

## Storms, Hurricanes, Tornadoes

**Q. Where do storms get their energy from?**

**A. From water vapor.**

It takes energy to convert liquid water into water vapor. Water molecules stick together in the liquid via hydrogen bonds. These bonds need to be broken to separate the molecules from each other. The energy contained in water vapor (which is invisible) is released when it condenses into clouds (which consist of little droplets of liquid water). A large storm can sweep up the water vapor from vast stretches of warm ocean, particularly in the tropics.

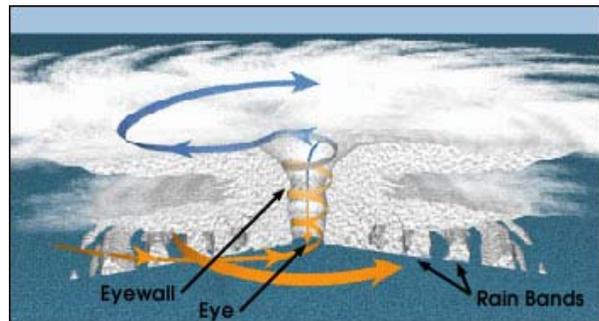
**Q: What causes the characteristic spiral shape of storm systems (cyclones)?**

**A: The rotation of the Earth, which generates the Coriolis force.**

If a low-pressure area forms in the atmosphere, air flows towards this region, but will be deflected perpendicular to its velocity by the Coriolis force (see next page). Instead of flowing straight towards the low pressure area, the air ends up circulating around it. This pattern of air flow is called a cyclone. In the Northern Hemisphere the direction of rotation around a low-pressure area is counter-clockwise.



Storm system over Iceland showing a counter-clockwise rotation around a the low pressure.



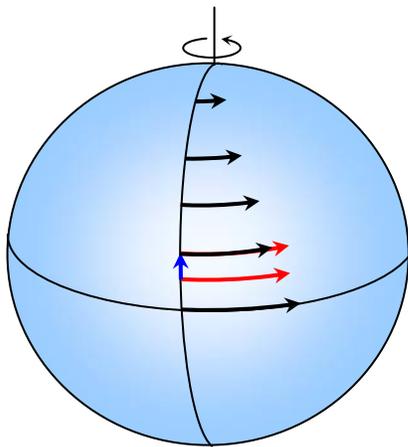
Schematic of a Hurricane:

Moist air is pulled into the low pressure region at the center, rises and condenses into clouds at the eyewall. It then gets expelled outwards at the top into high cirrus clouds. The low rain clouds rotate counter-clockwise, and the high cirrus clouds clockwise (inward flow instead of outward flow).

## Coriolis Force and Low Pressure Systems

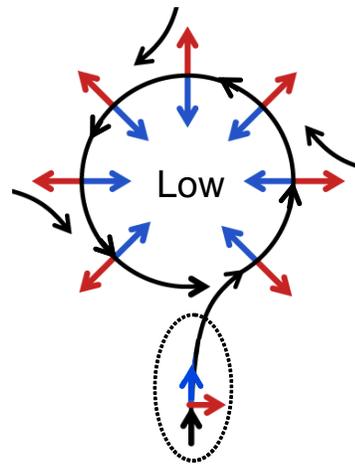
- The Coriolis force is due to the rotation of the Earth. In the Northern Hemisphere, the Coriolis force deflects towards the right (and in the Southern Hemisphere to the left).
- A low pressure system pulls air into its center.
- The combination of these two forces creates a counter-clockwise rotation of low pressure systems in the Northern Hemisphere (clockwise in the Southern Hemisphere).

Qualitative explanation:



The **Coriolis force** causes a **deflection to the right** in the **Northern Hemisphere**:

The surface of the Earth rotates faster near the Equator. If an air mass moves towards the North (blue arrow), its rotation speed is higher than the ground speed (red arrow vs. black arrow). The difference causes a deflection to the right.



**Counter-clockwise rotation** around **low pressure** in the **Northern Hemisphere**:

It is caused by *two* forces, the attraction towards low pressure (blue arrows) and the Coriolis force (red arrows). These forces are balanced when the motion is circular. The Coriolis force alone would produce a clockwise rotation, but the combination of the two forces makes it counter-clockwise.

