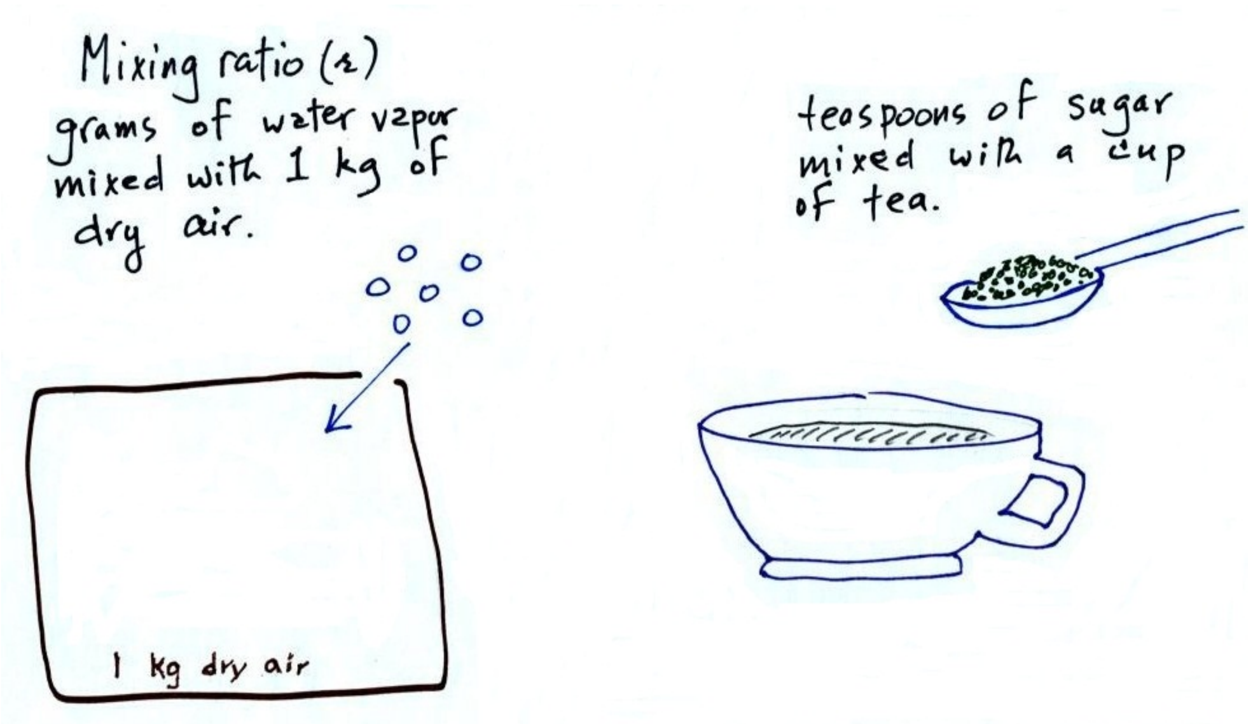
Module 7 - Lecture 19

The module is an introduction to an important new topic: humidity or the moisture in the air. This topic and the terms that we will be learning can be confusing. We will mainly be interested in four variables: mixing ratio, saturation mixing ratio, relative humidity, and dew point temperature. Our first job will be to figure out what these terms mean and how they are used. Then we will learn what causes these values to change.

The **mixing ratio** tells you how much water vapor is **actually** in the air. Mixing ratio has units of grams of water vapor per kilogram of dry air (the amount of water vapor in grams mixed with a kilogram of dry air). It is basically the same idea as teaspoons of sugar mixed in a cup of tea.



The value of the mixing ratio will not change unless you add water vapor to the air or remove water vapor from the air. Warming the air will not change the mixing ratio. Cooling the air will not change the mixing ratio unless the air is cooled below its dew point temperature and water vapor starts to condense. Because it is the "job" of the mixing ratio to tell you how much water vapor is contained in the air, it will not change unless water vapor is actually added to or removed from the air.

it's job

Mixing ratio (r) - one of many ways of specifying how much water vapor is actually in the air.

Just a number ---> big means lots of water vapor
small means not as much

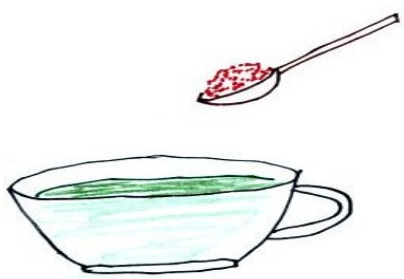
good

This number is not affected by changes in the air's temperature or pressure. Only changes value when you add or remove water vapor.

Analogy: actual number of students in a classroom

The **saturation mixing ratio** is an upper limit to how much water vapor can be found in air or the air's **capacity** for water vapor. It is a property of air and says nothing about how much water vapor is actually contained in the air (that is the mixing ratio's job). Warm air can potentially hold more water vapor than cold air. This variable has the same units: grams of water vapor per kilogram of dry air. You can look up saturation mixing ratio values for different air temperatures in a table.

There is a limit to how much sugar can be dissolved in a cup of hot water. You can dissolve more sugar in hot water than in cold water. The same reasoning applies to water vapor contained in air.



There's an upper limit

You can add 1 tsp of sugar to a cup of tea. It would dissolve.

You couldn't dissolve 10 tsp.

You can dissolve more sugar in hot water than in cold water.

