<u>Atmospheric Stability</u>

- We know that most clouds form as air rises, expands, and cools. But why does the air rise on some occasions and not on others? To answer these questions, let's focus on the concept of atmospheric stability.

When we speak of **atmospheric stability**, we are referring to a condition **of equilibrium**. For example, **rock A** resting in the depression in Fig. 1 is in ***stable*** **equilibrium**. If the rock is pushed up along either side of the hill and then let go, it will quickly return to its original position. On the other hand, **rock B**, resting on the top of the hill, is in a state of ***unstable*** **equilibrium**, as a slight push will set it moving away from its original position. Applying these concepts to the atmosphere, we can see that air is in stable equilibrium when, after being lifted or lowered, it tends to return to its original position—it resists upward and downward air motions. **Air that is in unstable equilibrium will, when given a little push, move farther away from its original position—it favors vertical air currents**. In order to explore the behavior of rising and sinking air, we must first review some concepts we learned in earlier chapters. Recall that a balloon like blob of air is called an *air parcel*.

- **When an air parcel rises, it moves into a region where the air pressure surrounding Temprature is lower. This situation allows the air molecules inside to push outward on the parcel walls, expanding it. As the air parcel expands, the air inside cools.**
- **If the same parcel is brought back to the surface, the increasing pressure around the parcel squeezes (compresses) it back to its original volume, and the air inside warms**.
- **Hence, *a rising parcel of air expands and cools, while a sinking parcel is compressed and warms*.**
- **If a parcel of air expands and cools, or compresses and warms, with no interchange of heat with its outside surroundings, this situation is called an <u>adiabatic process</u>.**
- **As long as the air in the parcel is unsaturated (the relative humidity is less than 100 percent), the rate of adiabatic cooling or warming remains constant and is about 10°C for every 1000 meters of change in elevation, or about 5.5°F for every 1000 feet. Since this rate of cooling or warming only applies to unsaturated air, it is called the dry adiabatic rate* (see Fig. 2).**
- **As the rising air cools, its relative humidity increases as the air temperature approaches the dew-point temperature. If the air cools to its dew-point temperature, the relative humidity becomes 100 percent. Further lifting results in condensation, a cloud forms, and latent heat is**

released into the rising air. Because the heat added during condensation offsets some of the cooling due to expansion, the air no longer cools at the dry adiabatic rate but at a lesser rate called the moist adiabatic rate. (Because latent heat is added to the rising saturated air, the process is not really adiabatic.†)

- **If a saturated parcel containing water droplets were to sink, it would compress and warm at the moist adiabatic rate because evaporation of the liquid droplets would offset the rate of compressional warming. Hence, the rate at which rising or sinking saturated air changes temperature—the moist adiabatic rate—is less than the dry adiabatic rate.**

