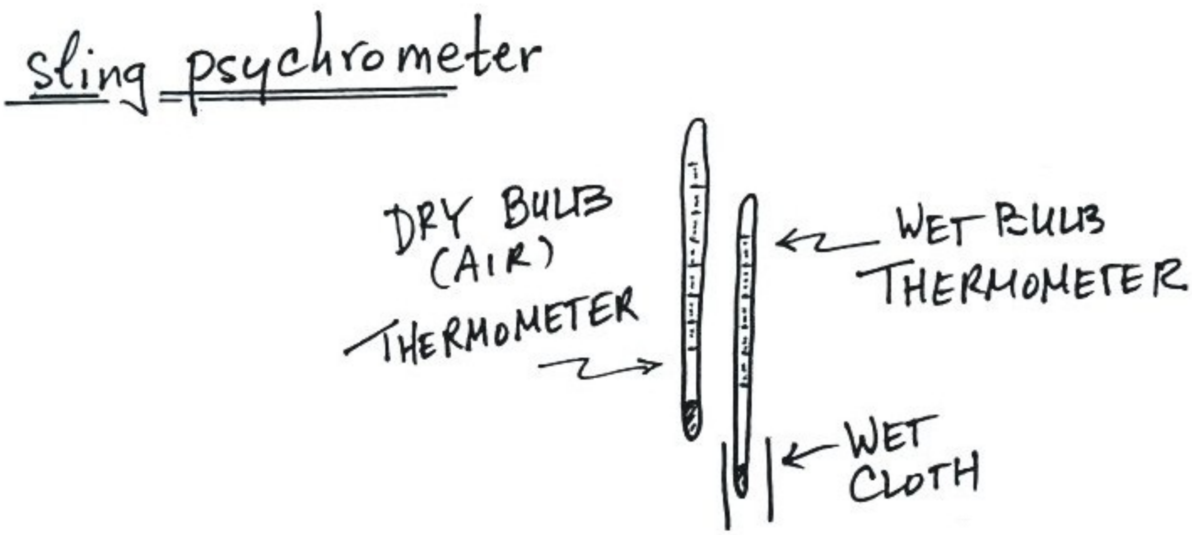
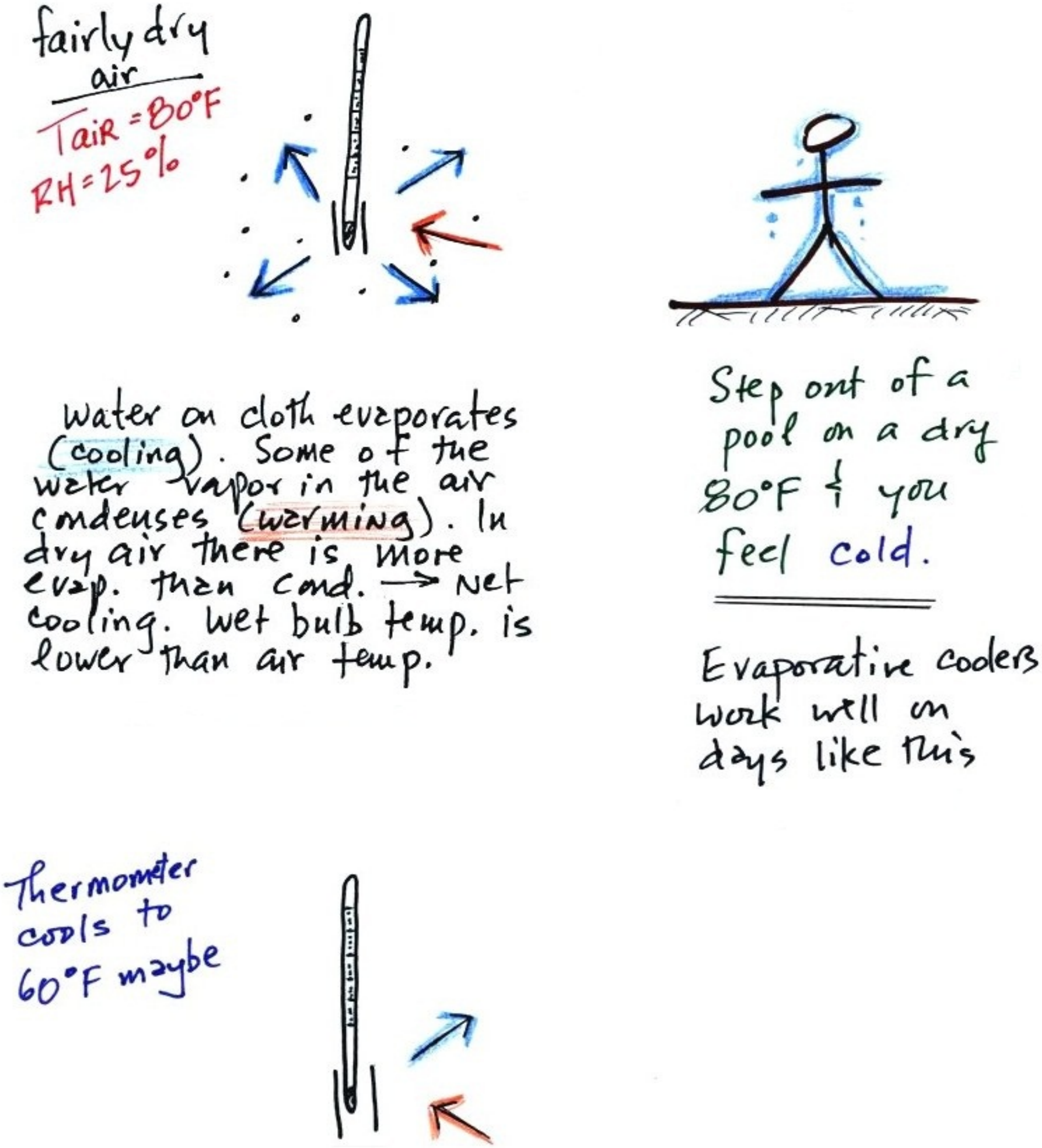
Module 7 - Lecture 21

One of the ways of measuring humidity is to use a sling psychrometer (swing might be more descriptive). A sling psychrometer consists of two thermometers mounted side by side. One is an ordinary thermometer and the other thermometer is covered with a wet piece of cloth (normally moistened with distilled water). To make a humidity measurement you swing the psychrometer around for a minute or two and then read the temperatures from the two thermometers. Measurements of the air temperature (dry bulb) and the dry-wet thermometer temperature difference (wet bulb depression) can be used to determine relative humidity and dew point. The wet thermometer will cool until the dew point temperature is reached.