The upper limit depends on temperature

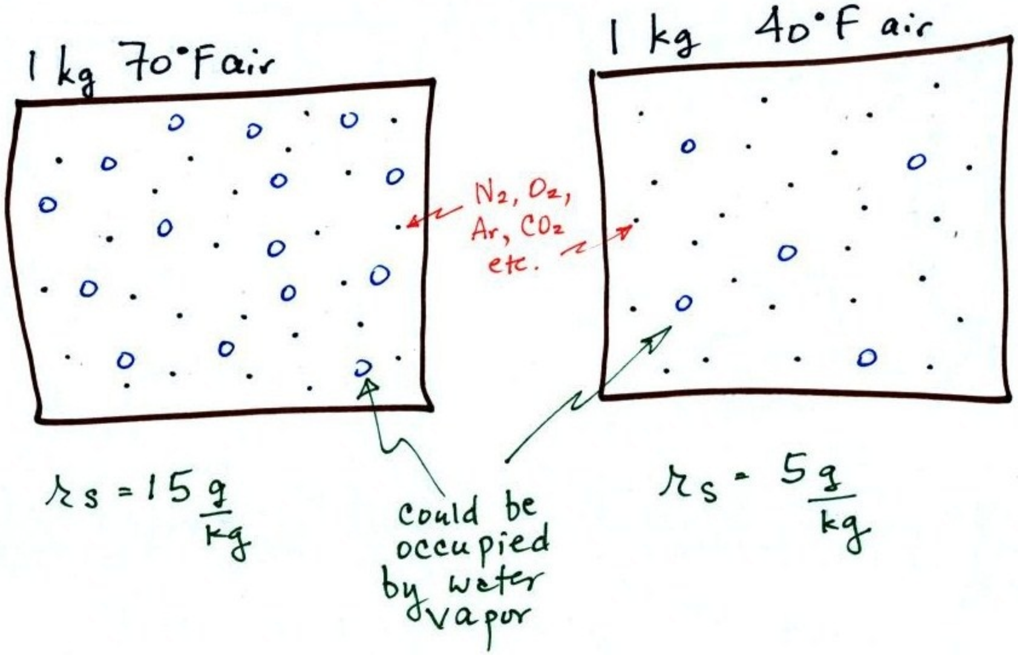
air's capacity for water vapor

Saturation mixing ratio (r_S) - the maximum amount of water vapor that can be found in air.

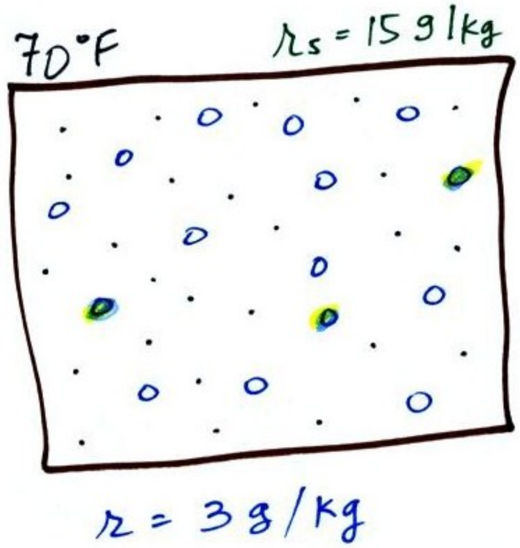
Depends on the air's temperature. Warm air can potentially hold much more water vapor than cold air.

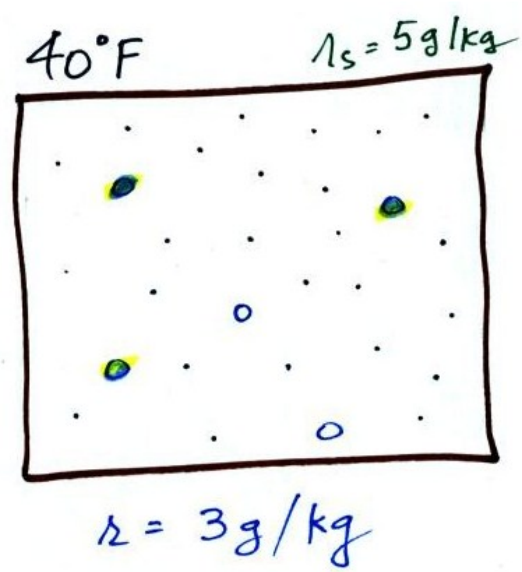
Analogy: number of seats in a classroom

The dependence of saturation mixing ratio on air temperature is illustrated below. The small specks represent all of the gases in air except for the water vapor. Each of the open circles represents 1 gram of water vapor that the air could potentially hold. There are 15 open circles drawn in 1 kg of 70^{0}F air; each 1 kg of 70^{0}F air could hold up to 15 grams of water vapor. The 40^{0}F air only has 5 open circles; the cooler air can only hold up to 5 grams of water vapor per kilogram of dry air.