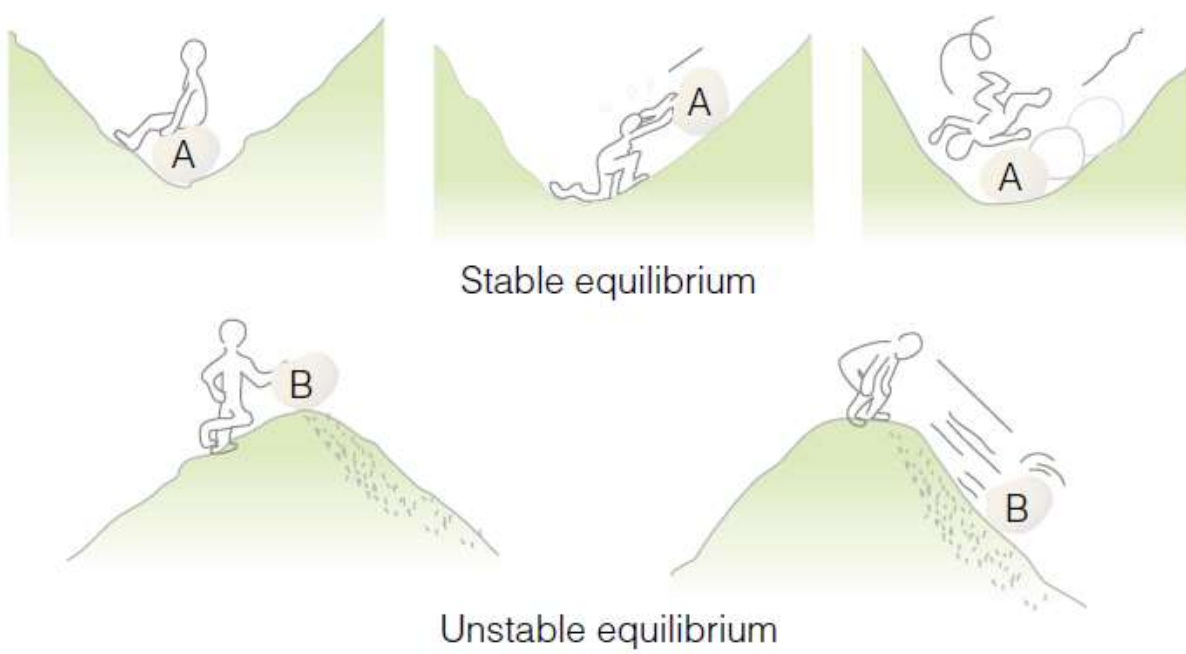


FIGURE .1 When rock A is disturbed, it will return to its original position; rock B, however, will accelerate away from its original position.

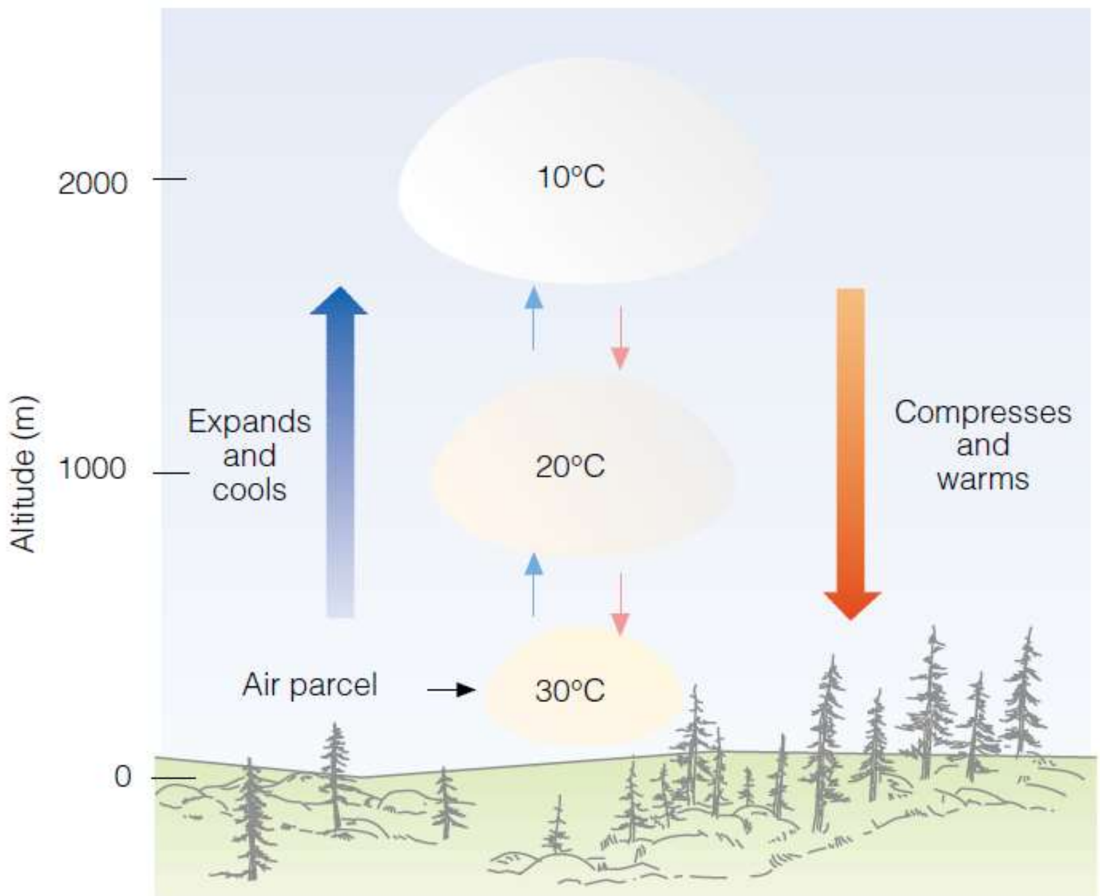


FIGURE 2. The dry adiabatic rate. As long as the air parcel remains unsaturated, it expands and cools by 10°C per 1000 m; the sinking parcel compresses and warms by 10°C per 1000 m.

