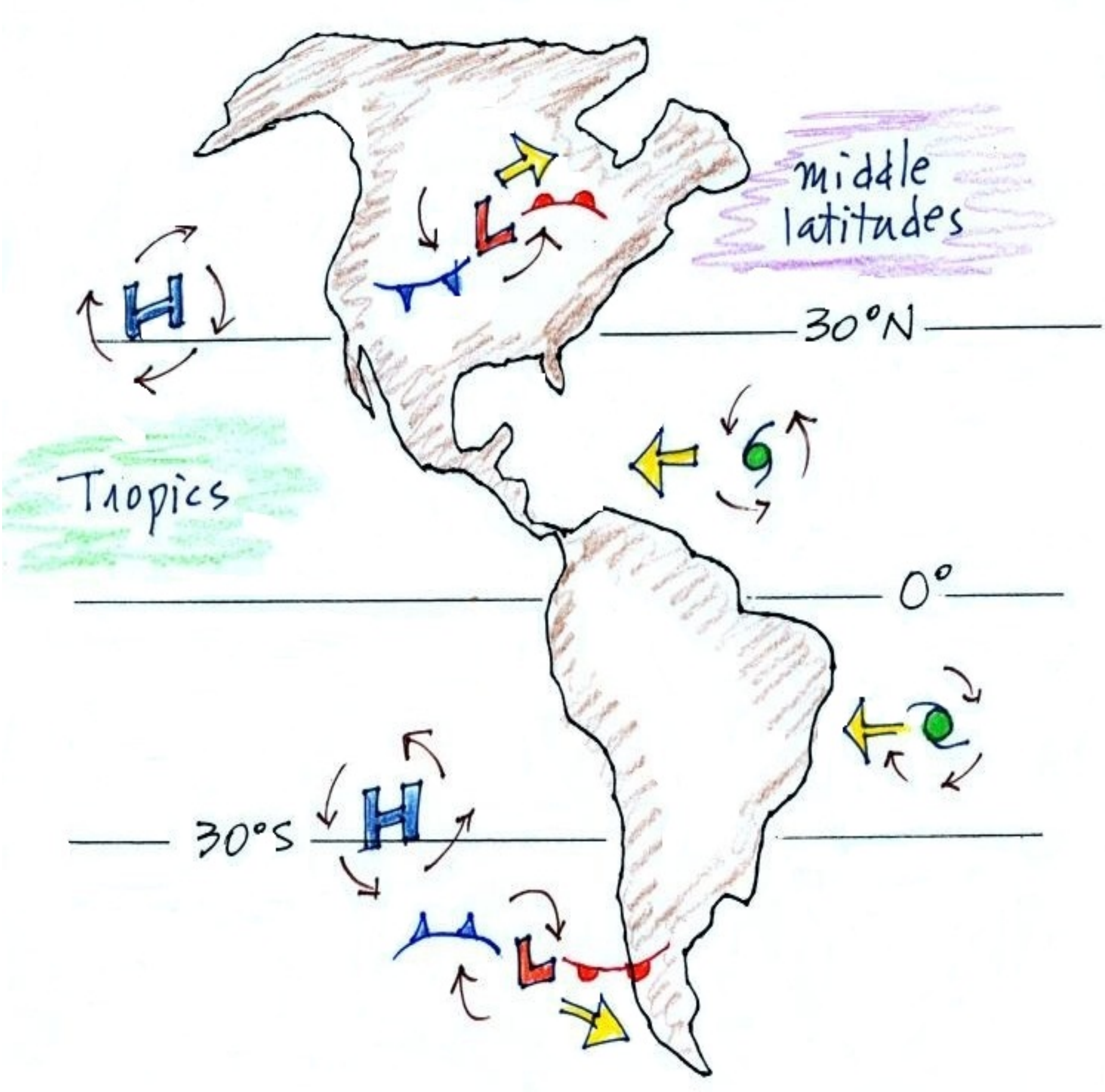
Module 9 - Lecture 25

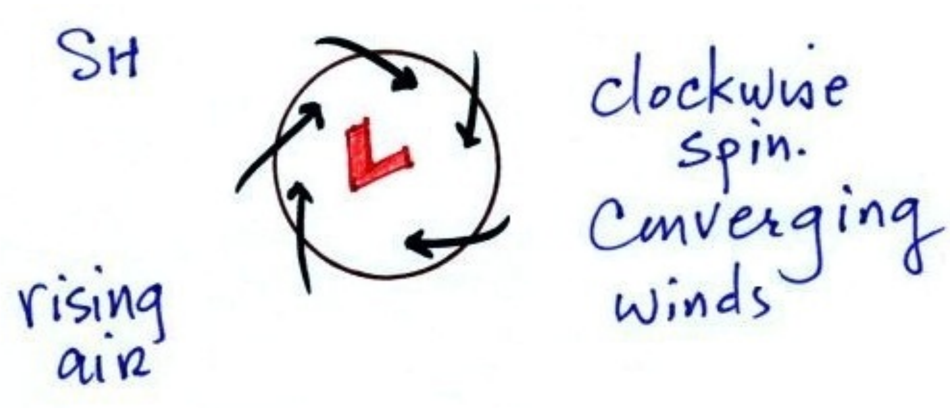
In this module we will be looking at surface and upper level winds. Storm systems in the tropics (0 to 30 degrees latitude) generally move from east to west. At middle latitudes (30 to 60 degrees), storms move in the other direction, from west to east. To understand why this is true, we need to learn something about the earth's global wind patterns.