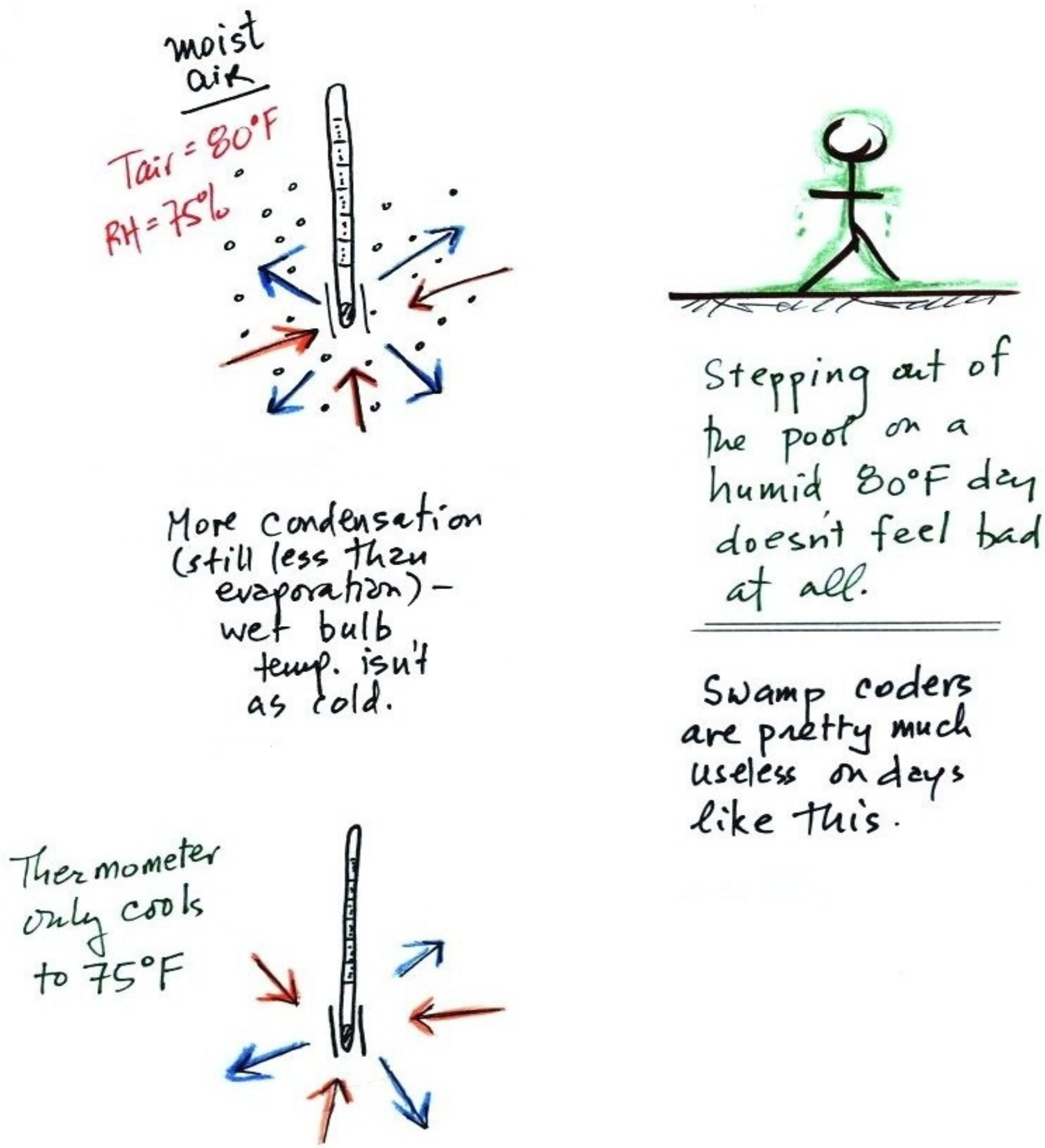
When you start to swing the wet bulb thermometer, water begins to evaporate from the wet piece of cloth, which is initially the same temperature as the dry bulb thermometer. Evaporation cools the thermometer, similar to the cold feeling you have when you step out of a swimming pool on a warm dry day. Evaporative coolers (swamp coolers) operate according to the same principle. Water also condenses upon the wet bulb thermometer. The condensation rate depends upon the concentration of water vapor in the air surrounding the thermometer. Condensation releases latent heat which warms the thermometer.

The figure below illustrates what happens to the wet bulb on a low relative humidity day. In this case, there is more evaporation (four arrows) than condensation (one arrow) and the wet bulb thermometer will drop. You would measure a large difference (20^0F) between the dry and wet bulb thermometers on a day when the air is relatively dry.

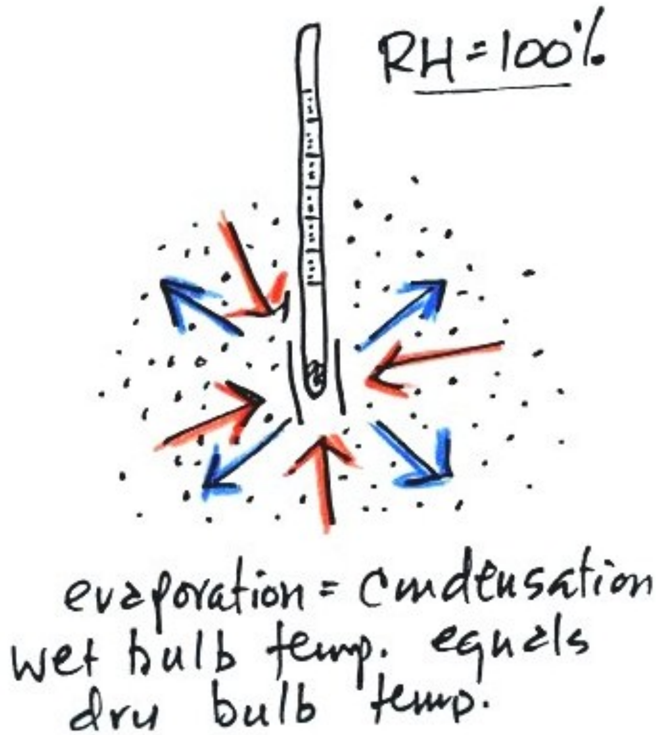


The next figure illustrates what happens on a day with high relative humidity. The air temperature is the same as the previous example, but there is a higher concentration of water vapor in the air. You would not feel as cold if you stepped out of a pool and swamp coolers will not provide much cooling on a warm humid day like this.

There are still four arrows of evaporation. Now there are three arrows of condensation instead of one arrow, which is due to the increased concentration of water vapor in the air surrounding the thermometer. The additional warming from the latent heat of condensation means that wet bulb thermometer will not become as cool as the previous example. The wet bulb temperature depression is now only 5^0F.



When the relative humidity is 100%, there is no difference between the wet bulb and dry bulb temperatures because the rates at which water is evaporating and water vapor is condensing are equal. The dry and wet bulb thermometers would both read 80^0F.



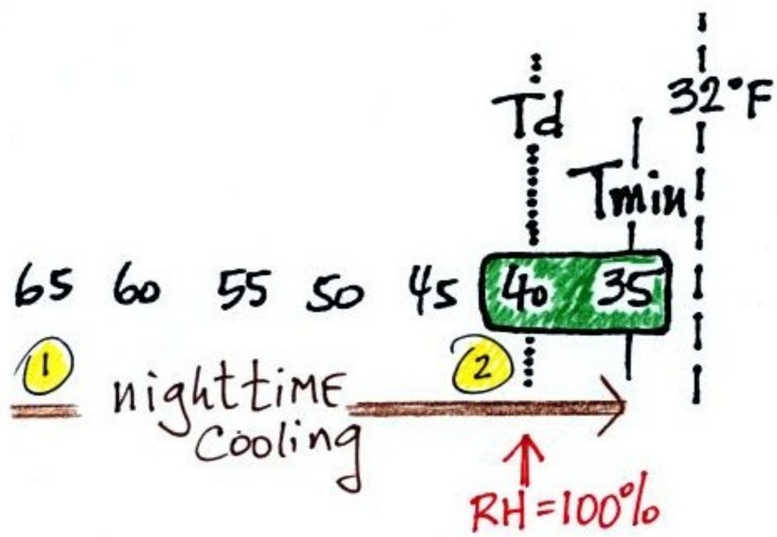
We learned about wind chill earlier in the course. A 40^0F day with 30 miles per hour winds will feel colder (because of increased transport of energy from your body by convection) than a 40^0F day with no wind. The wind chill temperature tells you how much colder it will feel.

