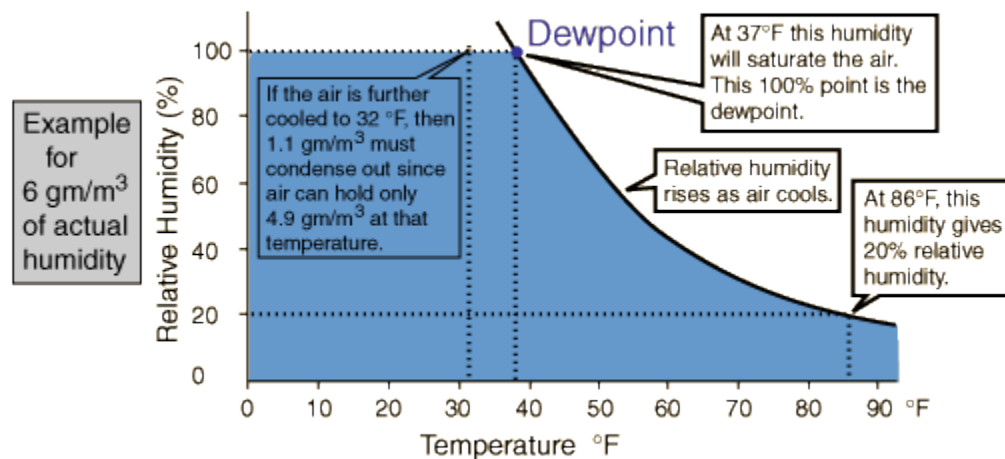


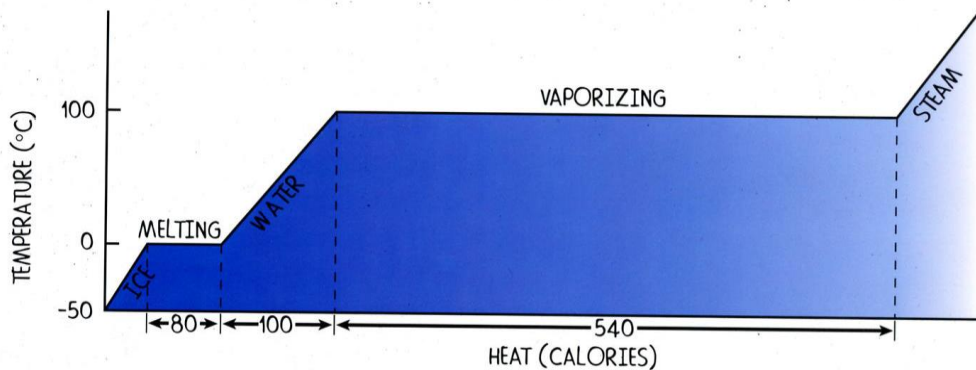
## VII. BRINGING AIR TO SATURATION:

- A. Lifting air in the dry adiabatic process.
- 1) This relies on the fact that air is compressible and expandable, and the fact that pressure decreases with height.
  - 2) So as we force air to rise, the external pressure pressing in on air decreases, and as the external pressure relaxes, expansion is permitted.
    - a. And expanding air cools, and as the air temperature cools, the vapor capacity drops.
  - 3) As a result, we can take air with even just a little bit of water vapor, and we can lift it to the point where that air can no longer hold the water vapor it has.
  - 4) At that point, the relative humidity is 100% and saturation has been achieved.
  - 5) We call this the dry adiabatic approach to **saturation**. (There was no heat exchange, just expansion).
  - 6) The adiabatic approach brought air to saturation without change of vapor content, by extracting heat. (Expanding the air and bringing it to a **lower pressure**).
- B. Dew Point Temperature:
- 1) We can bring air to saturation without changing its vapor content and without changing its pressure by extracting heat.
    - a. This is a **diabatic** process.
    - b. We're extracting heat and as a result, the air's temperature decreases.
    - c. And when it decreases all the way to meet its dew point, we have reached saturation, the **dew point approach to saturation**.
  - 2) Let's consider a sub-saturated sample of air, and let's subject it to isobaric cooling.
    - a. We're going to extract heat without pressure change and without altering its vapor supply.
    - b. So suppose I have a temperature and I have a dew point.
      - i) The temperature reflects the vapor capacity of the air, how much water vapor I can get in that air.
      - ii) The dew point temperature tells me vapor supply.
      - iii) Since the temperature is larger than the dew point, the supply is less than the capacity.
    - c. But I'm going to cool this air now by decreasing the temperature.
      - i) I can put the sample over ice or stick it in the refrigerator.
    - d. As the temperature decreases, the air's vapor capacity decreases as well.
      - i) So its relative humidity, the ratio between supply and capacity, is increasing.