Determining Stability

We determine the stability of the air by comparing the temperature of a rising parcel to that of its surroundings.
If the rising air is colder than its environment, it will be denser* (heavier) and tend to sink back to its original level. In this case, the air is *stable* because it resists upward displacement.
If the rising air is warmer and, therefore, less dense (lighter) than the surrounding air, it will continue to rise until it reaches the same temperature as its environment. This is an example of *unstable* air.
To figure out the air's stability, we need to measure the temperature both of the rising air and of its environment at various levels above the earth.

STABLE AIR

Suppose we release a balloon-borne instrument— a radiosonde (see Fig. 3)—and it sends back temperature data as shown in Fig.3. We measure the air temperature in the vertical and find that it decreases by 4°C for every 1000 m.
NOTE/ the rate at which the air temperature changes with elevation is called the lapse rate, Because this is the RATE at which the air temperature surrounding us would be changing if we were to climb upward into the atmosphere, refer to it as the **environmental lapse rate.**
Notice in Fig. 3a that (with an environmental lapse rate of 4°C per 1000 m) a rising parcel of unsaturated, "dry" air is colder and heavier than the air surrounding it at all levels. Even if the parcel is initially saturated (Fig. 3b), as it rises it, too, would be colder than its environment at all levels.
In both cases, the atmosphere is **absolutely stable because the lifted parcel of air is colder and heavier than the air surrounding it**. If released, the parcel would have a tendency to return to its original position.