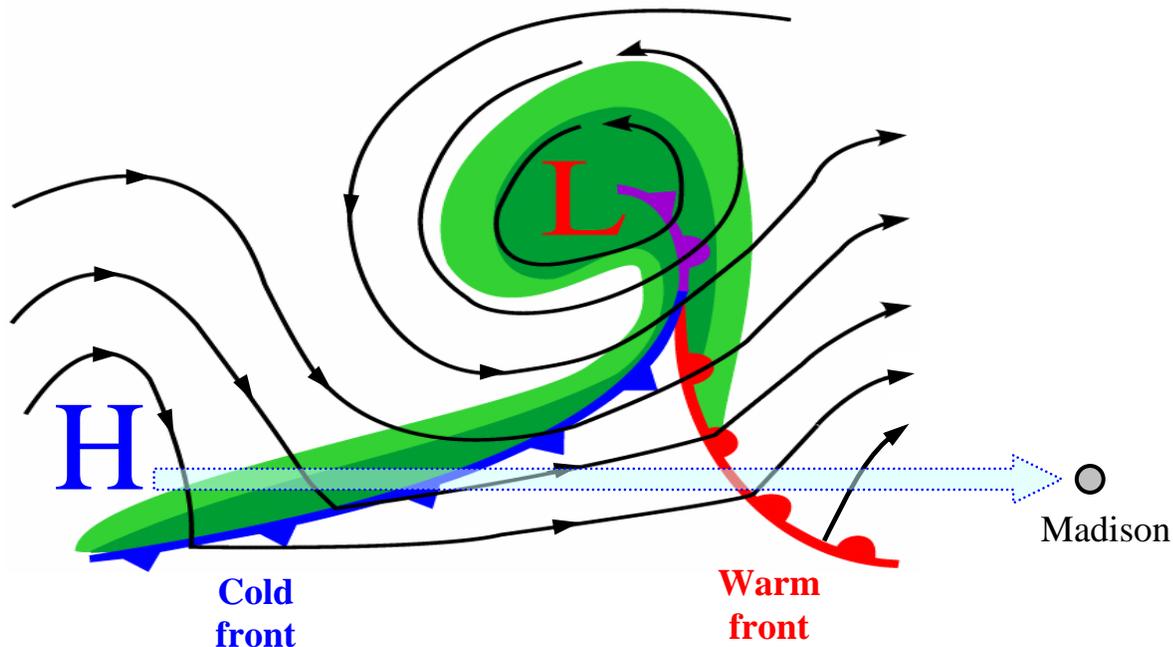
The **Coriolis force** is significant only for **large weather systems**, since the wind has to cover a significant fraction of the Earth to detect a change in the surface rotation. **Low pressure systems** and **hurricanes** are large enough. Tornadoes (and bathtub drains) are much smaller, so the Coriolis force is negligible. Nevertheless, tornadoes prefer a counter-clockwise rotation in the Northern Hemisphere, like hurricanes. This preferred rotation probably comes from the rotation of the much larger thunderstorms that spawn tornadoes.

## Change in Wind Direction from a Low Pressure System

For the latitude of Wisconsin and Central Europe, there is a typical weather pattern where a rainy low pressure system (**L** in the figure) is followed by sunny high pressure (**H** in the figure). The low pressure is caused by warm air, which is less dense, and the high pressure by cold, dense air.

During the passage of a low pressure system the wind rotates from South to West and North. The approach of a low pressure system announces itself by steady southerly wind, often combined with clear weather (great for sailing and wind-surfing). With the arrival of the warm front the wind turns steadily westward, and eventually it starts drizzling. After a period of steady rain the wind turns north and ushers in the cold front. It comes rather suddenly and produces showers and thunderstorms. Eventually, the wind rotates further and the sky clears for the high pressure system.

This pattern can be understood by realizing that most low pressure systems remain north of us and travel from west to east. The winds rotate counter-clockwise around the low pressure system and clockwise about the high pressure system that follows it. In between, the wind takes an S-shaped path.



## Global Wind Patterns

On a global scale, there are characteristic wind patterns that are driven by the rising hot air at the equator. These have helped sailors getting across oceans (trade winds), but also becalmed them (horse latitudes). And to return from the Americas to Europe, the sailors had to go farther North to pick up the Westerlies (or take advantage of the North-South shift of these zones with the seasons). The trade winds are caused by air that is pulled towards the equator to replace the rising air at the equator. The Coriolis force deflects them westwards (to the right in the Northern Hemisphere and to the left in the Southern Hemisphere).

Rising hot air creates low pressure, while sinking cold air creates high pressure. The high pressure in the horse latitudes creates a belt of deserts surrounding the globe, such as the Sahara. With global warming, this climate zone has a tendency to expand towards the North and to turn the Southwestern regions of the US into a desert (as well as the Mediterranean region in Europe). Low pressure at the polar front creates the storms that bring rain to the Northern US and Europe.