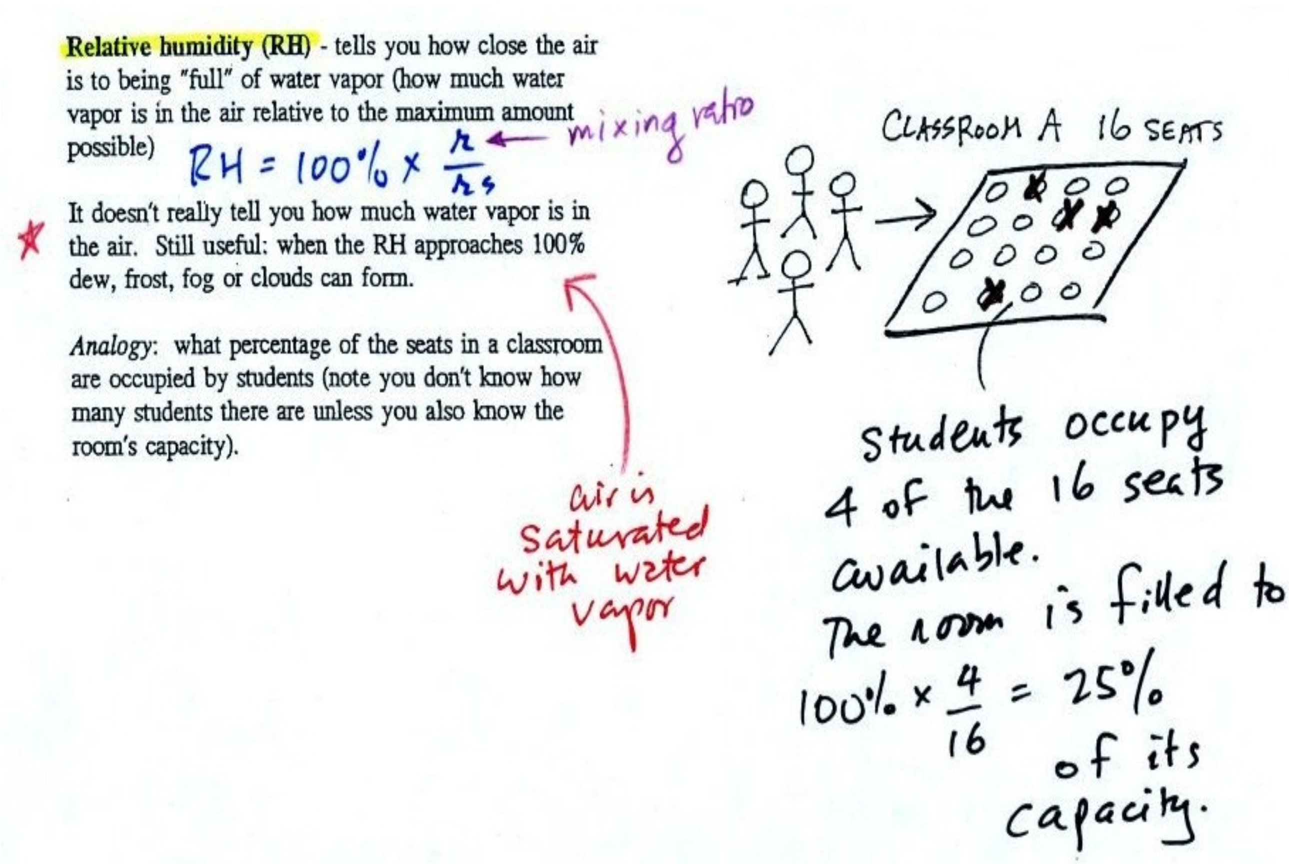


Now we have put some water vapor into the volumes of 70^0F and 40^0F air. Three of the open circles are now colored in. The same amount, 3 grams of water vapor, has been added to each volume of air. The mixing ratio, r, is 3 g/kg in both cases.



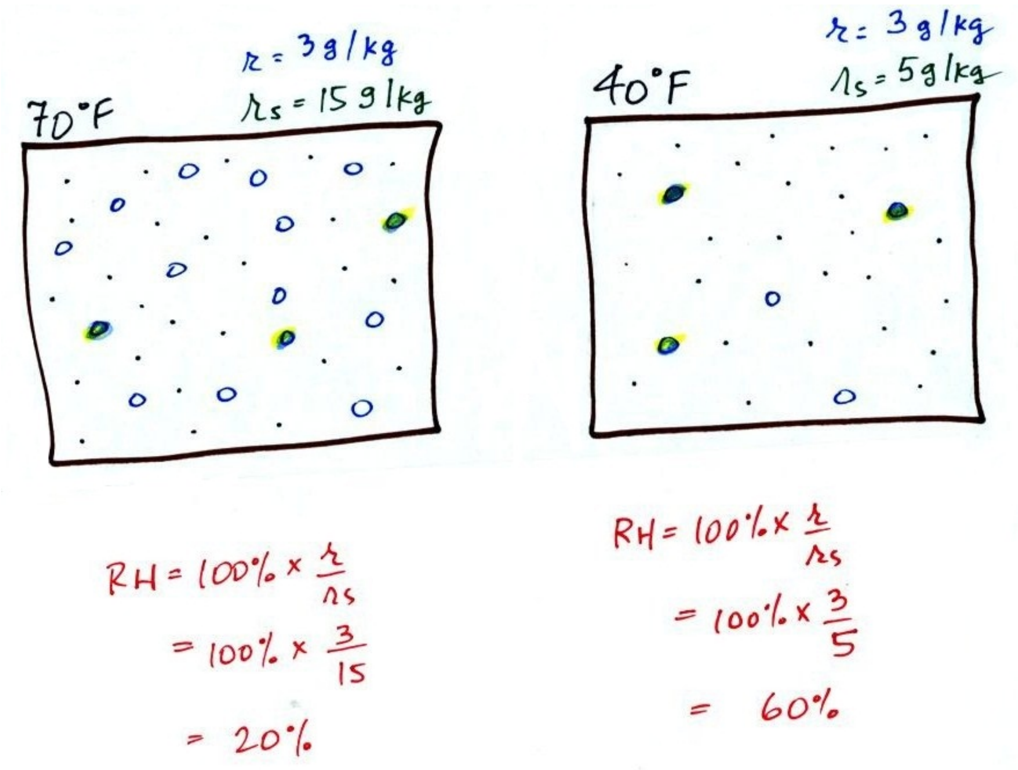


Relative humidity is the variable most people are familiar with. It tells you how "full" the air is with water vapor or how close it is to being filled to capacity with water vapor. Four students wander into Classroom A which has 16 empty seats. The classroom capacity is analogous to the saturation mixing ratio. Classroom A is filled to 25% of its capacity. You can think of four, the number of students, as being analogous to the mixing ratio. The percentage occupancy is analogous to the relative humidity.



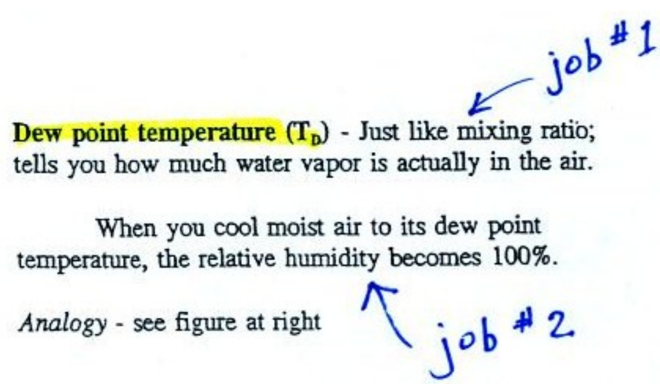
Instead of students and a classroom, you can think of air as having the potential to hold a certain amount of water vapor depending upon the temperature. At 70^0F, the air can hold a maximum of 15 grams of water and at 40^0F 5 grams. Imagine that air at both 70^0F and 40^0F each contain 3 grams of water vapor. The 70^0F air has a low relative humidity because the saturation mixing ratio at this temperature is large. The relative humidity at 40^0F is higher even though it has the same actual amount of water vapor because it is closer to being saturated.