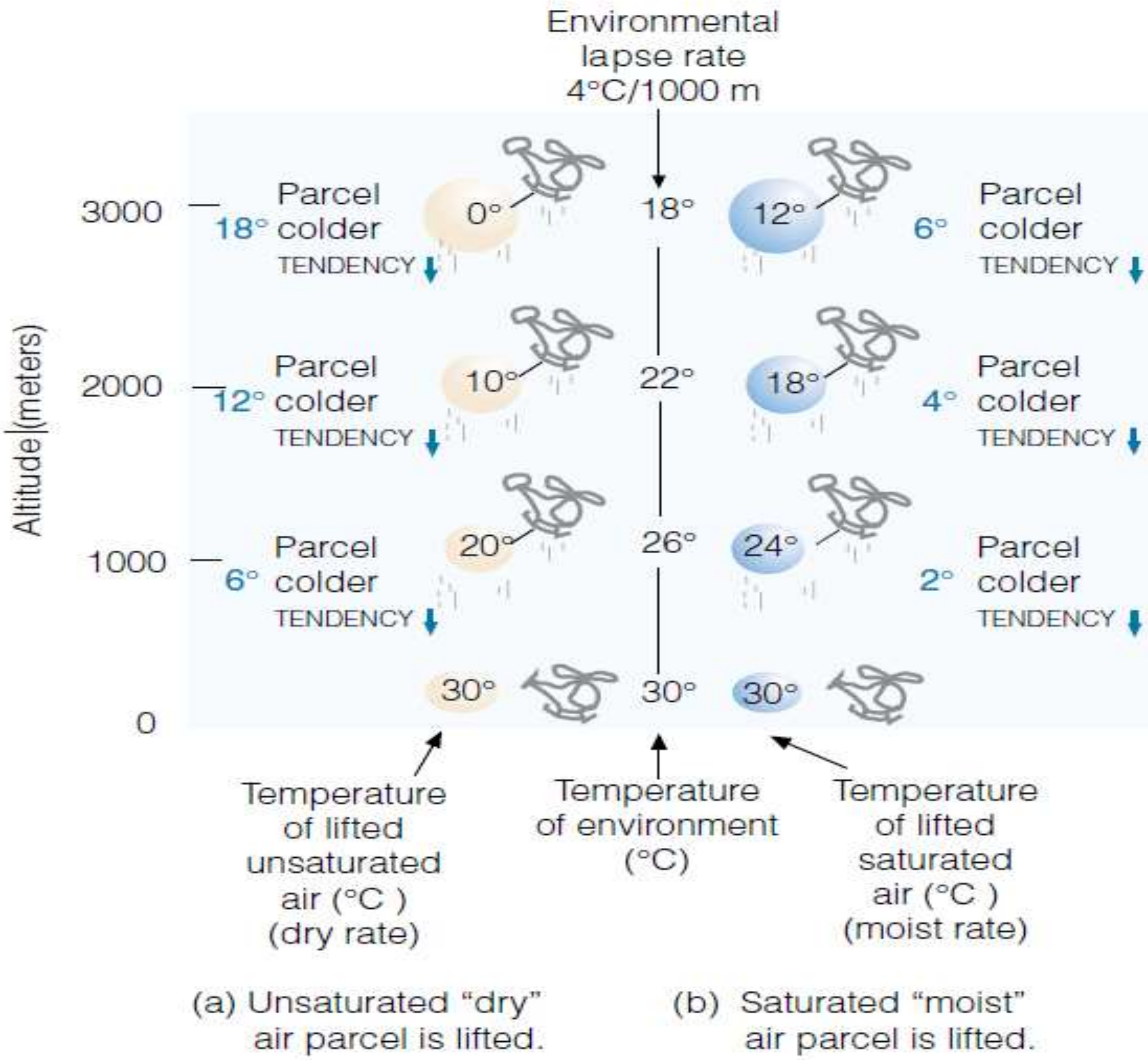


FIGURE.3.

A stable atmosphere. An *absolutely stable atmosphere* exists when a rising air parcel is colder and heavier (i.e., more dense) than the air surrounding it. If given the chance (i.e., released), the air parcel in both situations would return to its original position, the surface.

<u>UNSTABLE AIR</u>:

The atmosphere is unstable when the air temperature decreases rapidly as we move up into the atmosphere. For example, in Fig.4, notice that the measured air temperature decreases by 11°C for every 1000-meter rise in elevation, which means that the environmental lapse rate is 11°C per 1000 meters.

Also notice that a lifted parcel of unsaturated "dry" air in Fig.4a, as well as a lifted parcel of saturated "moist" air in Fig.4b, will, at each level above the surface, be warmer than the air surrounding them. Since, in both cases, the rising air is warmer and less dense than the air around them, once the parcels start upward, they will continue to rise on their own, away from the surface**. Thus, we have an absolutely unstable atmosphere.**

The atmosphere becomes more unstable as the environmental lapse rate steepens; that is, as the temperature of the air drops rapidly with increasing height. This circumstance may be brought on by either the air aloft becoming colder or the surface air becoming warmer.

Generally, then, as the surface air warms during the day, the atmosphere becomes more unstable it *destabilizes*.

layer where the top is dry and the bottom is humid, produces cooling and a more unstable atmosphere. The lifted layer becomes more unstable as it rises and stretches out vertically in the less dense air aloft. This stretching effect steepens the environmental lapse rate as the top of the layer cools more than the bottom.

The atmospheric layer from the surface up to 4000 meters in Fig. 5. has gone from stable to unstable because the rising air was humid enough to become saturated, form a cloud, and release latent heat, which warms the air. Had the cloud not formed, the rising air would have remained colder at each level than the air surrounding it. From the surface to 4000 meters, we have what is said to be a **conditionally unstable atmosphere**— the condition for instability being whether or not the rising air becomes saturated. Therefore, *conditional instability* means that, if unsaturated stable air is somehow lifted to a level where it becomes saturated, instability may result. In Fig. 5, we can see that the environmental lapse rate is 9°C per 1000 meters. This value is between the dry adiabatic rate (10°C/1000 m) and the moist adiabatic rate (6°C/1000 m). Consequently, *conditional instability exists whenever the environmental lapse rate is between the dry and moist adiabatic rates*.