Evaporative cooling will make you feel cold if you get out of a swimming pool on an 80^0F day with low relative humidity. You will feel less cold if the air is humid. Sling psychrometers make use of this phenomenon to measure relative humidity and dew point temperature.

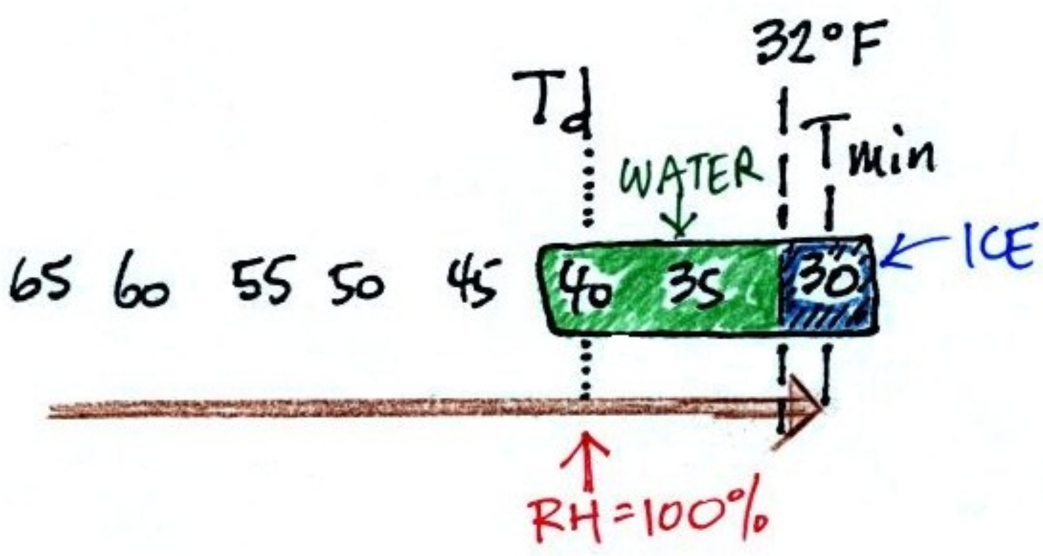
Your body tries to stay cool by perspiring. You will still feel warm on a hot, dry day but you will feel much warmer on a hot, humid day. The heat index measures how much hotter you'd feel on a hot humid day. The combination of heat and high humidity is a serious weather hazard because it can cause heatstroke (hyperthermia).

When moist air next to the ground is cooled below the dew point, the water vapor condenses into dew, frozen dew, and frost. People from the Midwest know how fun it is to scrape frost from their windshield on winter mornings. Frost can also form on the highway on winter mornings, creating slick driving conditions. In this section, we will start by looking at the different conditions that lead to the formation of dew and frost.

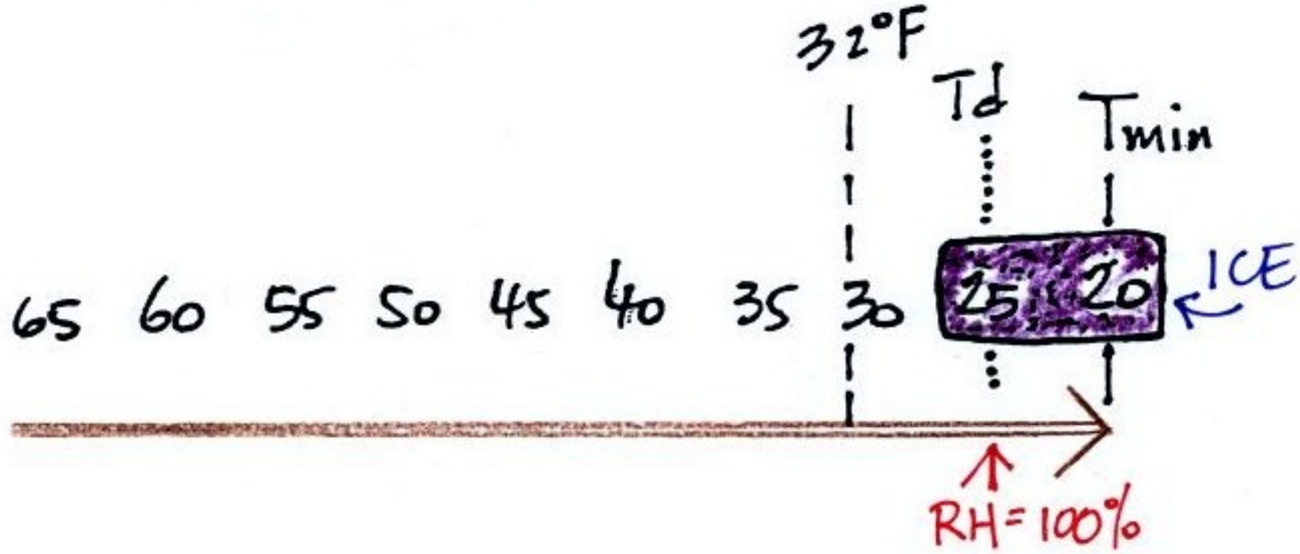
The picture below illustrates how dew is formed. In the early evening, the temperature of the air at ground level is 65^0F (Point 1). When the air temperature cools to the dew point (T_D) of 40^0F (Point 2), the relative humidity is now 100%. As the air temperature continues to cool, water vapor condenses onto the ground. The next morning you will find your newspaper and car covered with dew. The minimum temperature (T_{min}) is 35^0F.



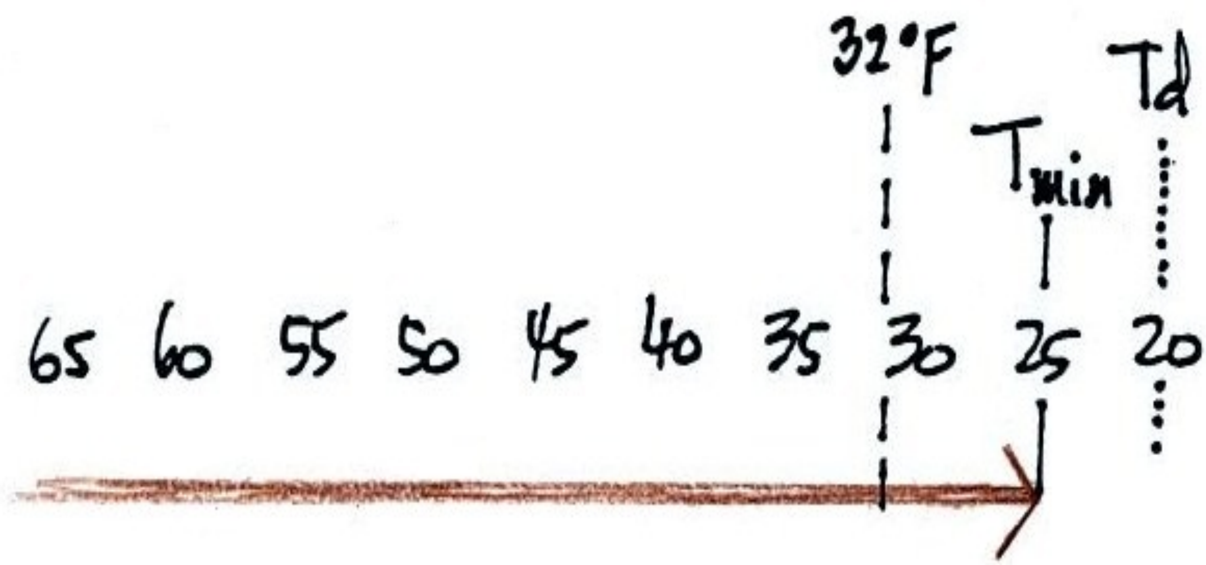
This night is similar except that the nighttime minimum temperature drops below freezing. Dew forms when the dew point temperature is reached. When the temperature drops below the freezing point of water (32^0F), the water freezes and turns to ice. This is frozen dew rather than frost. Frozen dew is often thicker and harder to scrape off your car windshield than frost.