Something important to note: **relative humidity does not tell you how much water vapor is actually in the air**. The two volumes of air below contain the same amount of water vapor (3 grams per kilogram) but have different relative humidity. You can have two volumes of air with the same relative humidity but different actual amounts of water vapor.



The **dew point temperature** has two jobs.

- It gives you an idea of the actual amount of water vapor in the air. In this respect it is just like the mixing ratio. If the dew point temperature is low, the air contains less water vapor. If it is high the air contains more water vapor.
- The dew point tells you how much you must cool the air in order to cause the relative humidity to increase to 100%, at which point a cloud, or dew or frost, or fog would form.


Dew point temperature (T_D) - Just like mixing ratio; tells you how much water vapor is actually in the air.

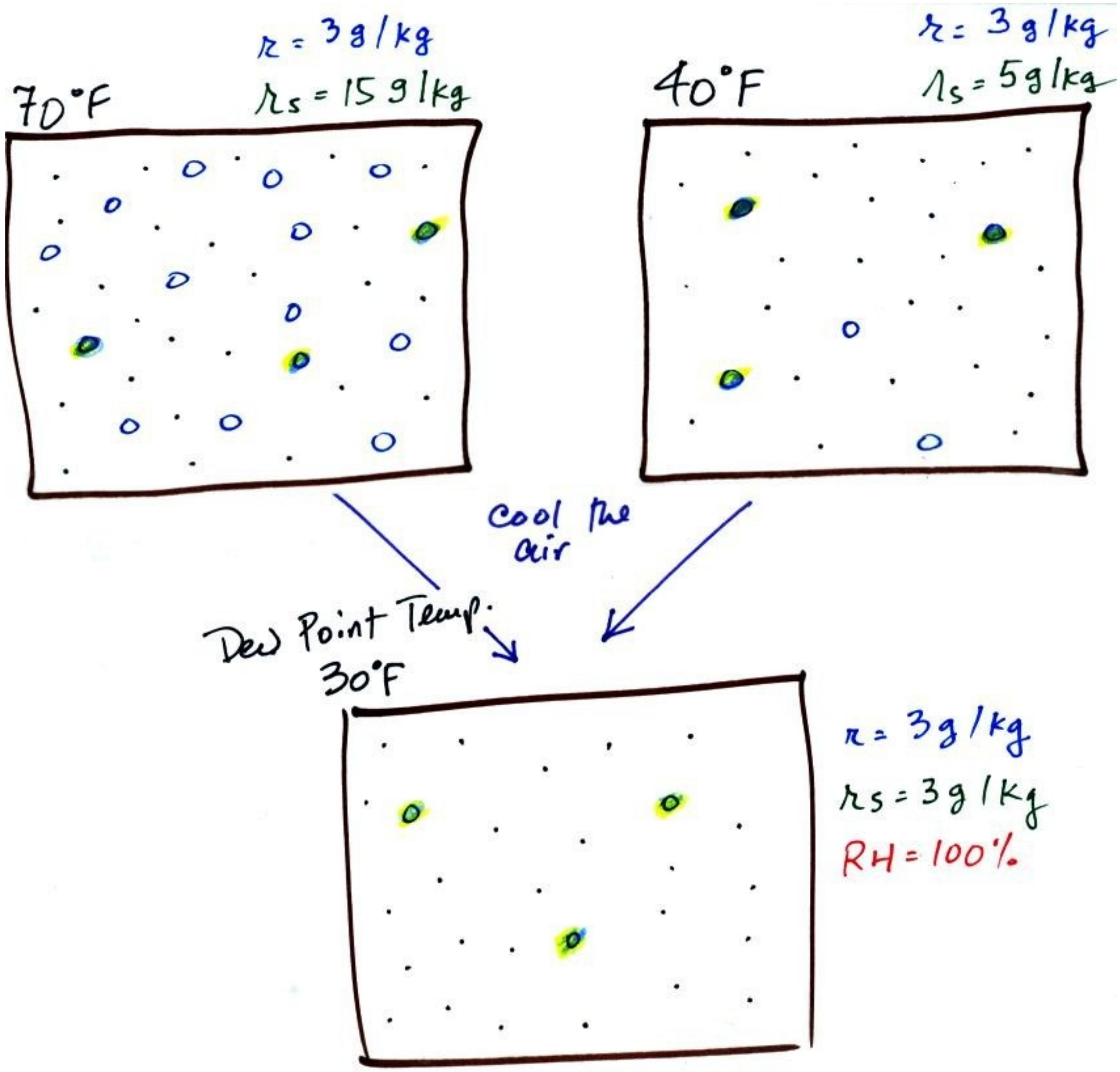
When you cool moist air to its dew point temperature, the relative humidity becomes 100%.