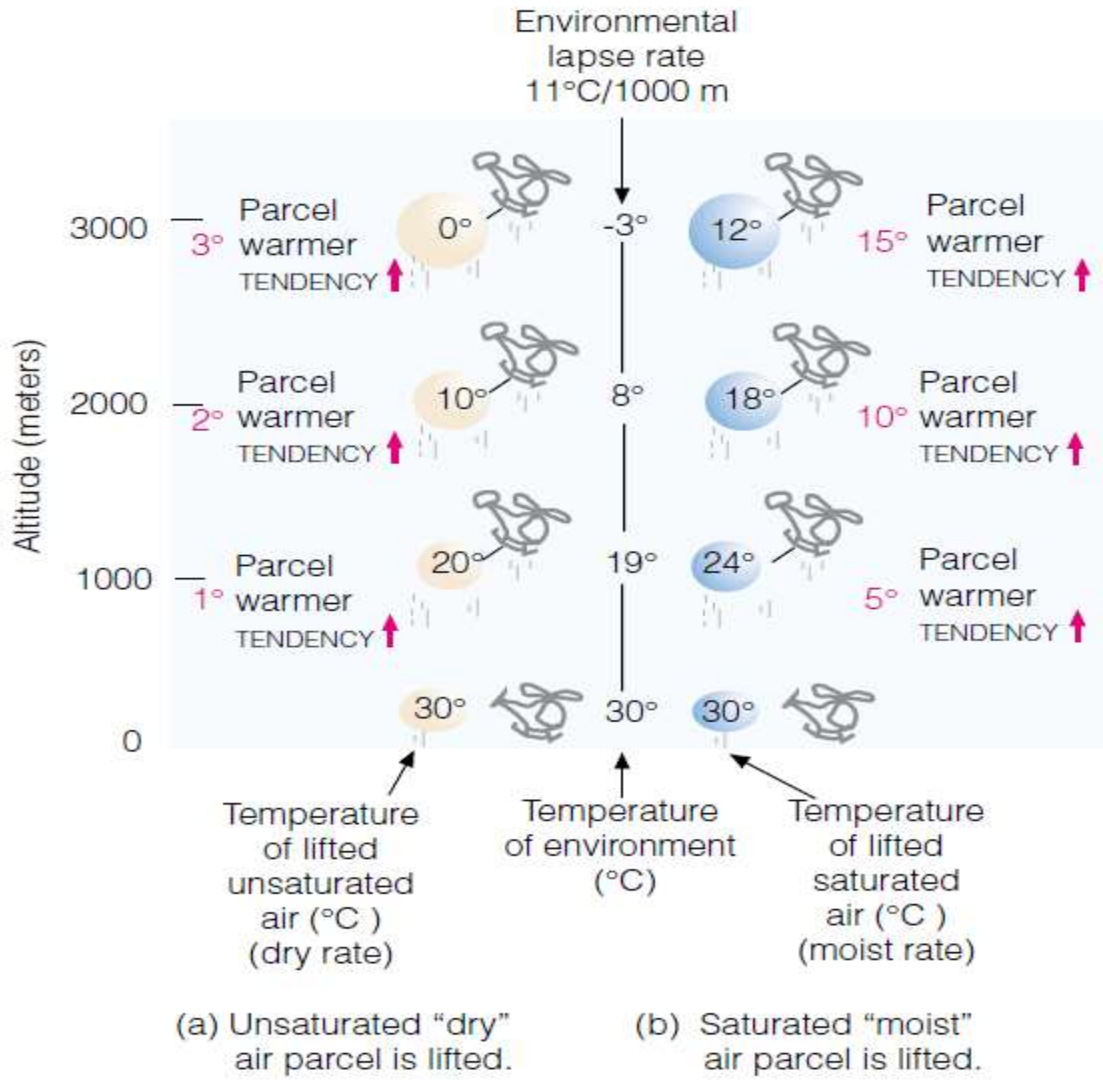


FIGURE 4. An unstable atmosphere. An *absolutely unstable atmosphere* exists when a rising air parcel is warmer and lighter (i.e., less dense) than the air surrounding it. If given the chance (i.e., released), the lifted parcel in both (a) and (b) would continue to move away (accelerate) from its original position.