- e. When I've managed to cool the air all the way down to its dew point, the sample is saturated.
  - f. The temperature and the dew point are the same.
    - i) Supply equals capacity.  $RH = 100\%$ .
  - g. Any bit of extra cooling now makes it supersaturated, and condensation will appear as a result.
    - i) **Dew** has formed.
  - h. So the dew point approach to saturation ----isobaric cooling without change of vapor supply.
- 3) Example: Let's start on a pleasant afternoon. The temperature is larger than the dew point everywhere, so the air is sub-saturated.
- a. But let's say after sundown, the vapor supply of air doesn't change, but the vapor capacity decreases as the temperature of the air near the ground cools.
    - i) The ground's surface under you has a low thermal inertia, and it's cooling quite well.
    - ii) That causes the air near the ground to cool, and the cooling is largest right near the ground.
  - b. If the air can cool all the way to its dew point, dew will form.
  - c. As we know, condensation requires a nucleus, or a surface to actually condense on. The ground surface is a great condensation nucleus.
  - d. If the dew point were below freezing, then frost would form instead because the surface is also a pretty good ice nucleus as well.
  - e. The most likely place along the ground to find dew or frost is on an object that has low thermal inertia and are good radiators of energy ---concrete, asphalt, metal railings, etc.



- f. Other good places are objects that have relatively large surface areas for their size so they radiate away their heat overnight even more efficiently, in more directions, like blades of grass and your car windows.
- 4) Example: Bridges are made of materials with small thermal inertia. They have more exposure to air, radiating energy away on all sides, especially below. Thus, other factors being equal, the bridge will cool to the dew or frost point before the adjacent roadway will.
- a. A particularly dangerous kind of ice can form on roadways, particularly bridges, when subfreezing air is chilled to the dew or frost point, but black ice is not black.
    - i) It's actually a very thin layer of very transparent ice.
    - ii) It is particularly slippery when newly formed. That means the temperature is close to freezing. If a thin surface layer of liquid water develops on that ice, it is especially slick, and you can melt a thin layer of thin black ice by friction, by walking on it, or by driving on it.
  - b. If air were able to cool to the dew point over a relatively deeper layer, not just at the surface, then we would have a fog instead.
- 5) Under the right conditions, air near the surface can chill to its dew point overnight fairly easily. Particularly if that surface has a low thermal inertia, if the winds are calm, the sky is clear, and the moisture content of the air aloft is not too large.
- a. Remember, water vapor is a greenhouse gas. Therefore, dew is not uncommon, particularly in deserts and indeed, nighttime dew is a major source of moisture for vegetation in places that otherwise don't get much rain and not much moisture.
  - b. Once the surface air reaches its dew point, however, further cooling is a lot more difficult.
  - c. Extra cooling would make the air supersaturated, and the excess vapor would then need to condense, and **condensation** is a warming process.
  - d. When water becomes liquid, heat is released. We call this "latent heat", hidden heat.
    - i) "Latent" comes from the Latin to lie hidden, the Greek work to escape notice.
  - e. This heat warms up the air that holds the condensing vapor, and that's the air that was cooling. So this represents resistance to further cooling.
  - f. If you don't expect your air mass at your location to change overnight, your minimum temperature will probably be no lower than your afternoon dew point.
    - i) If the air mass changes, if the sea or land breeze blows by, if a storm movers through, a front passes, etc., this rule doesn't work.



