Understanding the Coriolis Effect

The Coriolis effect is an apparent deflection of a course of motion that occurs because Earth is a sphere that is spinning on its axis (the daily rotation that gives rise to day & night). The deflection happens because the speed of rotation is faster near the equator and slower near the poles. We’ll work through why that is.

First let’s make sure we understand how things move around a rotating sphere, and what the terms are called.

Every 24 hours the earth goes through a rotation of 360° (a full circle), toward the east.

The amount of rotation in one hour is 15° (360 ÷ 24 = 15).
You can write this as a velocity: $15^\circ$ per hour ($15^\circ/\text{hr}$). That’s called the **angular velocity** because it is a measure of how large of an angle is covered per unit time.

The angular velocity of something on the earth’s surface is the same everywhere. You always do a full circle in one day. No matter where you are on the earth, if you are in Mexico City or Toronto, Canada, you will go around $360^\circ$ in 24 hours, or $15^\circ$ in one hour.

Let’s see how this looks for 6 hours. In 6 hours you would go through $15^\circ \times 6$, or $90^\circ$:

But how far you’ve travelled in actual **distance** (kilometers or miles, not angles) is different depending on where you are on the globe.

We’ve been looking at someone standing on the equator (like point A at the left). If you started further poleward than the equator, like at point B, you can see that the distance you would travel in 24 hours would be shorter, even though the angle is the same. That’s because the circumference (distance around) a sphere gets smaller as you move away from the equator. **You are basically making smaller and smaller circles as you move toward the poles.**
Let's look at actual numbers.

At the equator, the earth's radius (distance from center to surface) is 6378 kilometers [km], and its circumference (distance around the outside) is approximately 40,000 km \(^1\), as shown below at point A.

That means if you are standing at the equator, you will be moving with the rotating earth 40,000 km per day.

But if you're at a higher latitude, how much smaller is that circle? You just multiply by the cosine of your latitude:

\[
\text{circumference at latitude } N^\circ = \text{circumference at equator} \times \cos(N)
\]

Let's say our guy at B in the last figure is at latitude 60\(^\circ\). Then the distance he travels during one rotation of the earth (24 hours) is 40,000 km * \cos(60^\circ). The cosine of 60\(^\circ\) is 0.5. So the distance travelled in one day at latitude 60\(^\circ\) is 40,000 * 0.5 = 20,000 km, or exactly half that at the equator.

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\(^1\) Circumference is just 2\(\pi\) times the radius, 2\(\pi\) \(r\).
Now let’s calculate the speed of rotation at each location. At the equator, the velocity (distance/time) is 40,000 km in 24 hours, or:

\[
\frac{40,000 \text{ km}}{24 \text{ hours}} = 1667 \text{ km/hour}
\]

At 60° latitude, the velocity is:

\[
\frac{20,000 \text{ km}}{24 \text{ hours}} = 833 \text{ km/hour}
\]

So even though the angular velocity at both place is the same (15°/hr) the point at the equator is **traveling twice as fast**.

Now to the Coriolis part.

If something is moving with the earth (a person, ball, missile on the ground) **it has an eastward velocity from the rotation of the earth**, like that calculated above. If it’s launched off the surface, it will still have that eastward velocity until gravity brings it back down. (Friction from the air will slow it down a bit too.)

For example, if a person is standing at the equator with a ball, everything is moving together at 1667 km/hr -- the earth, the person, and the ball. If the person tosses the ball up, it keep traveling eastward with the earth below at 1667 km/hr, just like the person, and when it falls to the ground it will be at the person’s feet.

If it **didn’t** continue to move eastward at 1667 km/hr when tossed up in the air, it would land far to the west of the person!
Away from the equator, the eastward velocity will be smaller, but the same thing happens. **But the difference in velocity is the key to the Coriolis Effect, and you see it when an object is traveling horizontally over the rotating earth.**

Let’s say our guy is Superman, and instead of tossing the ball straight up in the air, he hurls it from the equator directly northward hundreds of miles.

When it starts out, it has northward velocity from Superman’s throw, but it also has the eastward velocity of its place of origin, 1667 km/hr. Below it the earth is spinning at 1667 km/hr when it is over the equator. However, as it travels northward to higher latitude, the earth below it is traveling more slowly. So instead of landing directly north, it gets ahead of the mark, landing further to the east. To determine its course, you have to consider the SUM of the two velocities, northward and eastward:

In the northern hemisphere the course is deflected to the right of the target, when looking from the perspective of the launch site. In the southern hemisphere it is to the left.
I find it’s easier to remember and visualize that in the N hemisphere the deflection is clockwise, and in the S hemisphere it is counter-clockwise, no matter what vantage point you’re looking from.