CONDITIONALLY UNSTABLE AIR

Suppose an unsaturated (but humid) air parcel is somehow forced to rise from the surface, as shown in Fig. 5, As the parcel rises, it expands, and cools at the *dry adiabatic rate* until its air temperature cools to its dew point. At this level, the air is saturated, the relative humidity is 100 percent, and further lifting results in condensation and the formation of a cloud. The elevation above the surface the cloud first forms (in this example, 1000 meters) is called the **condensation level(LCL).**
In Fig. 5, notice that above the condensation level, the rising saturated air cools at the *moist adiabatic*
rate. Notice also that from the surface up to a level near 2000 meters, the rising, lifted air is colder than the air surrounding it. The atmosphere up to this level is *stable*. However, due to the release of latent heat, the rising air near 2000 meters has actually become warmer than the air around it. Since the lifted air can rise on its own accord, the atmosphere is now *unstable*. The level in the atmosphere where the air parcel, after being lifted, becomes warmer than the air surrounding it, **is called the *level of free convection(LFC).***
The atmospheric layer from the surface up to 4000meters in Fig. 5.7 has gone from stable to unstable because the rising air was humid enough to become saturated, form a cloud, and release latent heat, which warms the air. Had the cloud not formed, the rising air would have remained colder at each level than the air surrounding it. From the surface to 4000 meters, we have what is said to be a **conditionally unstable atmosphere**— the condition for instability being whether or not the rising air becomes saturated. Therefore, *conditional instability* means that, if unsaturated stable air is somehow lifted to a level where it becomes saturated, instability may result.
that the average lapse rate in the troposphere is about 6.5°C per 1000 m (3.6°F per 1000 ft). Since this value lies between the dry adiabatic rate and the average moist rate, *the atmosphere is ordinarily in a state of conditional instability.* At this point, it should be apparent that the stability of the atmosphere changes during the course of a day. In clear, calm weather around sunrise, surface air is normally colder than the air above it, a radiation inversion exists, and the atmosphere is quite stable, as indicated by smoke or haze lingering close to the ground. As the day progresses, sunlight warms the surface and the surface warms the air above. As the air temperature near the ground increases, the lower atmosphere gradually becomes more unstable, with maximum instability usually occurring during the hottest part of the day. On a humid summer afternoon this phenomenon can be witnessed by the development of cumulus clouds.