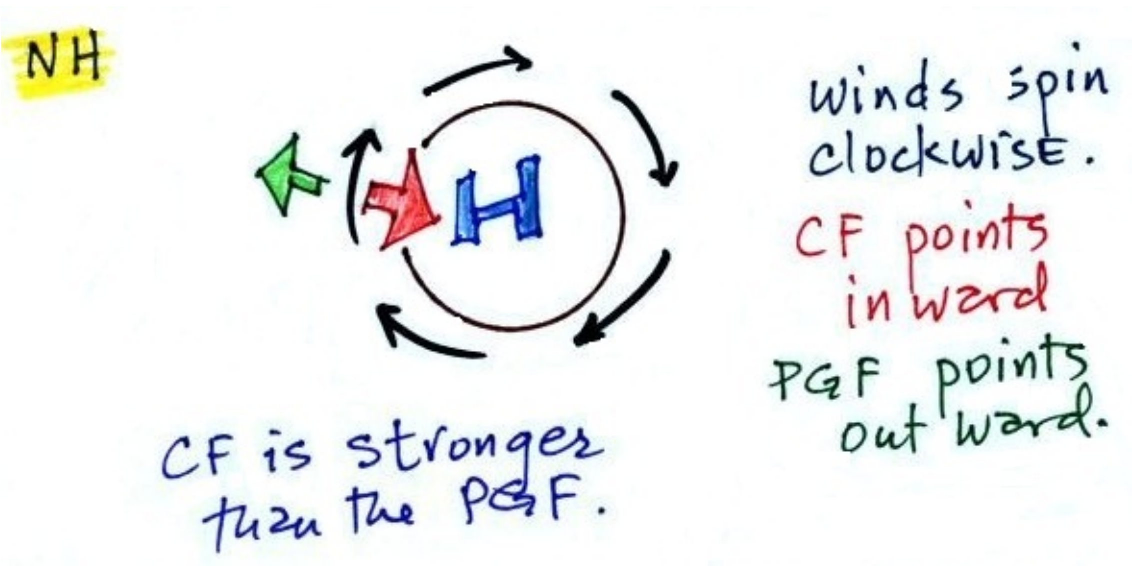
We will learn about surface and upper level winds in both the northern and southern hemispheres in 10 steps.

Step 1: An Overview

Winds spin counterclockwise around a low in the northern hemisphere and clockwise in the southern hemisphere.

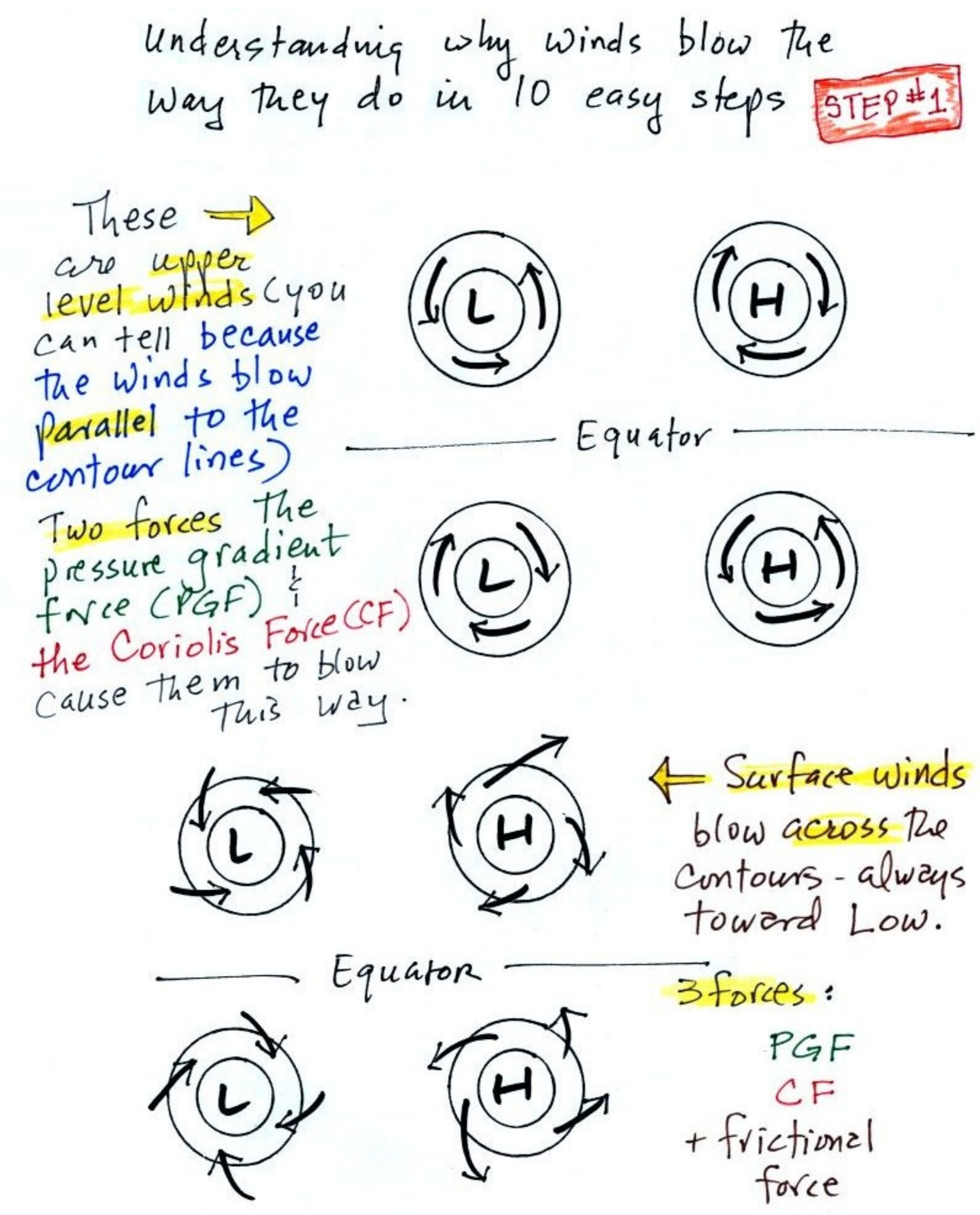


Winds spin clockwise around "anticyclones" (high pressure) in the northern hemisphere and counterclockwise in the southern hemisphere.



Upper level winds spinning around high and low pressure in the northern and southern hemispheres are shown in the first set of four pictures below. The first thing to notice is that **upper level winds blow parallel to the contours**. We will see that two forces, the pressure gradient force (PGF) and the Coriolis force (CF), cause the winds to blow this way. Eventually you will be able to draw the directions of the forces for each of the four upper level winds examples.