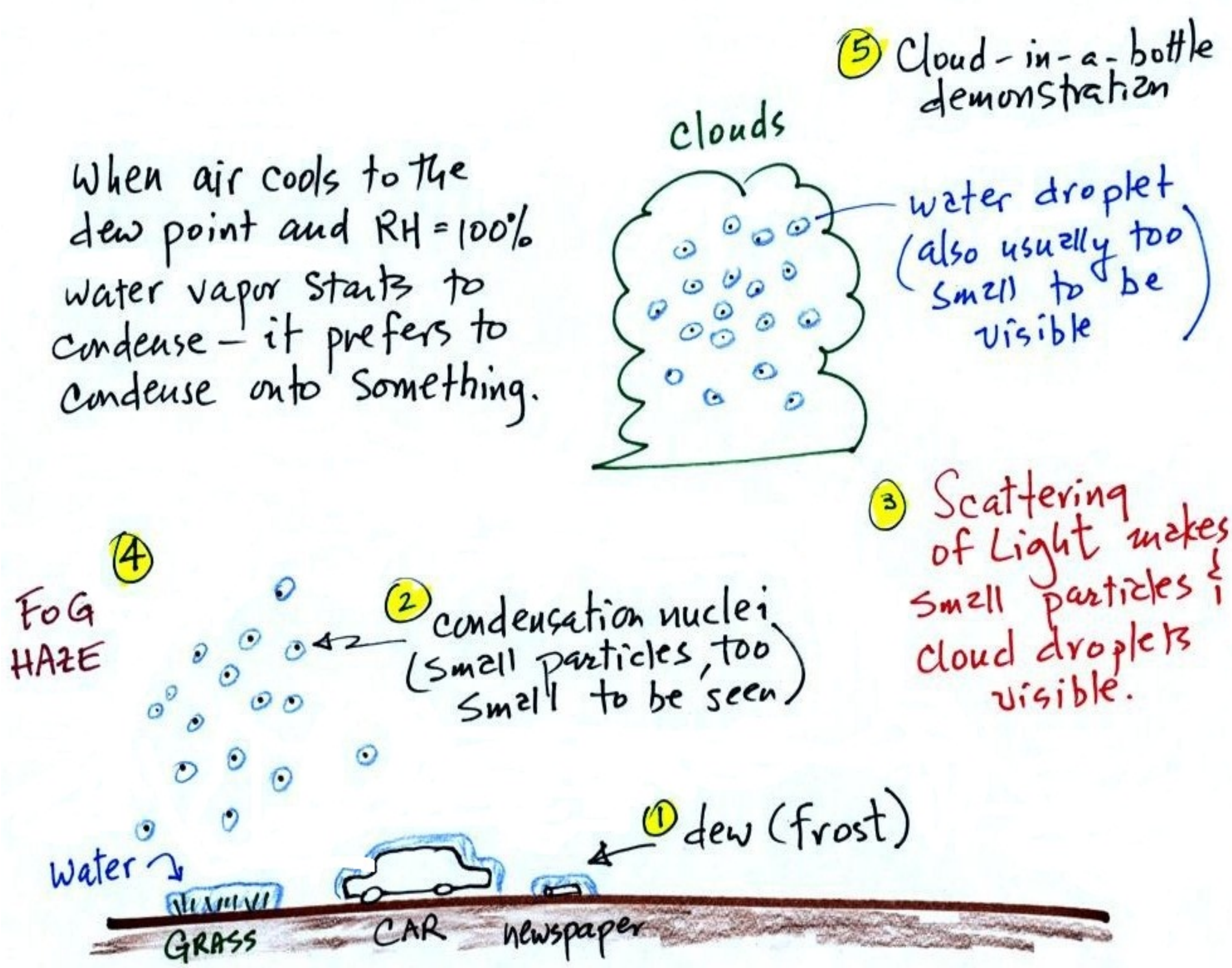
Now the dew point and the nighttime minimum temperature are both below freezing. When the relative humidity reaches 100%, the water vapor turns directly to ice (deposition). This is frost.



What happens on this night? The nighttime minimum temperature never reaches the dew point and the relative humidity never reaches 100%. No dew, frozen dew or frost forms.

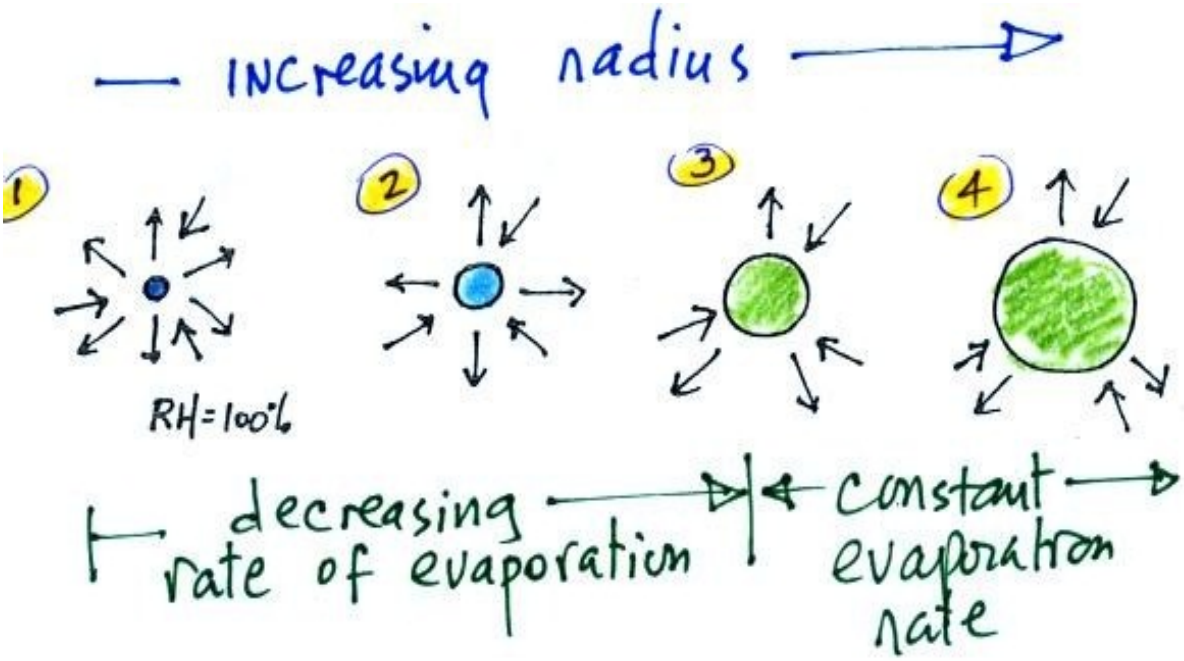


The picture below illustrates what happens when air is cooled to a temperature below the dew point temperature. When moist air near the ground is cooled below the dew point, water vapor condenses onto or is deposited onto the ground to form dew, frozen dew, and frost, as we discussed previously (Point 1). When air aloft is cooled to the dew point, water vapor condenses onto small airborne particles (condensation nuclei) and forms small water droplets (Point 2 below). Condensation nuclei are too small to be visible, but we can tell they are present because they either scatter light (Point 3), form haze or fog (Point 4) or form clouds which reflect sunlight (Point 5).