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Section 23.8

C. Wet Bulb Temperature:

- 1) Condensation is a warming process. Latent heat is released by the condensing vapor to the surrounding air. **Evaporation**, in contrast, is a cooling process.
  - a. When you climb out of a swimming pool, you feel cold because the liquid water on your skin is evaporating into sub-saturated air.
    - i) It takes energy---heat coming from you--- to break the bonds that hold water molecules together into liquid water drops.
    - ii) The water evaporates because the air is sub-saturated and the vapor supply is less than the vapor capacity.
    - iii) As evaporation proceeds, the number of vapor molecules around your skin increases, and the vapor supply and pressure both increase.
    - iv) As the difference between the vapor supply and the vapor capacity gets smaller, evaporation and the cooling it produces, slow down.
  - b. This is why we sweat.
    - i) Our body gives up some of its precious water in the hopes of gaining some evaporation cooling.
    - ii) The wind hastens the evaporation, and the cooling, by sweeping away those newly created water vapor molecules from the liquid water that evaporated from your skin.

- iii) The water is evaporating since the air is sub-saturated, and the vapor supply is less than the vapor capacity. The vapor pressure is too low, less than the saturation value.
- iv) As evaporation proceeds, the number of vapor molecules around your skin increases, and the vapor supply and the vapor pressure both get larger.
- v) In this way, the vapor deficit, the difference between the actual vapor pressure and it's saturation value, the difference between the vapor supply and the vapor capacity gets smaller, so evaporation and the cooling it produces slows down.
- vi) "Wind Chill": To increase evaporation cooling by taking away the newly created vapor molecules hanging around your skin.

### New Wind Chill Chart

		Wind (mph)												
		Calm	5	10	15	20	25	30	35	40	45	50	55	60
Temperature (°F)	40	36	34	32	30	29	28	28	27	26	26	25	25	
	35	31	27	25	24	23	22	21	20	19	19	18	17	
	30	25	21	19	17	16	15	14	13	12	12	11	10	
	25	19	15	13	11	9	8	7	6	5	4	4	3	
	20	13	9	6	4	3	1	0	-1	-2	-3	-3	-4	
	15	7	3	0	-2	-4	-5	-7	-8	-9	-10	-11	-11	
	10	1	-4	-7	-9	-11	-12	-14	-15	-16	-17	-18	-19	
	5	-5	-10	-13	-15	-17	-19	-21	-22	-23	-24	-25	-26	
	0	-11	-16	-19	-22	-24	-26	-27	-29	-30	-31	-32	-33	
	-5	-16	-22	-26	-29	-31	-33	-34	-36	-37	-38	-39	-40	
	-10	-22	-28	-32	-35	-37	-39	-41	-43	-44	-45	-46	-48	
	-15	-28	-35	-39	-42	-44	-46	-48	-50	-51	-52	-54	-55	
	-20	-34	-41	-45	-48	-51	-53	-55	-57	-58	-60	-61	-62	
	-25	-40	-47	-51	-55	-58	-60	-62	-64	-65	-67	-68	-69	
	-30	-46	-53	-58	-61	-64	-67	-69	-71	-72	-74	-75	-76	
	-35	-52	-59	-64	-68	-71	-73	-76	-78	-79	-81	-82	-84	
-40	-57	-66	-71	-74	-78	-80	-82	-84	-86	-88	-89	-91		
-45	-63	-72	-77	-81	-84	-87	-89	-91	-93	-95	-97	-98		

