightly to the right (to the west) on all sides before it reaches the drain, thus establishing a counterclockwise vortex. It is also claimed that workers in Australia were able to show the expected Coriolis phenomenon (clockwise vortex) in the Southern Hemisphere<sup>2</sup> (readers should note that this reference does not cite the authors or publications in which these astonishing results

allegedly appear). It should be noted, however, that these experiments, if real (Boston ~43° N; or, since the Australian city is not named, let us take Sydney for an example, ~33° S latitude), were conducted over a thousand miles from the equator where the Coriolis force is much larger than near the equator.

#### **Foucault's Pendulum and the Coriolis Effect**

In 1851, French physicist Jean Bernard Léon Foucault (1819-1868) demonstrated in an unusual way that the Earth rotates on its axis at a regular rate with a pendulum experiment. He used a 25 kg bob suspended by a 67-meter wire from the dome of the Panthéon in Paris. The pendulum was free to oscillate in any vertical plane.<sup>4</sup> A Foucault pendulum actually oscillates in a single plane, but the plane appears to change direction, due to the Coriolis effect, as the Earth rotates beneath it by an amount dependent upon the latitude at which the pendulum is located.

On the equator, where the Coriolis effect is zero, a Foucault pendulum does not change its apparent direction during one sidereal day (the time it takes for the Earth to complete one rotation relative to the stars). In the Northern Hemisphere, the apparent deflection of the pendulum's plane of oscillation is to the right (clockwise); in the Southern Hemisphere it is to the left (counterclockwise). At the poles, the pendulum would make one complete rotation in one sidereal day. Foucault pendulums are sometimes seen today in planetariums, observatories, and science museums. A circle is painted on the floor centered directly under the plumb line of the pendulum, with the radius a little less than the end of the pendulum's swing. Small pegs are set at regular intervals (e.g., every 10°) around the circle like dominoes, so that each one will be knocked over by the pendulum as the Earth rotates counterclockwise around the plumb line in the Northern Hemisphere (clockwise in the Southern Hemisphere). If the total number of blocks on the circle and the time between any two successive knockdowns are observed, it should be possible to estimate the time it would take for all the blocks to be knocked down (one complete revolution of the pendulum). The latitude of the California Academy of Sciences in San Francisco, for example, is 37° 46.2' north. The Foucault pendulum there makes one complete rotation in 39.18 hours.<sup>5</sup>

### Ballistics and the Coriolis Effect

The magnitude of the Coriolis acceleration (“force”) depends on the velocity of the moving mass, the speed of the Earth’s rotation, and the latitude where the mass resides at any given moment. To a person on the surface of the Earth in the Northern Hemisphere, the Coriolis force is to the right of the path of a moving object, causing the object to appear to curve to the right of its actual path (a straight line as seen from space) when facing the direction in which the mass is moving.<sup>6</sup>

Because a bullet fired from a handgun does not travel very far over the curvature of the Earth, its trajectory is negligibly affected by the Coriolis force. However, artillery shells from big naval guns can travel 20 miles or more and are affected by the Coriolis phenomenon. Likewise, rockets that can travel hundreds of miles over the curvature of the Earth are noticeably influenced by the Earth’s rotation, and that deflection must be factored into the projectile’s aim if it is to hit a small target far away. Consider a rocket at mid-latitude in the Northern Hemisphere being fired at a target several hundred miles due north. By the time the rocket reaches its target, the Coriolis force would seem to have pushed the rocket to the right (eastward) of the north-south longitudinal meridian that was its original aim. This is because initially, and throughout its flight path, the rocket has an eastward motion that is faster than the eastward motion of its target farther north. If the rocket at mid-northern latitude had been aimed due south, it would have been deflected to the right (westward) of its intended path because initially, and throughout its flight path, the rocket had an eastward motion that is *slower* than the eastward motion of its target further south. Since the Earth is rotating clockwise in the Southern Hemisphere, a projectile tends to miss its target to the left if its aim is not corrected for the Coriolis force.

If a projectile is fired due east or due west in the Northern Hemisphere, it will tend to be deflected southward (toward the equator) because of the curvature of the Earth’s surface (Coriolis effect). However, the complexity of forces acting upon a high speed projectile heading west against the eastward rotation of the Earth (especially the velocity of the projectile and its latitude) may result in the projectile veering to the right (north). At lower speeds, such a projec-

tile shot westward might miss its target to the left of (or possibly even hit) the target.