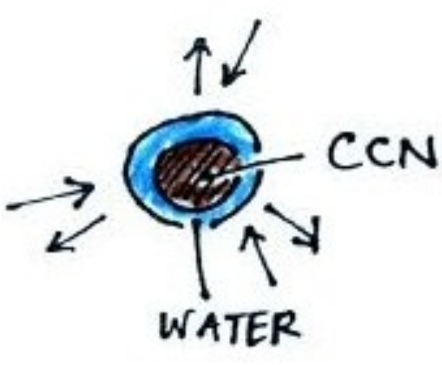


Condensation nuclei must be present for water droplets to form. Water vapor does not condense and form small droplets of pure water because very small droplets have an unusually high rate of evaporation. This is known at the curvature effect. Saturated air (relative humidity of 100%) is not able to supply enough condensation to offset the high rate of evaporation. If a small droplet suddenly forms it will quickly evaporate away.

The figure below shows four water droplets of varying radii. Note that the rates of condensation (three arrows) are equal in all four cases. The rate of condensation depends on the temperature and amount of moisture in the air surrounding each drop and is the same regardless of the droplet size. A very small droplet (Point 1) has a high rate of evaporation (six arrows of evaporation). The droplet at Point 2 is a little larger and the rate of evaporation has decreased to four arrows. But evaporation exceeds condensation for both droplets and they will quickly evaporate as soon as they are formed. If a water droplet is able to grow to a larger size through collisions with other water droplets (Point 3), the rate of evaporation has decreased to a point where it is balanced by an equal amount of condensation. The rate of evaporation will not decrease further if the droplet grows beyond this size (Point 4). The droplets at Points 3 and 4 are in equilibrium with their surroundings (equal rates of evaporation and condensation).



One way of avoiding the difficulty shown above is for water vapor to condense onto a small particle of some kind. In this case, you effectively start out with a larger droplet that does not have the high rate of evaporation found with very small droplets. The droplet shown below is in equilibrium with its surroundings. In this picture, CCN means cloud condensation nuclei.



Here are some basic characteristics of cloud condensation nuclei.

When air above the ground is cooled to or below the dew point, water vapor condenses onto small particles in the air called **condensation nuclei.**

cloud condensation nuclei

CCN characteristics:

0.1 µm or more in diameter — too small to be seen.

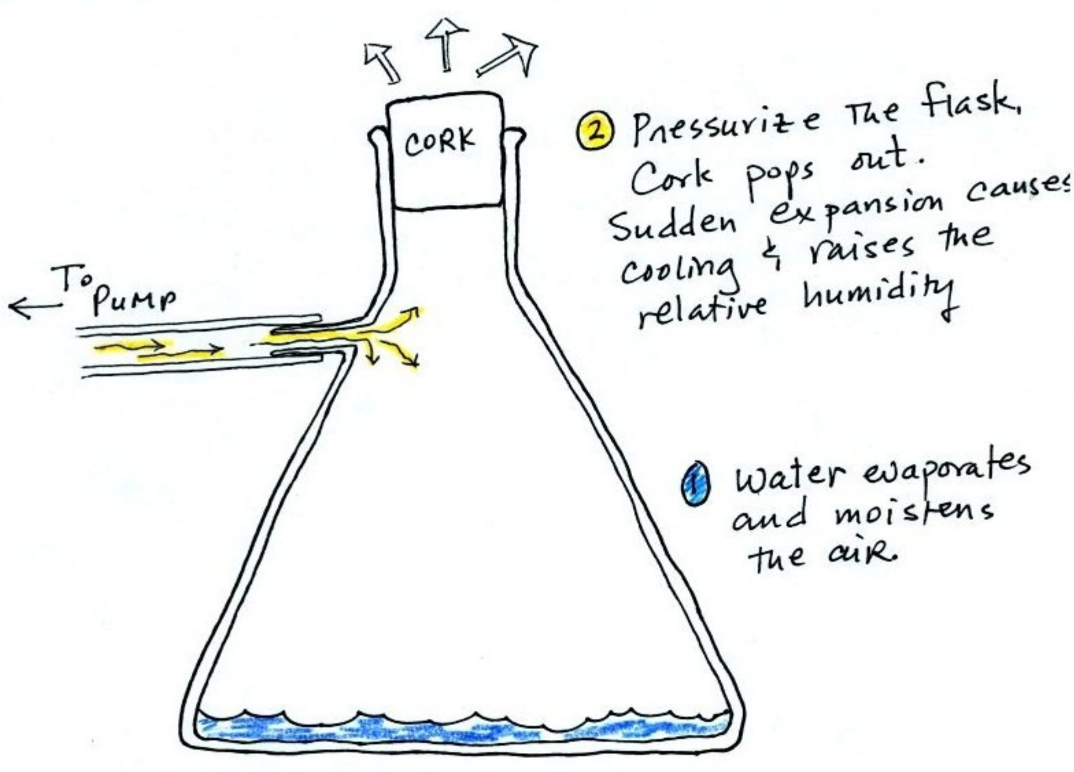
100s per cm^3 in clean air (Mt. Lemmon)

1000s per cm^3 in urban (polluted) air (Tucson)

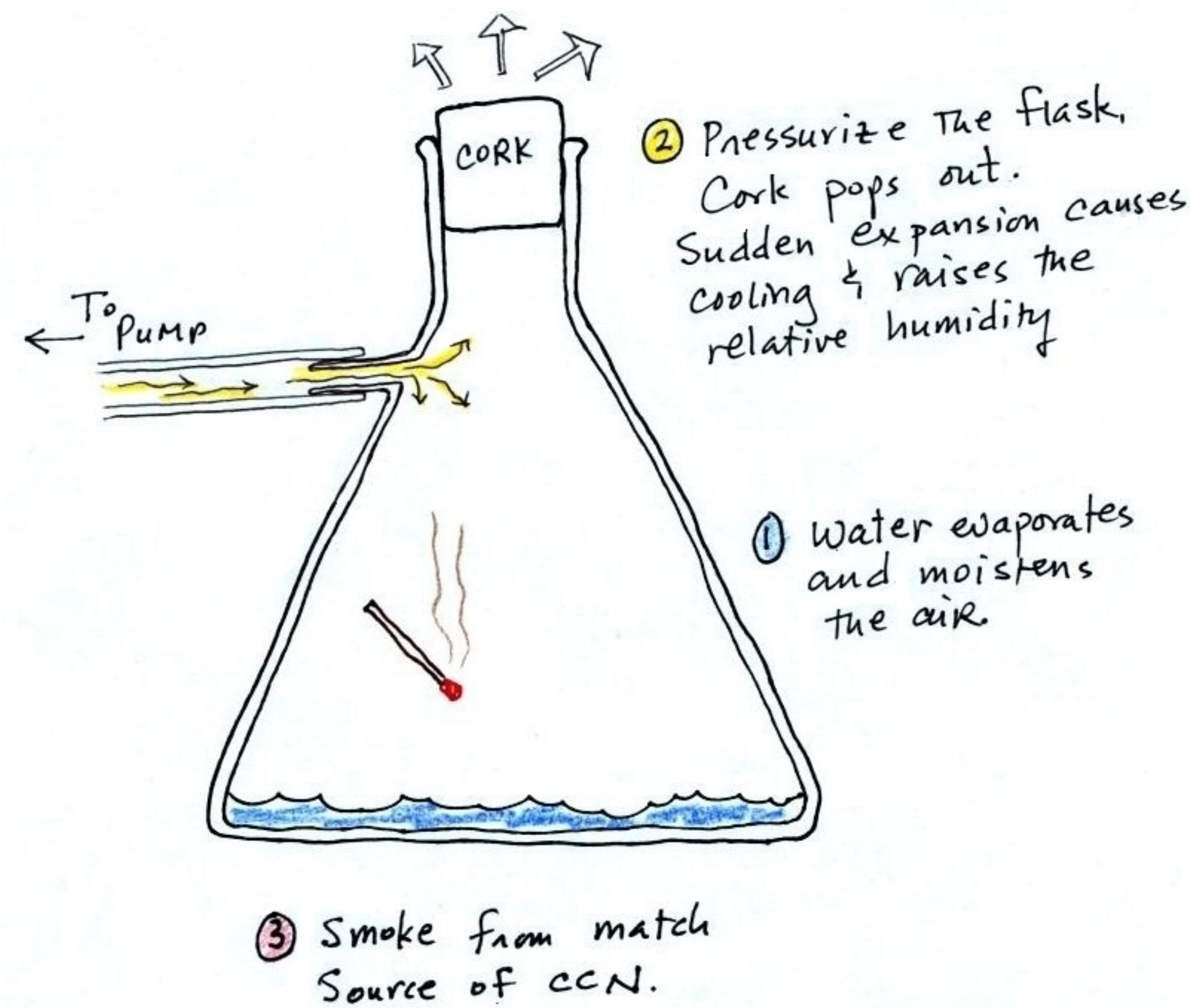
Condensation onto certain types of nuclei, **hygroscopic nuclei**, can begin to occur when the relative humidity is as low as 75%. An example is ordinary table salt.