Frostbite occurs in 15 minutes or less

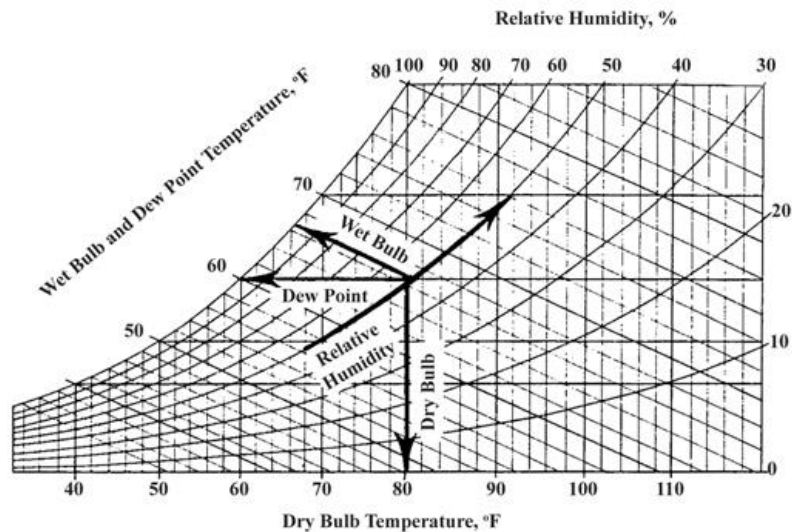
$$\text{Wind Chill (°F)} = 35.74 + 0.6215T - 35.75(V^{0.16}) + 0.4275T(V^{0.16})$$

Where, T = Air Temperature (°F)  
V = Wind Speed (mph)

- 2) We have seen that evaporation also moistens the air that it cools, and thus, it can bring air to saturation.
  - a. Example: Suppose I have a sub-saturated air sample, T = 30°C, 86°F, and the dew point is 10°C, or 50°F. The VC = 28 g/kg and the VS = 5 g/kg.
    - i) You're 20 g/kg short of saturation.
    - ii) You want to saturate the air and this time, you choose to do it by supplying the missing vapor.
    - iii) Can you fit 20 more grams of water vapor into that kilogram of air? **NO!**

- b. Evaporation does increase the vapor supply, but evaporating that water takes energy from the air cooling it, and as it cools, the vapor capacity decreases, so the air is progressively less able to hold the water vapor you're trying to give it.
  - c. The vapor capacity is larger than the vapor supply. The temperature is higher than the dew point.
  - d. As the water vapor content increases, during evaporation, the vapor supply increases and therefore the dew point goes up. But the temperature and the vapor capacity are decreasing. They're decreasing due to the cooling of evaporation.
  - e. So as the dew point rises, the temperature decreases, and the temperature and the dew point are going to meet somewhere in the middle at a new temperature, and that's the temperature we call the "wet bulb".
- 3) For air brought to saturation by the "wet bulb" process, the new temperature and the vapor supply are larger than their original values, but the temperature and the vapor capacity are also smaller.
- a. You didn't fit as much water vapor into the air as you were expecting, and that's the wet bulb approach to saturation. [This also shows us the limitations of sweating.]
  - b. Evaporation gets me less cooling because the temperature will only decrease to its wet bulb because the dew point is rising as I increase the vapor supply.
- D. Any sample of air has 3 temperatures to describe it's vapor properties: Its regular or actual temperature, its dew point temperature, and the wet bulb temperature. [All 3 temperatures tell us something important about humidity].
- 1) The actual temperature tells us vapor capacity.
  - 2) The dew point tells us vapor supply, the actual water vapor content, and it shows how much I can cool the air without changing the vapor supply before saturation is reached.
    - a. If I do this, the actual temperature also changes, becoming the same as it's dew point, which is fixed in this particular process.
  - 3) The wet bulb tells me how much I can cool that air by evaporation.
    - a. If I cool the air this way, its actual temperature is decreasing. It's changing and becomes the same as its wet bulb.
    - b. The dew point temperature of this air also changes during this process as well.
- E. At saturation, all 3 temperatures are equal and it doesn't matter how we got to saturation.
- 1) If air is already holding all the vapor it can, it's already at its dew point because dew has already formed.