Analogy - see figure at right

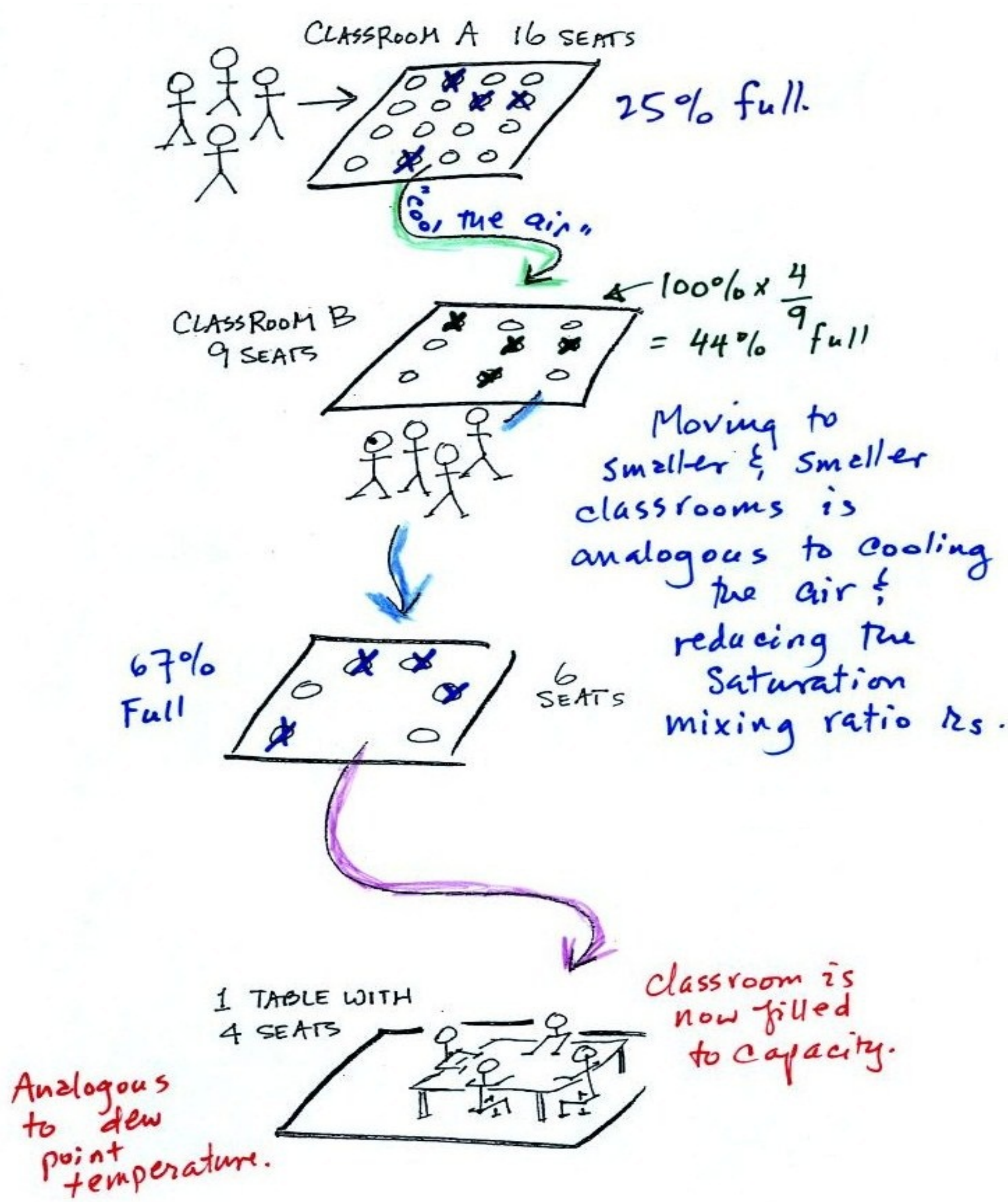
job # 1

job # 2

Let us use the previous example to illustrate the concept of dew point. We have air parcels (a balloon of air) at 70^0F and 40^0F each containing 3 grams of water vapor. Now we will cool each parcel to the temperature at which the actual water vapor concentration is equal to the saturation mixing ratio. At 30^0F, the saturation mixing ratio is equal to 3 grams per kilogram of dry air. At this temperature, water vapor in both samples would begin to condense into liquid. 30^0F is the dew point temperature of both air samples.

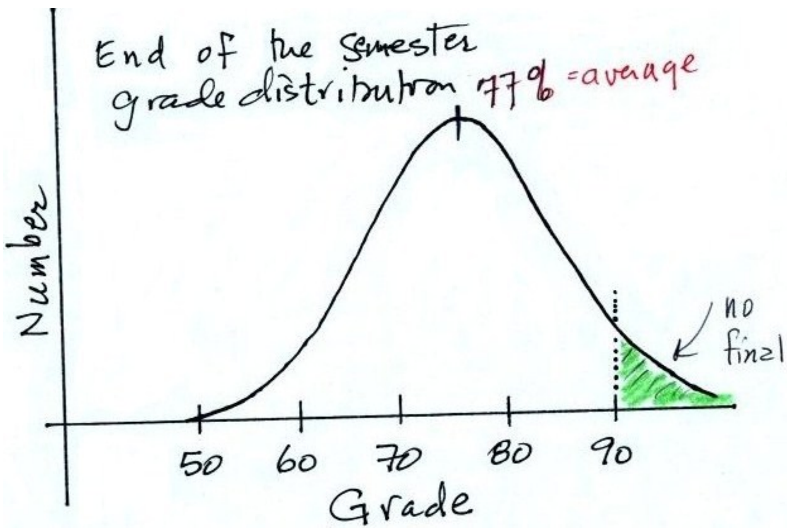


Now we will return to the analogy involving students and classrooms. The four students move into classrooms with smaller and smaller capacities. The decreasing capacity of the classrooms is analogous to the decrease in the saturation mixing ratio that occurs when you cool air. Eventually the students move into a classroom that they just fill to capacity. This is analogous to cooling the air to the dew point. If the four students were to move to an even smaller classroom, they would not all fit inside. The same is true of moist air. If you cool moist air below the dew point, some of the water vapor will condense.