salt particles in the air come from: the ocean.

In the classroom version of this course, we perform a demonstration that illustrates the importance of condensation nuclei for the cloud formation. We use a strong, thick-walled, four liter flask containing a small amount of water, which moistens the air in the flask (Point 1). We pressurize the air in the flask with a bicycle pump until the pressure blows the cork out of the top of the flask (Point 2). The air inside the flask expands outward and cools. The sudden cooling increases the relative humidity of the moist air in the flask to 100%. Water vapor condenses onto condensation nuclei and a faint cloud became visible. The cloud droplets are too small to be seen with the human eye. You can see the cloud because the water droplets scatter light.

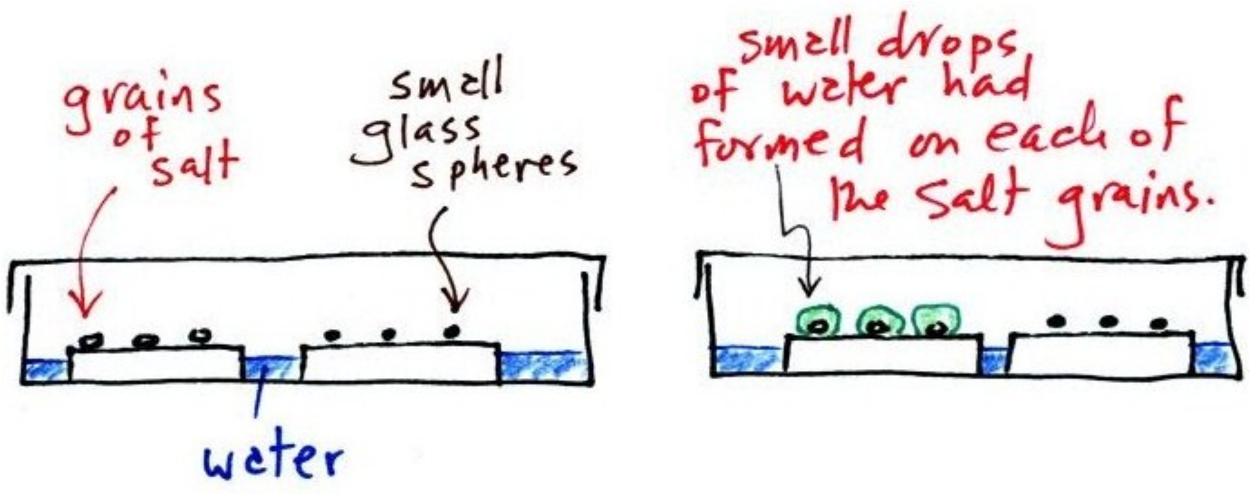


The demonstration is repeated again and this time a burning match is dropped into the bottle (Point 3). The smoke from the match adds lots of condensation nuclei to the air in the flask. This time a much bigger cloud is formed



Small droplets can also form on condensation nuclei particles that dissolve in the water. The rate of evaporation from the resulting water solution is less than that of pure water. This is known as the solute effect. Because of the solute effect, it is possible for droplets to form when the relative humidity is less than 100%. Condensation nuclei that allow this to happen are called hygroscopic nuclei. In humid parts of the US, water will condense onto the grains of salt in a salt shaker causing them to stick together. Grains of rice absorb moisture which keeps this from happening and allows the salt to flow freely out of the shaker when needed.

In the classroom version of this course we show a short video that demonstrates how water vapor preferentially condenses onto small grains of salt rather than small spheres of glass. At the start of the demonstration (left figure below), small grains of salt (soluble in water) are placed on a platform in a Petri dish containing water. Small spheres of glass (insoluble) are placed in the same Petri dish. After about 1 hour (below right), small drops of water form around each grain of salt but not the glass spheres.