- 2) If the air is already saturated, I can't evaporate any more liquid water into it, so it's already at its wet bulb.
- 3) If the air is sub-saturated, the wet bulb temperature falls in between the other 2 temperatures. [The temperature is highest, the dew point is lowest, the wet bulb is in between].



- F. We measure wet bulb temperature with a device called the "sling psychrometer".
- 1) This consists of 2 thermometers that are mounted side by side.
  - 2) One thermometer bulb is fitted with a sock, which we make moist by dipping in water, and this is what make the wet bulb wet.
  - 3) The other bulb is left dry in order to measure the actual temperature.
  - 4) We operate it by swinging it around.
  - 5) It's not changing the temperature that is measured by the dry bulb, but the device is being swung to force air through the sock, promoting evaporation of the air that is trapped between the sock and the wet bulb.



G. Boiling is actually rapid evaporation.

- 1) A bubble that forms in a pot of boiling water is subject to pressure from both the atmosphere and the liquid water.
- 2) The boiling point is the temperature at which saturation vapor pressure pushing out from the bubble matches the external pressure pushing back.
- 3) The fact that pressure decreases with height explains why the boiling point decreases with elevation above sea level.
  - a. As we ascend, there is less force pushing down, not only on us, but also on the bubbles.
  - b. So the temperature at which saturation vapor pressure in the bubbles is able to stave off this external pressure pushing down is relatively lower. So therefore, this is why some food never cooks at higher elevations---because the boiling point to the water is lower due to the lower atmospheric pressure.
- 4) Phase changes occur at constant temperature, as well at constant pressure.
  - a. The phase transition between solid and liquid water also involves latent heating and cooling. [80 cal/g @ sea level]
    - i) This is called the latent heat of fusion or melting, depending on the direction of the process.
  - b. The phase transition between liquid and vapor occurs at a constant temperature and also involves latent heating and cooling. [540 cal/g @ sea level]
    - i) The reason is because the energy being added to the system is not being used to increase the temperature of the water. Instead, it's going to breaking the bonds between the molecules in the liquid.
    - ii) This is called the **heat of fusion**.
  - c. The energy required to break bonds between molecule and ice is not as large as that's needed for water. The latent heat of melting is 7.5X smaller than the latent **heat of vaporization**, which is required for liquid water to convert to vapor.

H. Summary:

- 1) There are 3 ways of bringing air to saturation, all 3 involving cooling.
- 2) Air is sub-saturated when its vapor supply is less than its vapor capacity, so saturating air is a matter of decreasing that capacity, increasing the supply, or doing both simultaneously.
- 3) Vapor capacity is a very strong function of temperature.
  - a. The very best way to decrease capacity is to lower that temperature.
- 4) The adiabatic expansion approach to saturation operates by expansion cooling.
  - a. The temperature drops as the pressure is reduced, without change of vapor content, until the vapor capacity and supply are the same.





- 4) You are taking a shower with warm water, some of which is evaporating into the room air. You notice that before the room air become noticeably foggy, condensation has already begun forming on your bathroom mirror. Why?
  
- 5) Under what atmospheric and surface conditions are we likely to get frost on the ground?
  
- 6) What is a psychrometer? Describe it and what does it measure?
  
- 7) Let us suppose you measured the dry temperature to be 80°F, and a wet bulb temperature of 66.5°F. Then your weather station says it to be a 50% Relative Humidity. What is the Dew Point temperature? If the day is calm and you don't expect a change in Air Mass, what will be the lowest temperature that you can possible get by morning? Why?
  
- 8) I want to kill the bugs in a river, that would make me sick at 15,000ft elevation. How would I do that?
  
- 9) How does the actual, dew point, and wet bulb temperatures compare when the air is saturated? Why?
  
- 10) Why do you get dew on the grass in the desert in the morning?