### Wind Systems, Hurricanes and the Coriolis Effect

The Sun warms the air and ocean surface near the Earth’s equator more than it does nearer the poles. The uneven heating of the atmosphere is the cause of wind. A region of relatively low atmospheric pressure is called a *cyclone*. Cyclones are characterized by cloudiness and high humidity. Air from regions of higher pressure surrounding the cyclone moves inward from all directions toward the center (core) of lowest pressure. This pressure gradient, plus the Coriolis effect (acting at right angles to the inward flow of air), causes a cyclone to rotate counterclockwise around its core in the Northern Hemisphere; clockwise in the Southern Hemisphere.

*Anticyclones* are regions of relatively high atmospheric pressure. Air tends to flow outward in all directions from the core of an anticyclone toward the surrounding regions of lower pressure. This pressure gradient, plus the Coriolis effect (acting at right angles to the outward flow of air), causes an anticyclone to rotate clockwise around its core in the Northern Hemisphere; counterclockwise in the Southern Hemisphere. Anticyclones tend to have weather characteristics opposite to those of cyclones. Cyclones that develop in mid latitudes (30° to 60° north or south of the equator) commonly move from west to east along with the prevailing westerly winds in the upper atmosphere. There are no prevailing winds within about 700 miles north or south of the equator (a region called the “doldrums”). Tropical cyclones that develop over oceans nearer the equator (10° to 30° north or south of the equator) move from east to west with the flow of the trade winds there. Wind velocity depends upon the magnitude and direction of the atmospheric pressure gradient between high and low pressure areas. The Coriolis force cannot change the velocity of a wind system, but it can change its direction. The effects of the Coriolis force on weather systems and major oceanic currents may also be combined in complex ways with other factors such as wind direction/speed, friction, and geographical/topological features.

Hurricanes are large vortexes of air rapidly moving around an area of very low atmospheric pressure. The core of the hurricane, called

the “eye,” has little, if any, wind. Hurricanes tend to develop from storms in the tropical regions of the Atlantic, Pacific, and Indian Oceans. They may become hundreds of miles in diameter, with winds minimally 73 miles per hour (sometimes called “typhoons” in the North Pacific Ocean). Hurricanes are not observed at the equator, but they have been seen at five degrees away from the equator where the Coriolis effect starts to become a significant factor.<sup>7</sup> Near the equator in the North Atlantic Ocean, a tropical cyclone (rotating counterclockwise) initially moves westward from the coast of Africa under the influence of the westerly blowing trade winds. Then, as it gathers rotational speed, it tends to curve to the right (northward) and clockwise around the rim of an area of higher pressure, largely due to the Coriolis effect. The vortex of a hurricane might be the best model with which to compare the bucket experiment because they both have the same rotational direction (reversed in each hemisphere) around a well-defined center (hurricane eye vs. bucket drain hole).

#### The Coriolis Effect in Pop Culture

One episode (6th season, 16th episode) of the TV show *The Simpsons* has bad boy Bart arguing with his brainy sister Lisa about how water drains from a sink. Lisa tells Bart that sinks in the Northern Hemisphere drain counterclockwise, but drain clockwise in the Southern Hemisphere due to the Coriolis effect. Bart tests the theory by running water down the sink and flushing the toilet. They both drain counterclockwise. He then phones an Australian who checks several sinks and toilets and reports they all drain clockwise. The viewer is left believing that Lisa was right. The truth is that water can drain from a toilet in either direction in either hemisphere depending on initial conditions such as the shape of the bowl, direction of the water entering the bowl, the size and position of the drain hole relative to that of the container, and the speed of the flush.

The January 27, 1995 episode of TV's *The X-Files* has FBI agents Fox Mulder and Dana Scully investigating a ritual murder in a small New Hampshire town whose residents feel that supernatural forces are at work.<sup>8</sup> Mulder turns on a water fountain, watches the water drain away, and then exclaims:

Mulder: “The water!”

Scully: “What’s wrong with it?”

Mulder: “It’s going down the drain counterclockwise.

The Coriolis force in the Northern Hemisphere dictates that it should go down clockwise.”

Scully: “That isn’t possible.”

Mulder: “Something is here Scully ... Something is making these things possible.”