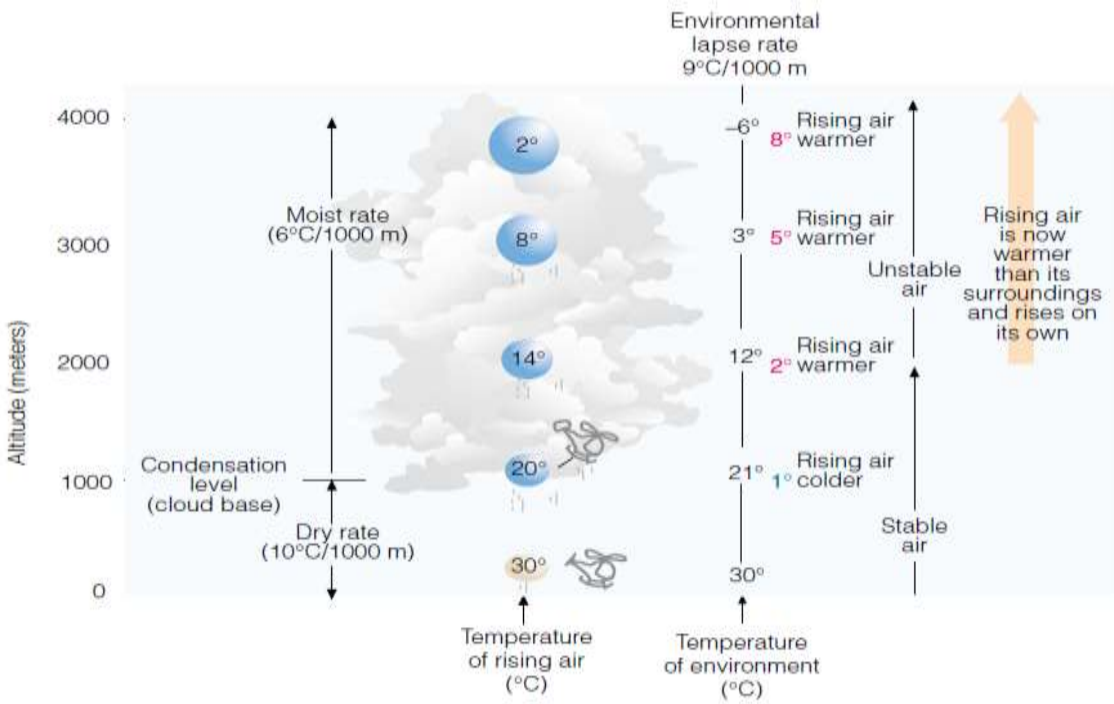
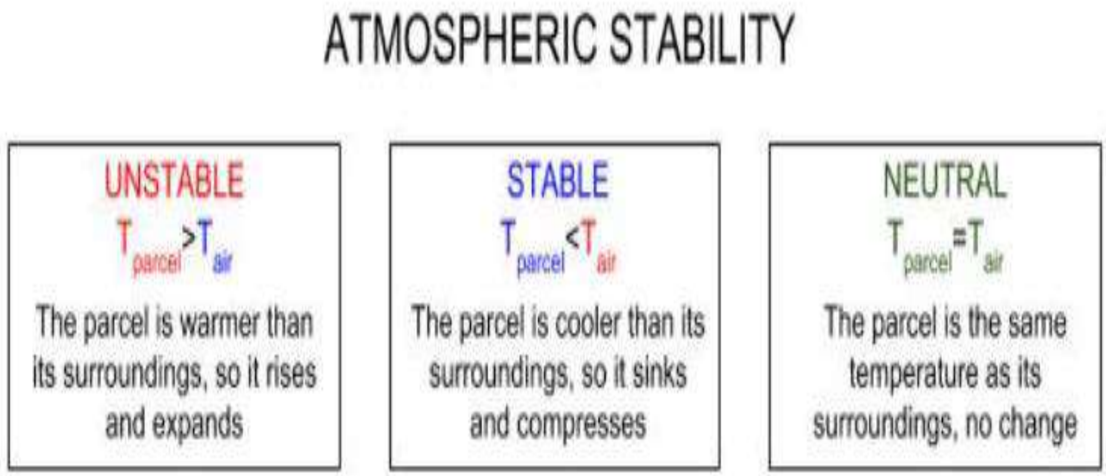


FIGURE.5. Conditionally unstable air. The atmosphere is conditionally unstable when unsaturated, stable air is lifted to a level where it becomes saturated and warmer than the air surrounding it. If the atmosphere remains unstable, vertical developing cumulus clouds can build to great heights.

Conclusion:

- The air temperature in a rising parcel of *unsaturated* air decreases at the dry adiabatic rate, whereas the air temperature in a rising parcel of *saturated* air decreases at the moist adiabatic rate.
- The dry adiabatic rate and moist adiabatic rate of cooling are different due to the fact that latent heat is released in a rising parcel of *saturated* air.
- In a *stable atmosphere*, a lifted parcel of air will be colder (heavier) than the air surrounding it. Because of this fact, the lifted parcel will tend to sink back to its original position.
- In an *unstable atmosphere*, a lifted parcel of air will be warmer (lighter) than the air surrounding it, and thus will continue to rise upward, away from its original position.
- The atmosphere becomes more stable (stabilizes) as the surface air cools, the air aloft warms, or a layer of air sinks (subsides) over a vast area.

- The atmosphere becomes more unstable (destabilizes)as the surface air warms, the air aloft cools, or a layer of air is lifted.
- Layered clouds tend to form in a stable atmosphere, whereas cumuliform clouds tend to form in a conditionally unstable atmosphere.



Reference : Essential of Meteorology by C. Donald Ahrens

Chapter 5/[**Cloud Development and Precipitation]**