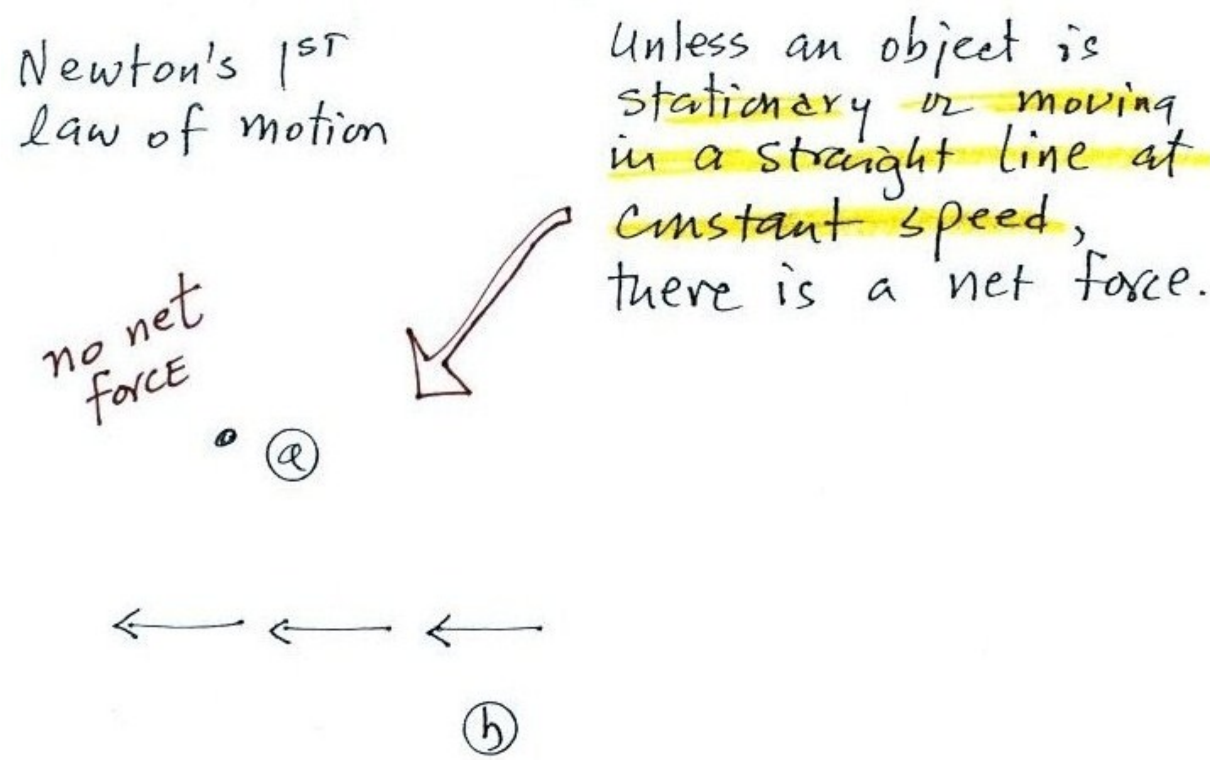
The four drawings at the bottom of the page show surface winds blowing around high and low pressure in the southern hemisphere. **Surface winds blow across the contour lines** and always toward low pressure. The frictional force is what causes this to occur.



Step 2: Newton's First Law of Motion

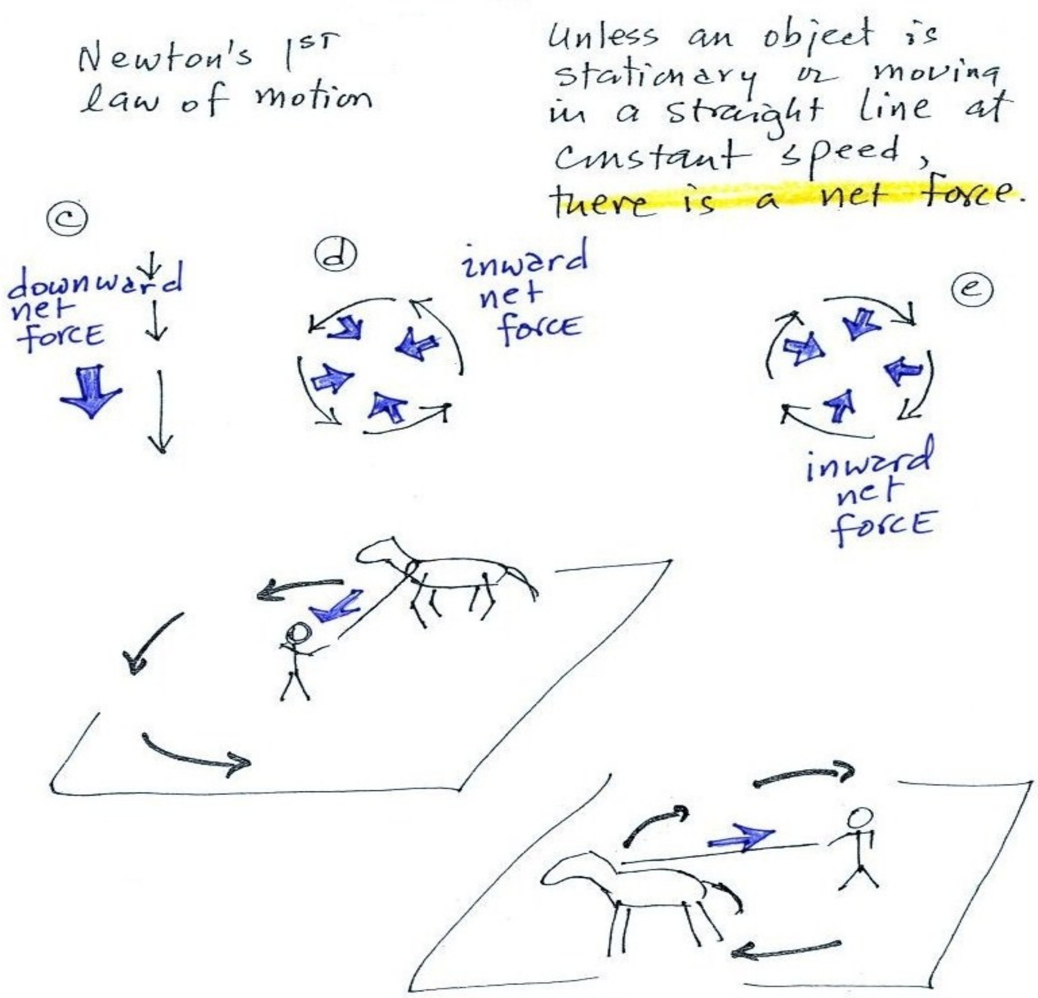
Before learning about the specific forces that cause the wind to blow, we will review Newton's First Law of Motion. **Every object persists in its state of rest or uniform motion unless a force acts to change the motion.**

In the figure below, the object at Point a is stationary and the object at Point b is moving at a uniform rate of speed. There is no net force on either object because the state of motion is not changing. No net force does not mean there are not any forces at all. Instead it means that all the forces must cancel each other out.