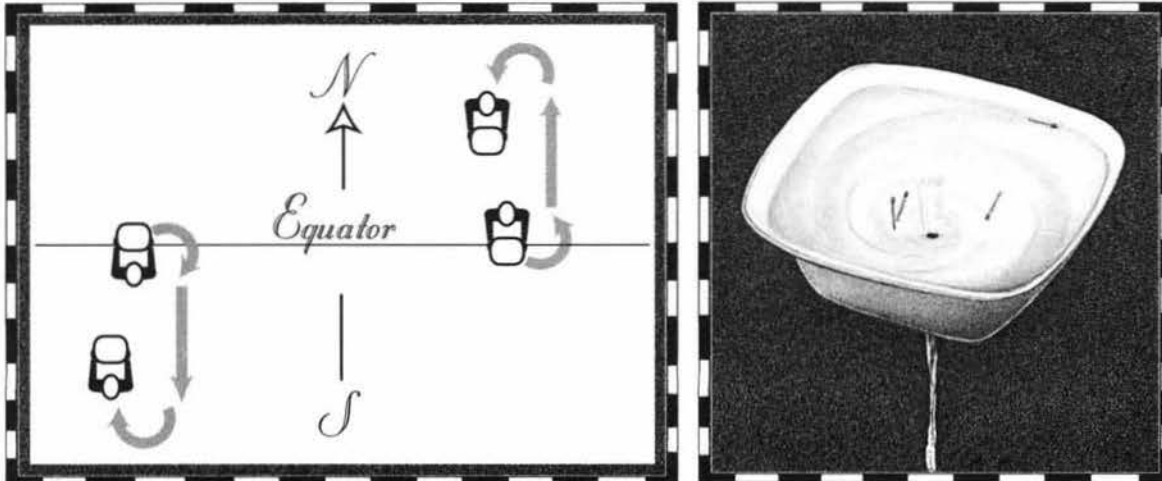
Scully is supposed to be a physician with an undergraduate degree in physics. Even so she gets it wrong!

Unfortunately, even real science teachers and even worse, science textbooks do not always present the correct facts about the Coriolis effect. For example, a physics textbook for scientists and engineers used at Nottingham University in the U.K. says “on a smaller scale, the Coriolis effect causes water draining out of a bathtub to rotate counter clockwise in the Northern Hemisphere.”<sup>8</sup> The physics textbook I used as a graduate student didn’t get the story wrong, but perhaps this was only because it didn’t even mention the Coriolis phenomenon or Foucault’s pendulum.

Even TV shows that attempt to be scientific rather than entertainment can get it wrong. On a BBC special seen on PBS—*From Pole to Pole*—that they proudly called “the biggest series the BBC’s Natural History Unit has ever done” host Michael Palin fell for Kenyan Peter McLeary’s coriolis fakery.<sup>9</sup>

McLeary: “This is the Northern Hemisphere (gesturing to his left), and this is the Southern Hemisphere (gesturing to his right). If you drain a sink when you’re on the northern side of the equator, and you watch the water as it drains, you will see that the water always rotates clockwise.” This scene shows a pan with water draining clockwise; floating match sticks are used to make the motion easier to see. “This phenomenon is caused by the rotation of the Earth. The effect becomes stronger according to how far you move to the north or south and becomes weaker according to how close you go towards the line [the equator]. So that’s why we have to give some distance from the equator so that the rotation can be noticeable.”

Palin: “This is known as the Coriolis effect and Peter McLeary has given this same lecture every day for the last six years. It’s delivered in the burnt out shell of an old hotel. The equator used to run



Left: Figures holding a pan of water make two turns to start their water rotating under the guise of moving back away from the equator. Right: A square pan makes it easier to control rotation direction.

through the middle of the bar. I bet they were always floating match sticks in the middle of the beer."

McLeary carries his pan and water about ten meters to the south of the spot marking the equator, and turns to face the audience.

McLeary: "So, this changes to counterclockwise, indicating that now we are on [*sic*] the Southern Hemisphere."

A shot is shown of the water in the pan draining counterclockwise. The camera transitions to a scene where McLeary is placing a water-filled pan directly on the equatorial marker.

McLeary: "So, now we are right on the equator, and as we drain the water, you'll see there will be no rotation. It just drains straight down. And that's how we prove that we are right on the equator." Now we see water draining with no apparent rotation.

Palin: "It does work."

#### How Is the Fakery Done?

Here is how the trick can be done.<sup>9</sup> On the equator, the performer fills the pan and leaves it undisturbed for as long as possible to damp most water

movement induced by the filling process. A deeper pan works better. If the hole in the bottom of the pan is small it takes longer before any rotation is detected. The trickster can move the pan before such motion can be easily seen. If the pan is circular, it is difficult to unobtrusively make the water start rotating, but if it is square, this is easier to do. When the performer is going to go north from the equator (or any place he wants to call the equator) he stands in front of the pan and faces south. He then picks it up, turns around by turning to his left (thus starting the water turning), walks north and turns around by again turning to his left, and faces his audience. He adds a tracer (such as matches or pepper) to the surface of the water, removes the stopper from the bottom of the pan, and lets the water drain out. He makes the claim that it is the rotation of the Earth that causes the water to spiral as it does. He then goes back to the equator, but this time he stands in front of the pan and faces north. After filling the pan, he picks it up and turns to his right, walks south, again turns around by turning to his right, and faces his audience. He then announces that the water rotates opposite to the previous experiment because of the rotation of the Earth. ▼

#### References

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