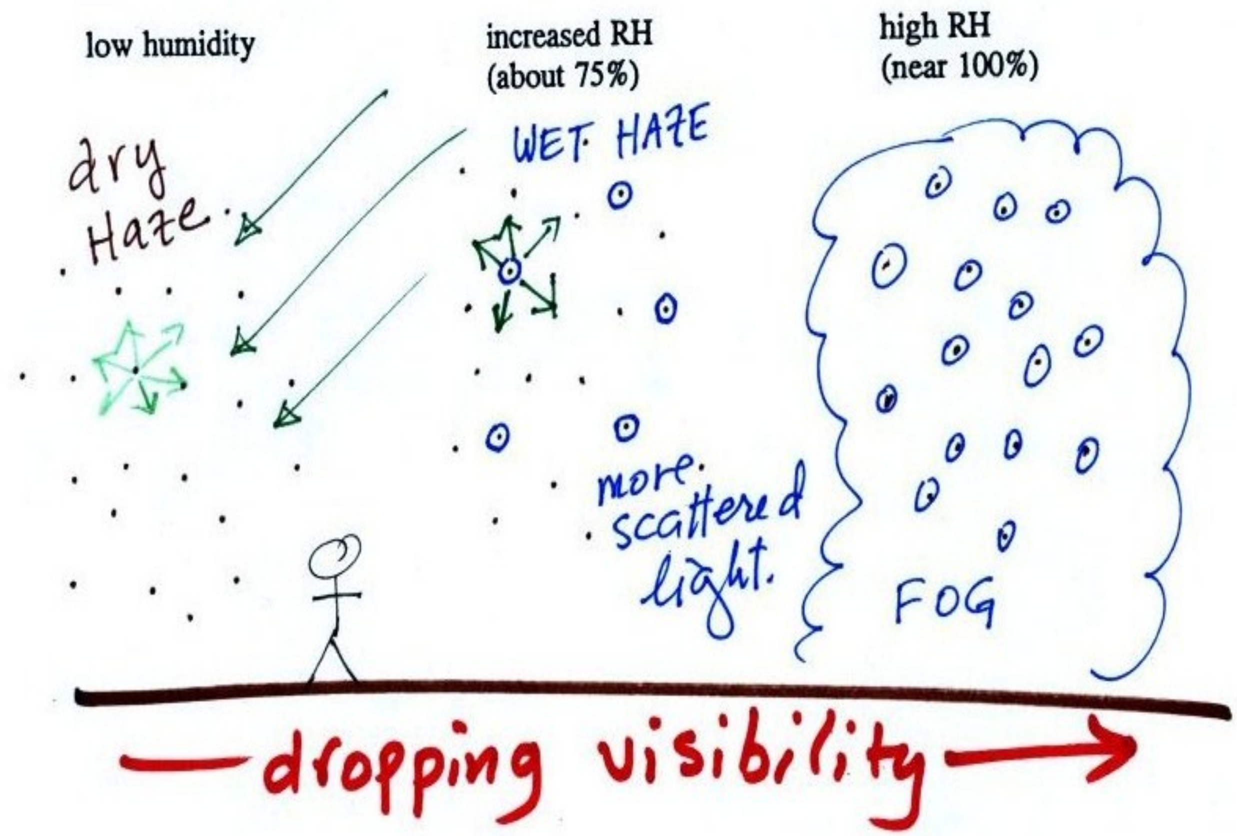


Condensation nuclei are too small to be seen by the human eye, but you know they are present because they scatter sunlight. The size of condensation nuclei is influenced by the amount of water vapor in the air. At high relative humidity, condensation nuclei absorb water vapor and grow to a size that scatters more sunlight. Nitrogen and oxygen molecules also scatter sunlight, which is why the sky appears blue.

The figure below shows how cloud condensation nuclei and relative humidity can affect the appearance of the sky and visibility. When the relative humidity is low (left picture), the deep blue color of the sky is mixed together with white sunlight scattered by the condensation nuclei. This changes the color of the sky from a deep blue to a bluish white color. The higher the condensation nuclei concentration, the whiter the sky becomes. This is called "dry haze."

The middle picture shows what happens in more humid regions of the country. Because the relative humidity is high, water vapor begins to condense onto some of the condensation nuclei particles (the hygroscopic nuclei) in the air and forms small water droplets. The water droplets scatter more sunlight than just small particles alone. The increase in the amount of scattered light is what gives the air its hazier appearance. This is called "wet haze."

Finally when the relative humidity increases to 100%, fog forms. Fog can cause a severe drop in the visibility. The thickest fog forms in dirty air that contains lots of condensation nuclei.



To produce fog you first need to increase the relative humidity (RH) to 100%. You can do this either by cooling the air (radiation fog) or adding moisture to and saturating the air (evaporation or steam fog). Both will increase the ratio in the relative humidity formula below.

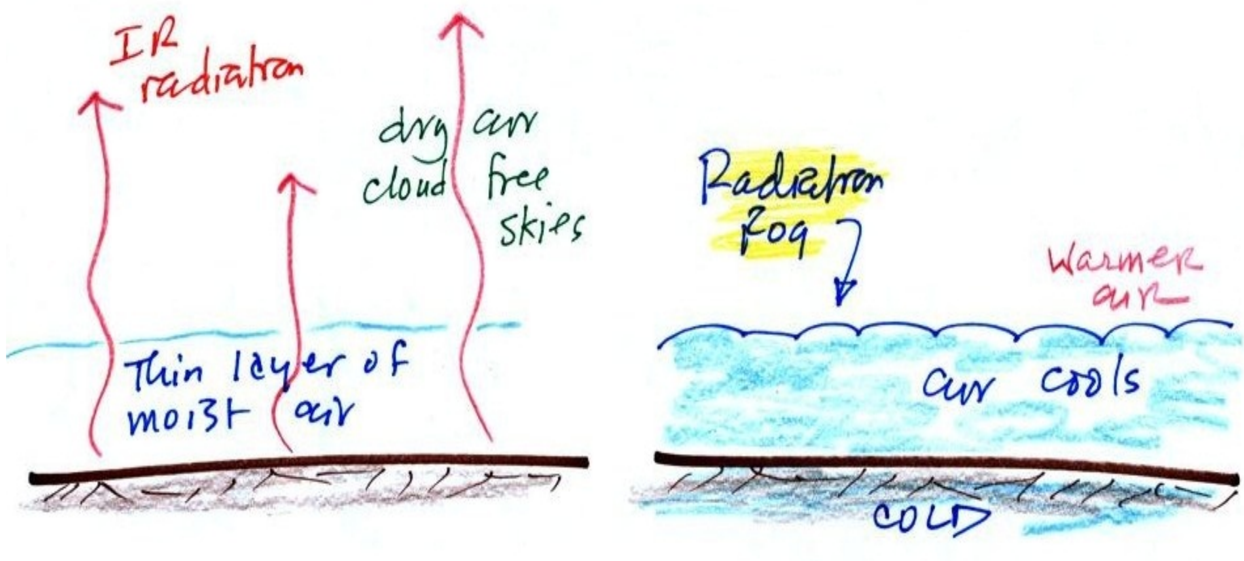
Fog (kinds you might see in Tucson)

$$RH = 100\% \times \frac{r}{r_s}$$

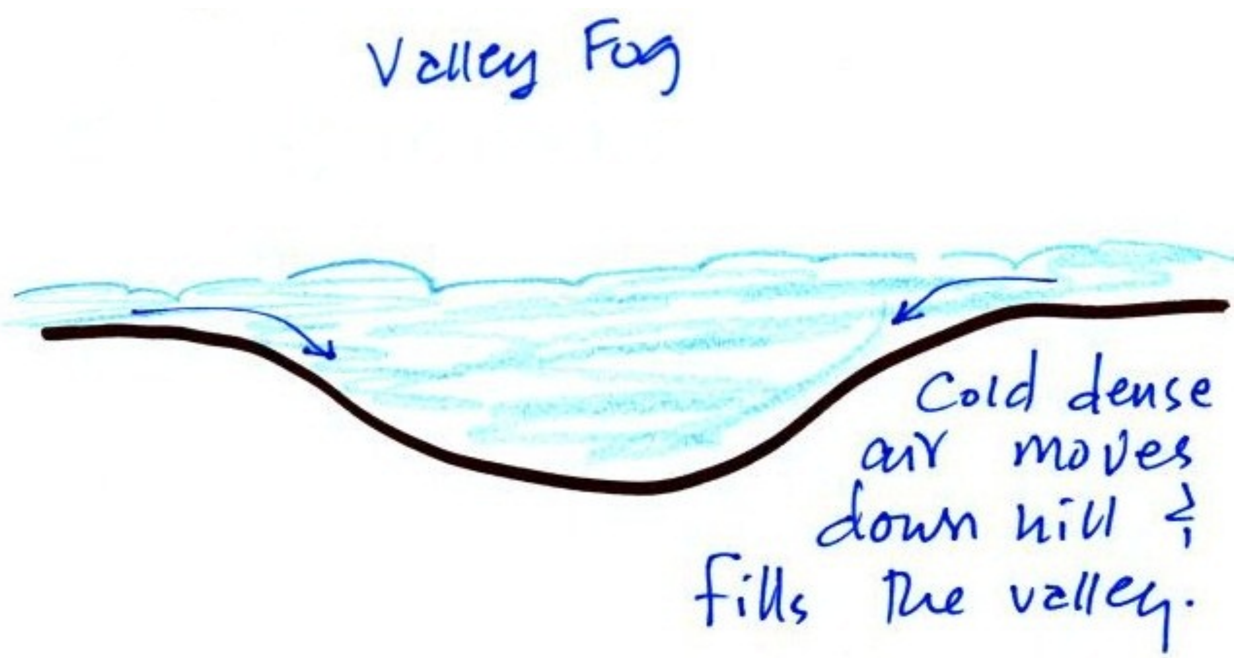
add moisture to air

cool the air

Probably the most common type of fog in Tucson is **radiation fog**. The ground cools during the night by emitting infrared radiation (left figure below). The ground cools the most rapidly and becomes the coldest when the skies are free of clouds and the air is dry except for a thin layer near the ground. Air in contact with the ground cools and radiation fog can form (right figure above. Because the fog cloud is colder than the air right above, the fog clouds "hug" the ground.