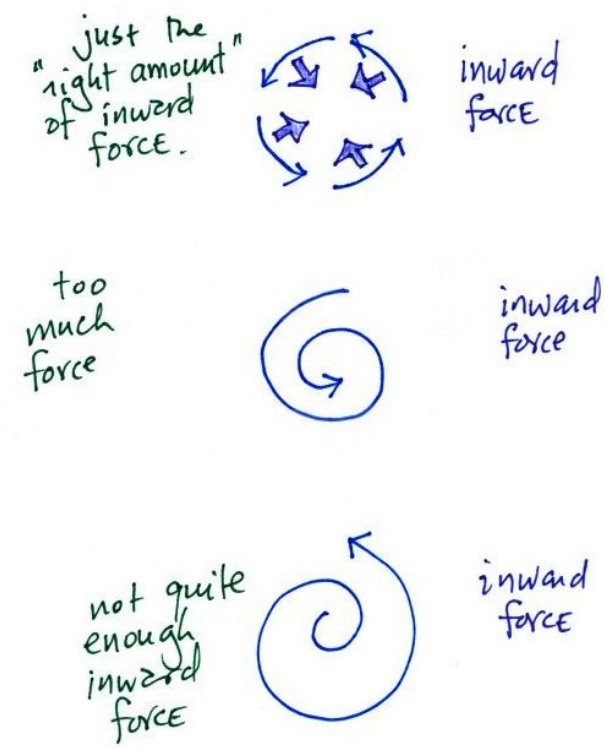
The figure below shows examples in which a net force is present. In other words, the forces do not cancel each other out. At Point c the motion is a straight line but the speed is increasing. At Point c and Point d, a person is training a horse that is running in a circle. These points show constant speed but force is required to keep the motion circular.

The directions of the net forces are also shown in each case. The net force at Point c is downward. At Point c and Point d, the net force is inward. The person exercising the horse must pull inward to keep the horse running in a circle; it does not matter which direction the horse is moving.



What is the direction of the net force in the three following examples?

The answers are shown in the figure below. A net inward force is needed in all three cases but the amount of force is different. The amount of inward force is "just right" in the first figure, a little "too strong" in the second figure, and "not quite strong enough" in the bottom figure.



Step 3: Understand the Pressure Gradient Force

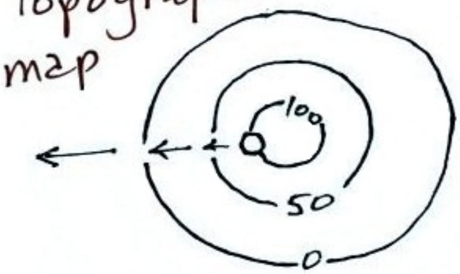
Now we will start to look at the forces that cause the wind to blow. We will learn rules for the direction and the strength of each force. Each force will have a "unique" characteristic that makes it different from the other forces.

We will begin with the pressure gradient force (PGF). The pressure gradient force always points towards the area of low pressure and causes stationary air to begin to move toward the low pressure area. The pressure gradient force can be compared to a rock, which will always roll downhill.

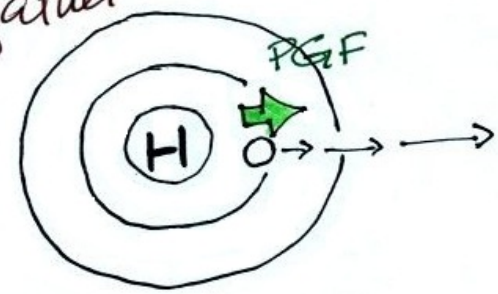
A weather chart is analogous to a topographic map, as shown in the figure below. A topographic map has contours which represent points that have the same altitude. In the same way, a surface weather map has contours representing points which have the same sea level pressure. We learned in a previous lecture that upper level maps have altitude contours representing the height at which a certain pressure such as 500 mb is reached.

Step3

Topographic map



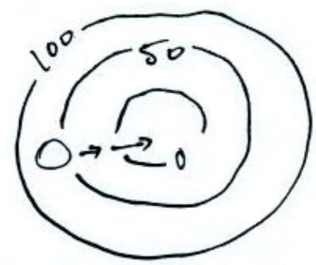
weather map

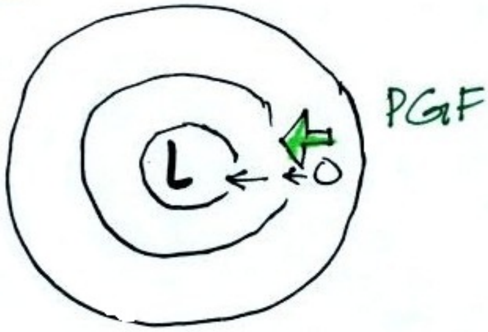


PGF is a little like a rock on a hill. A rock will always roll downhill (from H altitude toward L altitude)

☆ ① PGF can start stationary air moving

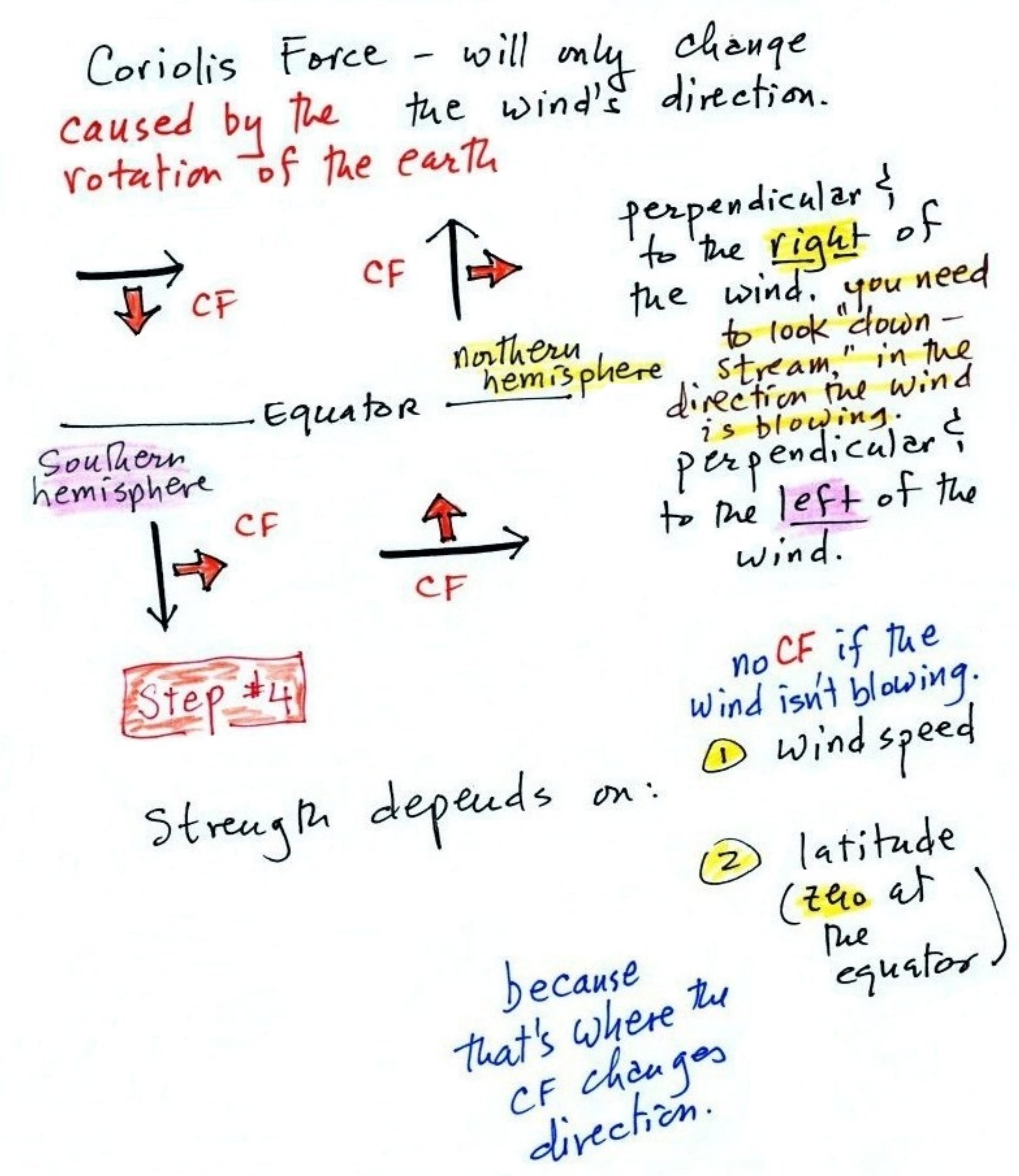
② PGF is perpendicular to the contours, always points toward Low.