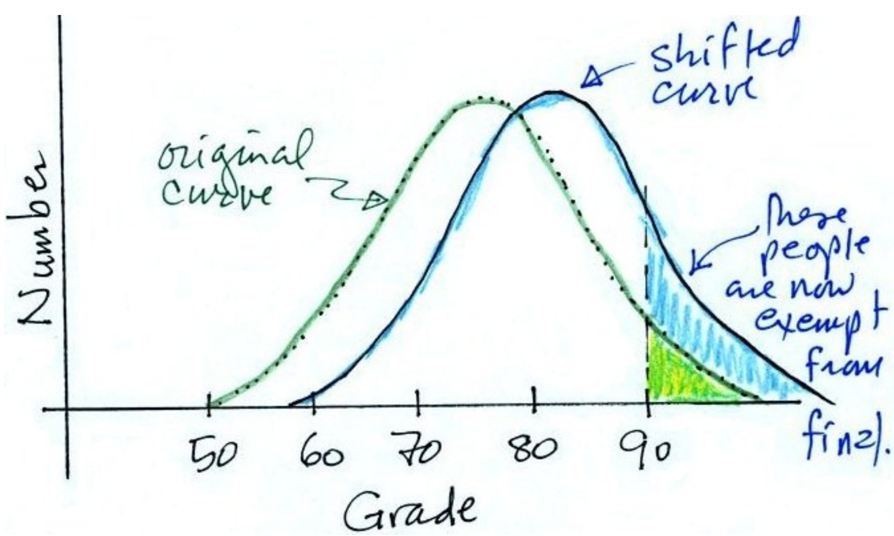


Now we will discuss (i) why there is an upper limit to the amount of water vapor that can be found in air and (ii) why this depends upon the air's temperature.

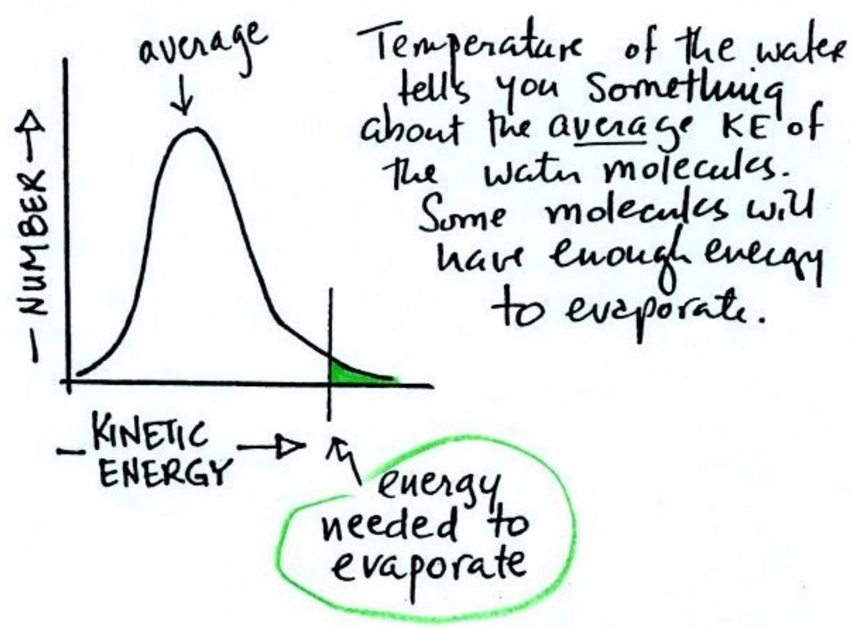
Before talking about water vapor, we will discuss some basic statistical concepts using grade distribution below as an example. The average appears to be about 77%. In the classroom version of this course, students with grades equal to or greater than 90.0% at the end of the semester are exempt from the final exam.



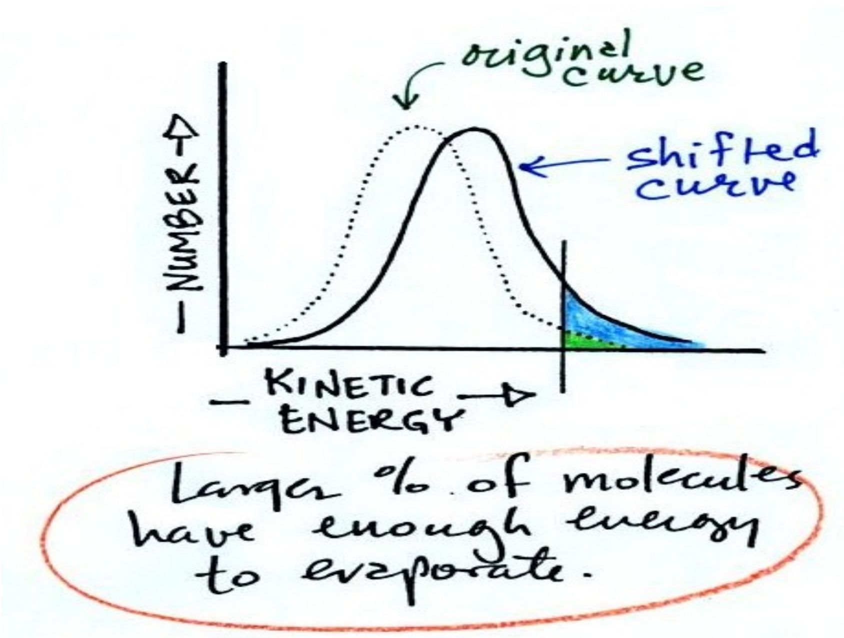
What would happen if 5 pts were added to everyone's grade? Would the curve shift to the right or the left? Would the average grade increase, decrease or remain the same? Would the number of people who are exempt the final increase, decrease or remain the same? It is easy to see that the curve shifts to the right, the average grade increases and the number of people exempt from the final increases.