Valley fog is a kind of radiation fog that occurs when the cold, dense foggy air moves downhill and fills low lying areas. Because the fog reflects sunlight, it is often difficult for the sun to warm the air and dissipate thick clouds of valley fog.



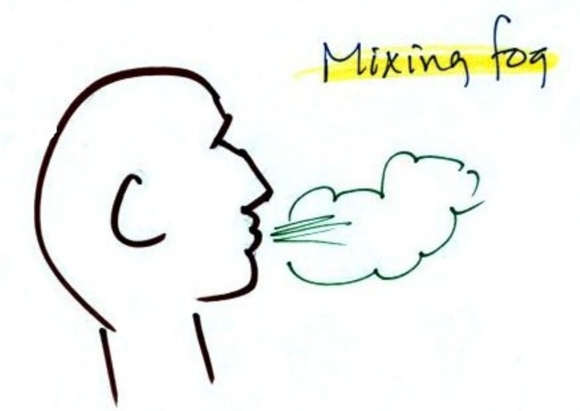
Valley fog in Tucson: this picture was taken from the Catalina Highway on the way up to Mount Lemon.

<u>Steam fog or evaporation fog</u> (also sometimes known as mixing fog) is commonly observed on cold mornings over the relatively warm water in a swimming pool. Water evaporating from the pool saturates the cold air above. Because the fog cloud is warmer than the cold surrounding air, the fog clouds float upward.

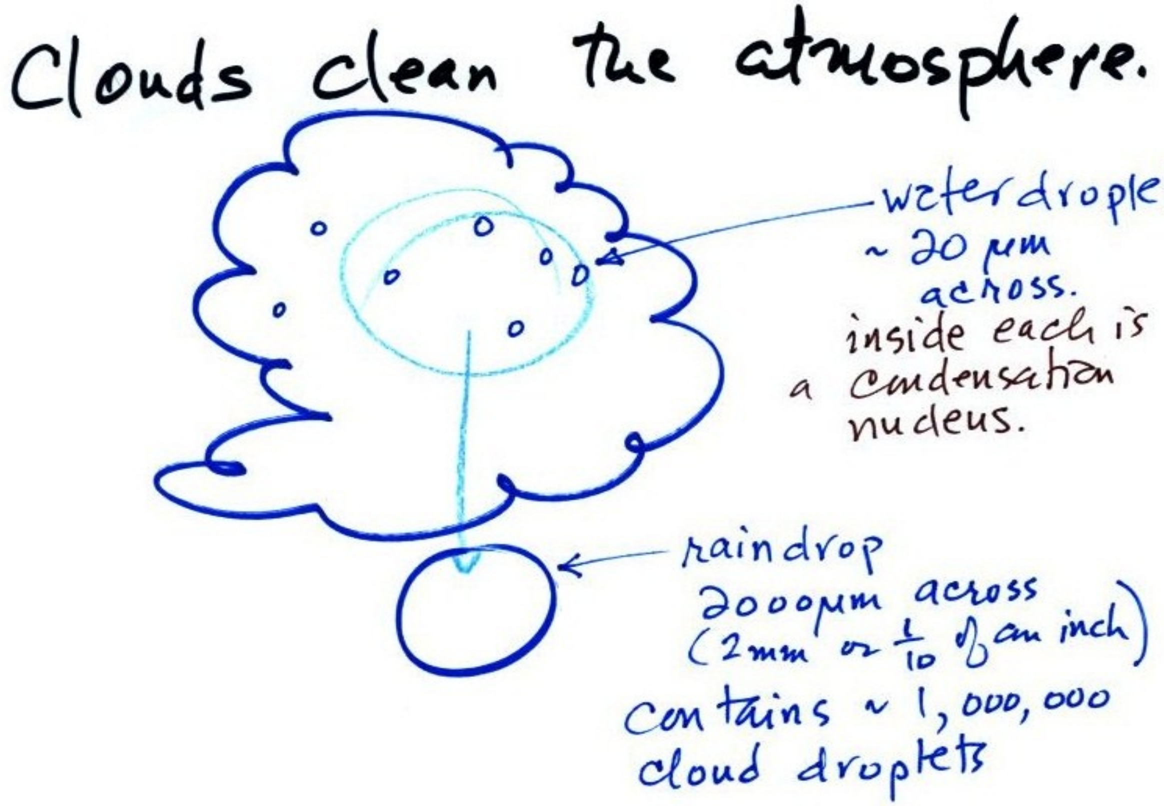
Advection fog occurs when the wind blows moist air over a cool surface, such as when warm inland air blows over a cool ocean. This is a common phenomenon in California because of the cold ocean currents. The picture below shows advection fog in Santa Barbara, California.

Advection fog also occurs in the Great Lakes during the spring and early summer, when the air is warm but the water is still fairly cold. Here is advection fog at the Wind Point Lighthouse in Wind Point, Wisconsin near the Illinois/Wisconsin border.

When you "see your breath" on a cold day you are seeing **mixing fog**. Warm moist air from your mouth mixes with the colder air outside. The mixture is saturated and a fog cloud forms.



Clouds are one of the best ways of cleaning the atmosphere. Cloud droplets form on particles, the droplets "clump" together to form a raindrop, and the raindrop carries the particles to the ground. A raindrop can contain 1 million cloud droplets so a single raindrop can remove a lot of particles from the air. You may have noticed how clear the air seems the day after a rainstorm; distant mountains are crystal clear and the sky has a deep blue color. Gaseous pollutants also dissolve in the water droplets and are carried to the ground by rainfall.



A cloud that forms in polluted air (below right) is composed of a large number of small droplets and is more reflective than a cloud that forms in clean air (below left). Similar to the cloud-in-a-bottle demonstration, the cloud that was created when the air was full of smoke particles is much more visible than the cloud made with cleaner air. This is called the **Twomey Effect** and is named after the University of Arizona professor who discovered it.

The Twomey Effect has implications for climate change. The combustion of fossil fuels adds carbon dioxide to the atmosphere. There is concern that increasing carbon dioxide concentrations will enhance the greenhouse effect and cause global warming. Combustion also adds condensation nuclei to the atmosphere, just like the burning match added smoke to the air in the flask. More condensation nuclei could make it easier for clouds to form, make clouds more reflective, and increase the amount of cooling from clouds. There is still quite a bit of uncertainty about how clouds might change and how this might affect climate (remember too that clouds are good absorbers of infrared radiation).

Climate change: burning fossil fuels → add CO_2 to the atmosphere — WARMING

→ add condensation nuclei (smoke) to the air. Clouds that form in this dirtier air might be more reflective — cooling