Step 4: Understand the Coriolis Force

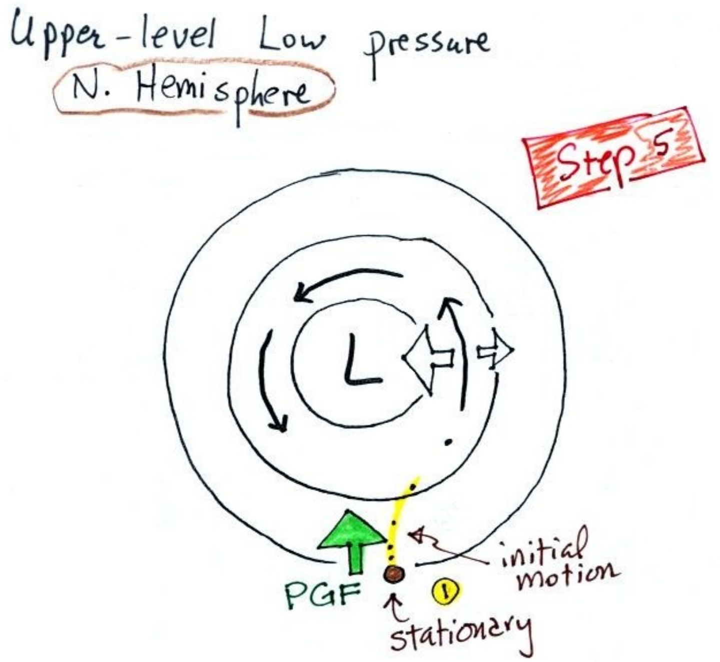
The Coriolis force (CF) is caused by the rotation of the earth and always points perpendicular to the wind. In the northern hemisphere, the Coriolis force deflects the wind to the right and in the southern hemisphere the Coriolis force deflects the wind to the left. **<u>The Coriolis force does not change the wind speed; it can only change the wind direction</u>**. You can learn more about the cause of the Coriolis force at http://www.youtube.com/watch?v=_36MiCUS1ro.



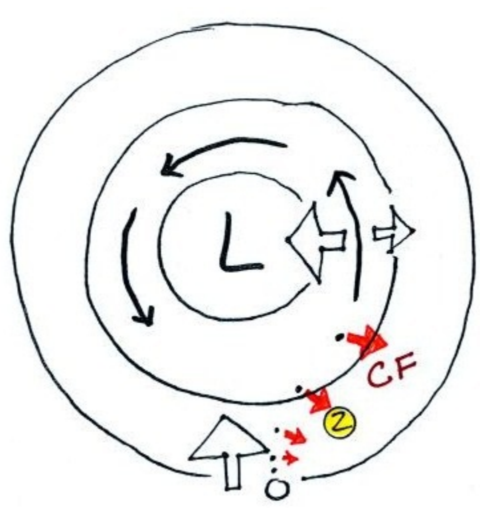
Step 5: Upper Level Low in the Northern Hemisphere

The pressure gradient force and the Coriolis force are the two forces that we need to consider when we study upper level winds. We will learn later in this lecture that the frictional force is also important for surface winds.

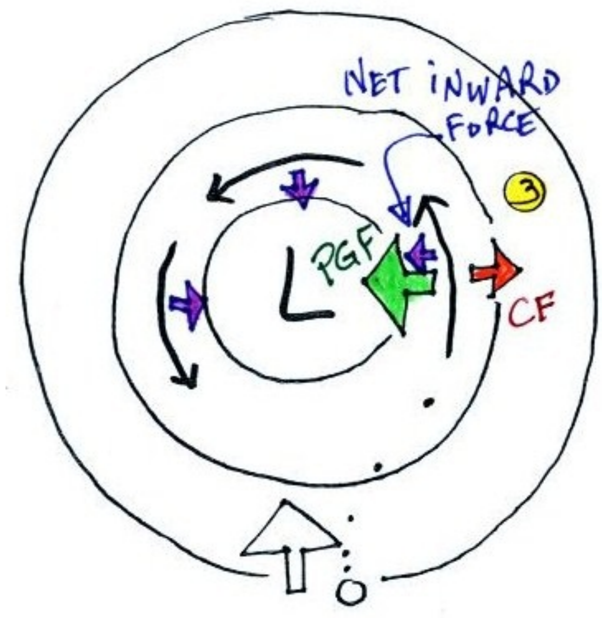
We start with stationary air at Point 1 in the figure below. The pressure gradient force at Point 1 is pointing toward the center of low pressure.



Once the air starts to move, the Coriolis force causes it to turn to the right because this is a northern hemisphere chart (below). As the air moves inward, it picks up speed and the strength of the Coriolis force increases.