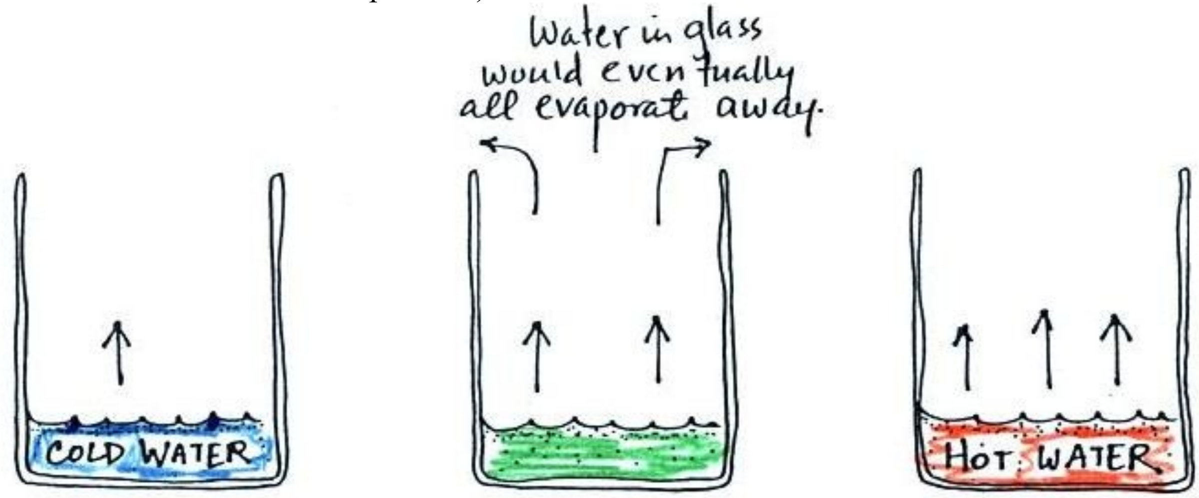
Instead of grades, the figure below shows the distribution of the kinetic energies of water molecules in a glass of water. There is an average kinetic energy and some of the water molecules at the far right end of the curve have sufficient kinetic energy to evaporate (similar to students that are exempt from the final exam).



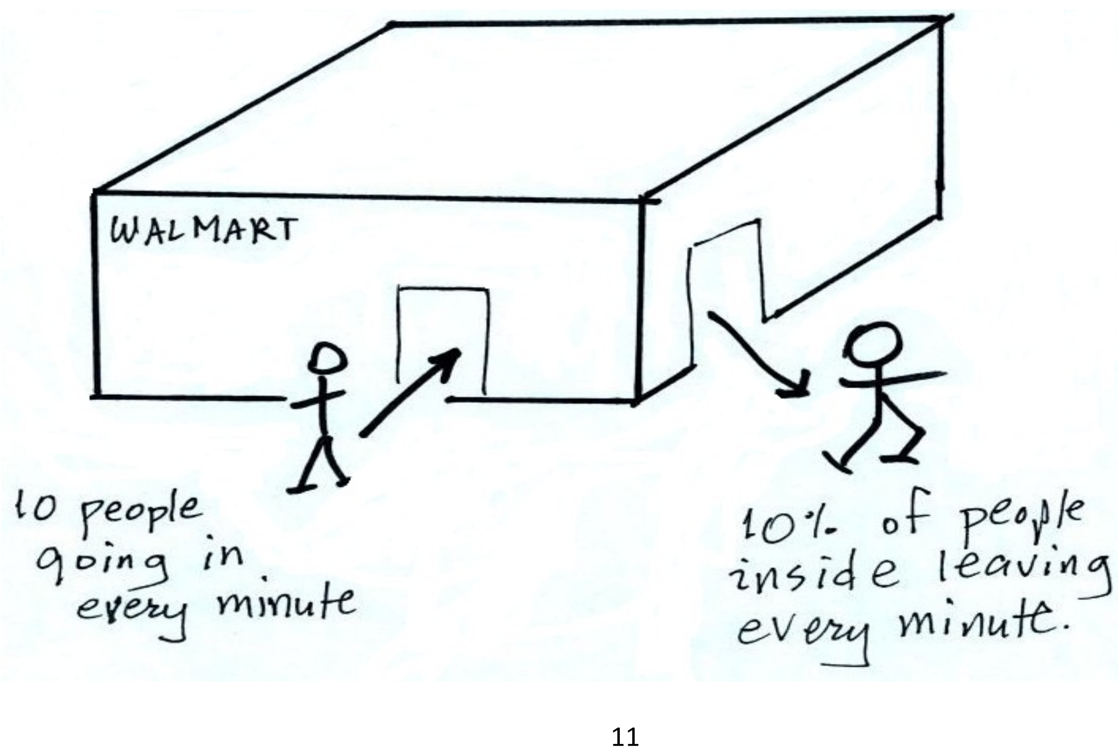
If the water were heated, would the curve shift to the right or the left? Would the average kinetic energy of the water molecules increase, decrease or remain the same? Would the number of water molecules, with sufficient kinetic energy to evaporate increase, decrease or remain the same? The new curve is shown below.



Temperature is a measure of the average kinetic energy of the atoms or molecules in a material. The value of the average kinetic energy would increase and more molecules would lie to the right of the threshold and be able to evaporate. Thus we conclude that hot water evaporates more rapidly than cold water. This is shown pictorially below (the number of arrows is a measure of the rate of evaporation).



We will use the number of people inside a store as a way to illustrate **<u>saturation vapor pressure</u>**. When the front door is first opened, people will start streaming into the Walmart. The number of people in the store will start to increase. Eventually some fraction of the people inside will start to leave. The number inside will grow to the point that the number of people leaving balances the number entering.



The question is how many people would have to be inside the Walmart in order for the two rates to be equal? The solution is shown below using some made up numbers. It is easy to see that if the rate of people entering the store were higher, the number inside would increase. If the rate were to decrease then the number of people inside would get smaller.