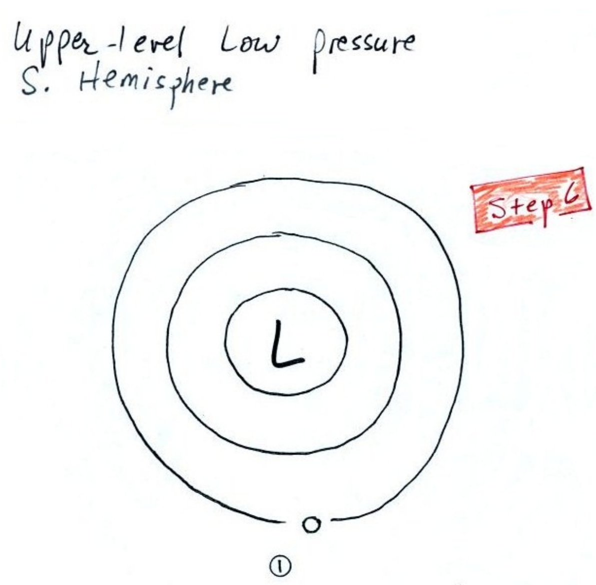


Eventually the wind is blowing parallel to the contour lines. Note that the pressure gradient force and the Coriolis force are pointing in opposite directions but are not of equal strength. The inward pressure gradient force is stronger than the Coriolis force. The difference provides the net inward force needed to keep the air blowing in a circular path, similar to the previous example of the horse trainer pulling the rope so that the horse continues to run in a circle. Winds blow parallel to the contours and spin in a counterclockwise direction around upper level lows in the northern hemisphere.



Step 6: Do a Similar Analysis for the Southern Hemisphere

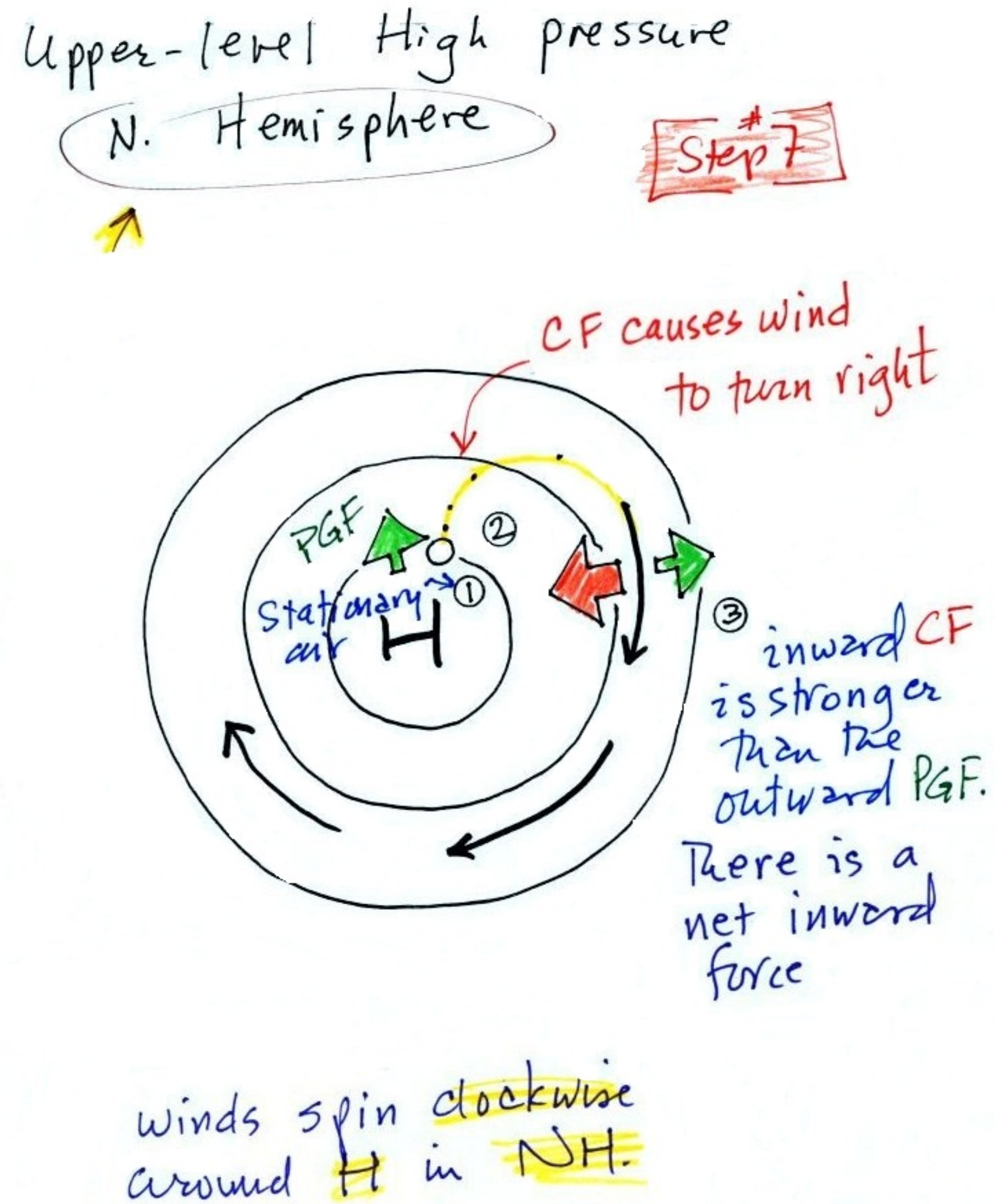
See if you can figure out what to do with this figure. When you think you have the answer click http://www.atmo.arizona.edu/courses/spring10/nats101s1/lecture_notes/forces_winds/step6b.jpg.



Step 7: Upper-level High Pressure System in the Northern Hemisphere

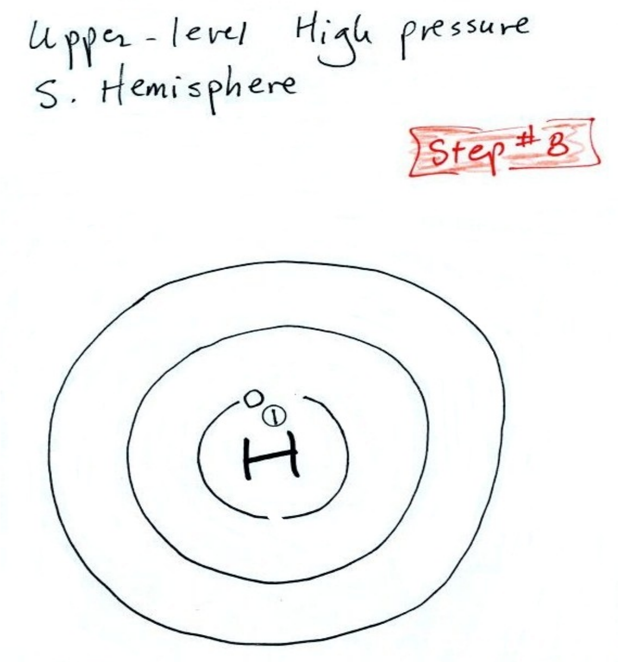
Now we will look at the development of winds around upper level centers of high pressure. In the figure below, the pressure gradient force points outward towards the direction of lower pressure (Point 1). This causes the stationary air to begin to move outward. The initial motion is shown with a yellow dotted line. Once the air begins to move, the Coriolis force will bend the wind to the right until it is blowing along the contours.

At Point 3, the wind is blowing parallel to the contour lines. The pressure gradient force is pointing outward and the Coriolis force is pointing inward. The Coriolis force is stronger than the pressure gradient force, which provides the net inward force needed to keep the wind blowing in a circular path. Upper level winds spin clockwise around high pressure in the northern hemisphere.



Step 8: Upper-level High Pressure System in the Southern Hemisphere

Try this example again on your own. When you think you have the answer, click http://www.atmo.arizona.edu/courses/spring10/nats101s1/lecture_notes/forces_winds/step8b.jpg.



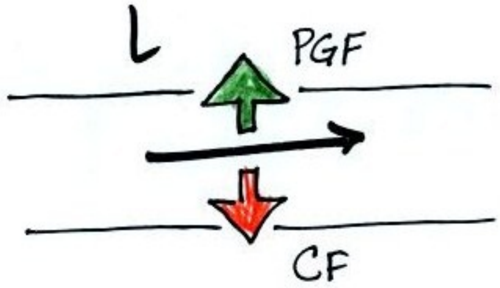
Step 9: Forces Affecting Surface Winds

Now we will look at surface winds. There are three forces that influence the direction of surface winds: pressure gradient force, Coriolis force and frictional force. Without frictional force, the wind blows parallel to the pressure contours.

The top picture in the figure on the next page shows upper level winds blowing parallel to straight contours. The pressure gradient force and the Coriolis force point in opposite directions and have the same strength. Because the net force is zero, the winds blow in a straight line at constant speed. The reason is Newton's First Law, which we have discussed previously in this lecture.

We add the frictional force in the second picture. **The frictional force points in a direction 180 degrees opposite to the wind. It slows the wind down but does not change its direction**. The strength of the frictional force depends on wind speed (no frictional force if the wind is calm) and the surface the wind is blowing over (less friction over the ocean than when the wind is blowing over the land).

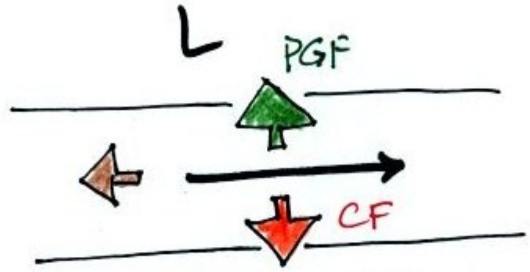
Slowing the wind weakens the Coriolis force so that no longer balances the pressure gradient force (Picture 3). The stronger pressure gradient force causes the wind to turn and blow across the contours toward the low (Picture 4). Eventually the Coriolis force and the frictional force, working together, can balance out the pressure gradient force. When this balance is reached the wind will continue to blow in a straight line at constant speed across the contours.



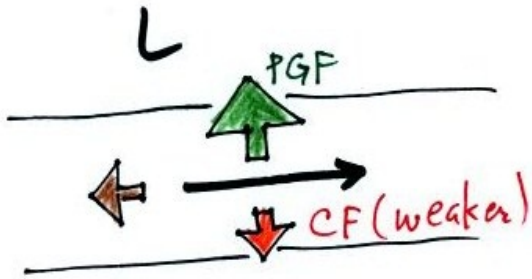
upper level wind (parallel to contours)
PGF and CF only

Surface winds
new force: friction

Friction always points opposite the wind and can only slow the wind.