$$\text{rate entering} = \text{rate leaving}$$

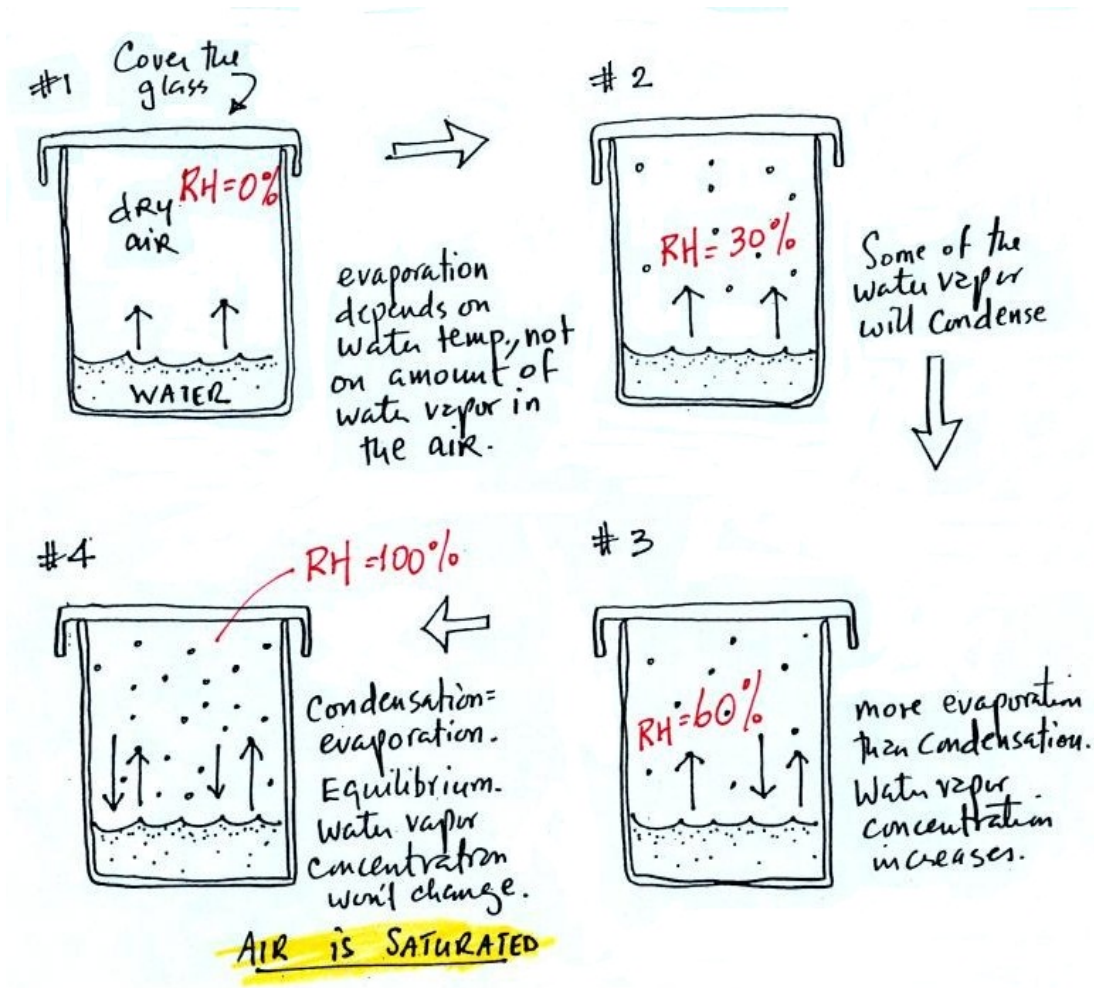
$$10\ \frac{\text{people}}{\text{min}} = 10\% \times \text{no. of people inside}$$

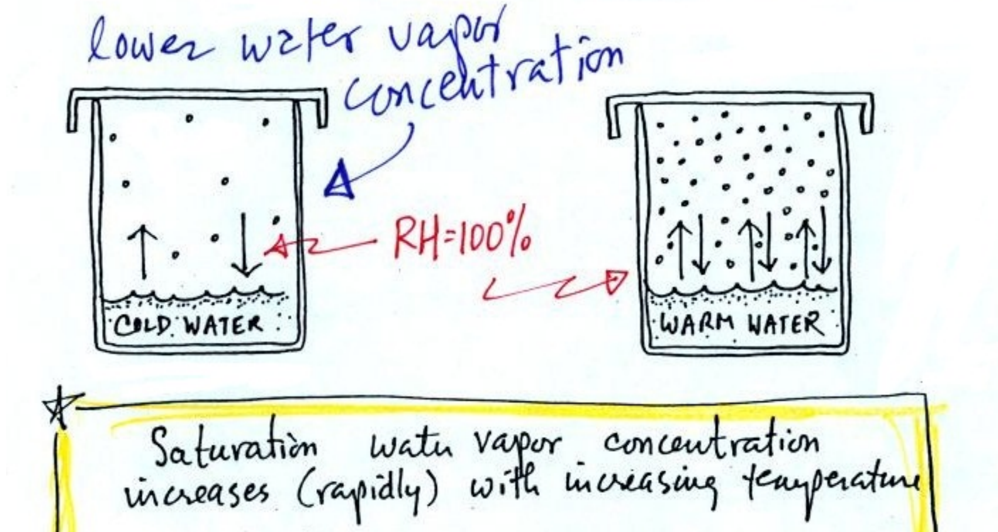
$$\frac{10\ \frac{\text{people}}{\text{min}}}{0.1} = \text{no. people inside} = 100$$

10% in decimal form

We can use this Walmart problem to better understand the saturation of air with water vapor. There is initially no water vapor in the air in the covered glass (Picture 1 in the figure below), which is analogous to people entering a Walmart store just as it opens in the morning. The concentration of water vapor begins to increase (Picture 2) until some water vapor molecules will condense (Picture 3). In the same way, some shoppers who are finished buying what they need will leave Walmart as other shoppers enter. Eventually the rate of water evaporation will be equal to the rate of water vapor condensation (Picture 4). The air is now considered saturated, which means that the concentration of water vapor will not increase unless the air temperature is raised. The air above the water has a relative humidity of 100%.

Cups filled with cold and warm water are shown at the bottom of the figure. Because of different rates of evaporation (slow in cold, rapid in warm water) the water vapor concentrations at saturation are different. Cold saturated air contains less water vapor than warm saturated air. Note that the two glasses have different amounts of water vapor but the relative humidity is the same.





Saturation water vapor concentration increases (rapidly) with increasing temperature

We will end this lecture with a table that shows the dependence of saturation mixing ratio on air temperature. Note that the value of the saturation mixing ratio doubles for every 20^0F increase in temperature.

Approximate water vapor saturation mixing ratios

AIR TEMP (°F)	r_s (g/kg)
20	2
25	2.5
30	3
35	4
40	5
45	6
50	7.5
55	9
60	10.5
65	12.5
70	15
75	18
80	21
85	25
90	30
95	35
100	42

The same data are shown in graphical form below.