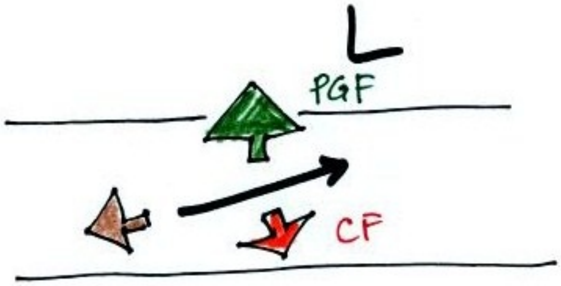


weakens the CF.
CF no longer balances PGF

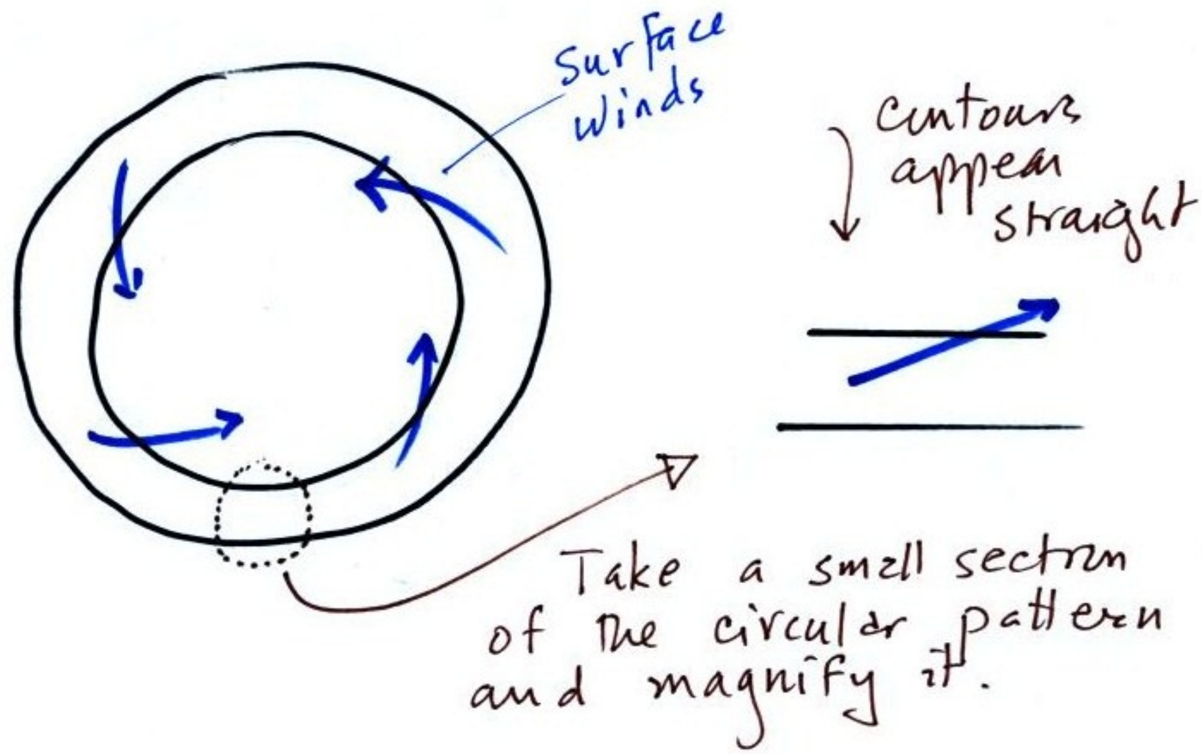


STEP #9

wind ends up blowing across the contours always toward Low pressure.



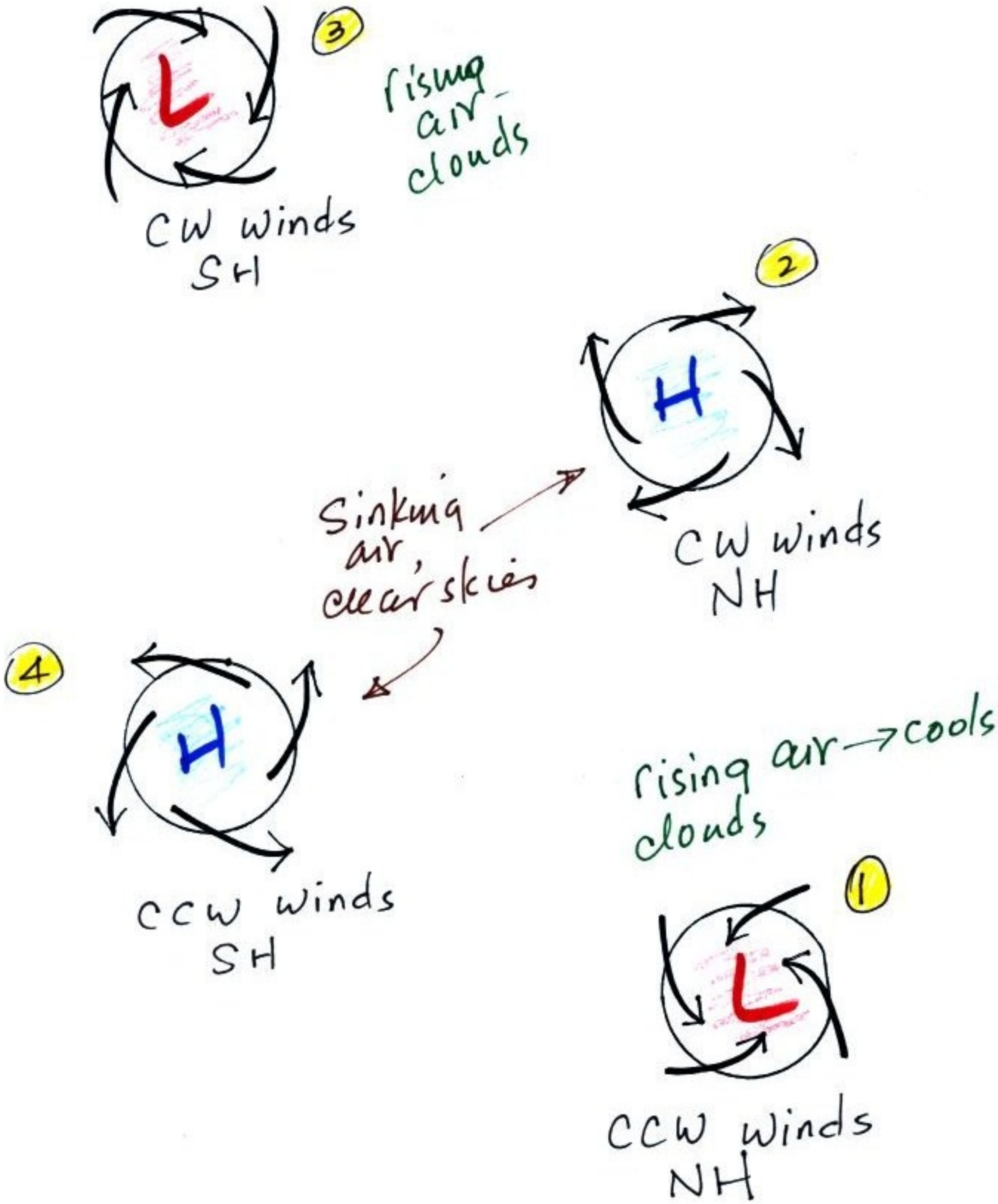
Now the transition from the straight contours above to the circular contours below might be a little abrupt. But if you focus on a very small part of a larger circular pattern the contours look straight. The important thing to remember is that surface winds will always blow across the contours toward low.



Step 10: A Summary of Surface High and Low Pressure Systems
The figure on the next page summarizes surface high and low pressure systems in the north and south hemispheres. The wind spiral inward towards the center of the low pressure systems (Pictures 1 and 3) and spiral away from the centers of high pressure systems (Pictures 2 and 4).

Earlier in the class we learned that converging surface winds create rising air motions. Rising air expands and cools and can cause clouds to form. Clouds and stormy weather are associated with surface low pressure in both hemispheres. Diverging winds created sinking wind motions and result in clear skies.

Remembering the flow directions for each hemisphere can be challenging. I suggest Example #1: surface winds spin counterclockwise and spiral inward around centers of low pressure in the northern hemisphere (something we learned fairly early in this course). Then remember that winds spin in the other direction and blow outward around high pressure in the northern hemisphere (2). The spinning directions of the winds reverse when you move from the northern to the southern hemisphere. Thus you find clockwise spinning winds and inward motion around low pressure (3) and counterclockwise and outward spiraling winds around high pressure in the southern hemisphere.


3
rising air clouds
CW winds SH
2
Sinking air, clear skies
CW winds NH
4
rising air → cools clouds
CCW winds SH
1
CCW winds NH