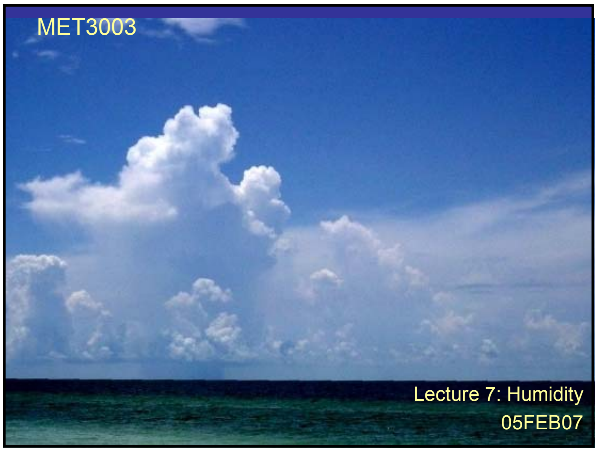
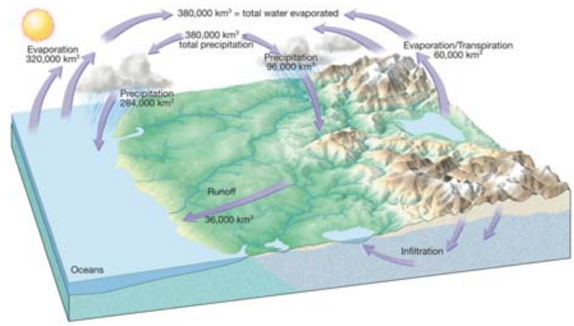
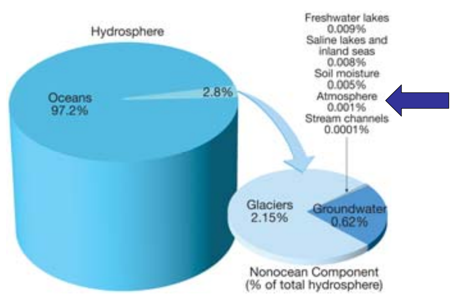


The Hydrologic Cycle



Where is All the Water?



Vapor cycled through the Atmosphere each year would cover the Earth to a depth of 1 meter as liquid

Temperature and Heat

- **Specific Heat:** The amount of heat required to produce a 1°C change in temperature in a kilogram of stuff.
- We will use ***Joules*** for thermodynamic calculations (J = energy required to accelerate a mass of 1 kg to a speed of 1 m s^{-1}.
- L&T use calories
  - Amount of heat required to warm 1 *gram* of water 1°C
  - 4.187 J = 1 calorie
- **Examples of Specific Heats in** J K^{-1} kg^{-1} **:**
  - Liquid water 4187
  - Ice 2106
  - Water vapor 1952
  - Dry Air 1004 (constant pressure)
  - Dry Air 717 (constant volume)
  - Typical rock 800-1000
- **Don't let me catch any of you using calories, unless you are on a diet.**

Phase Changes

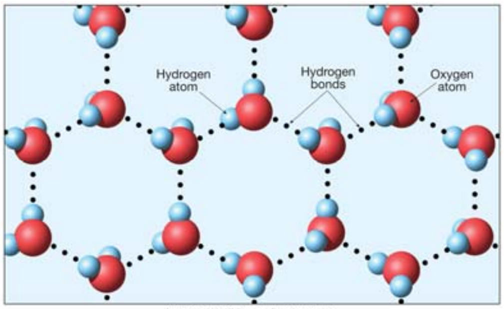
- Examples: Feeezing, Melting, Evaopration, Condensation, …
- ***Latent heat:*** Heat absorbed or released by a change of phase---by evaporation condensation, freezing melting.
- Molecules moving faster than average tend to escape from the denser of two phase whereas molecules moving slower than average tend to be captured by the denser phase.
  - Melting, evaporation, and ***sublimation*** (ice→ vapor) all cool the environment.
  - Freezing, condensation, and ***deposition*** (vapor→ ice) warm the environment.
- Latent heat of vaporization for water is Lv = 2.5 x 10^6 J kg^{-1}
- Latent heat of fusion is Lf = 0.334 x 10^6 J kg^{-1}
- Condensation of one gram of water vapor in a kilogram of air:

$$\frac{L_v}{c_p} = \frac{2500\times10^6 \ {}^{o}\mathrm{kg}^{-1}}{1004\ {}^{o}\mathrm{K}^{-1}\mathrm{kg}^{-1}\times1000\mathrm{g\ kg}^{-1}} = 2.49\frac{{}^{o}}{\mathrm{g\ kg}^{-1}}$$

- Because condensation of a small amount of water can cause a big temperature change, latent heat plays a large role in the atmosphere.

H_2O Phase Changes

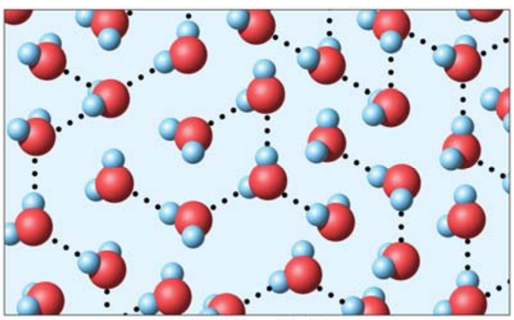
Ice



Frost on a Window Pane

An example of ***Deposition***, <u>not</u> freezing.

Water

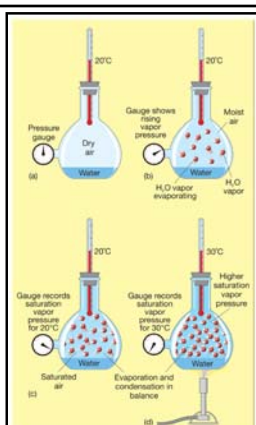


Condensation of Water Vapor Generates Fog

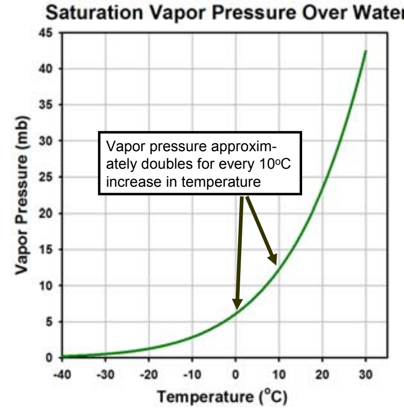
Ice fog may be generated by Deposition from vapor, or a water fog may freeze on contact with a cold surface.

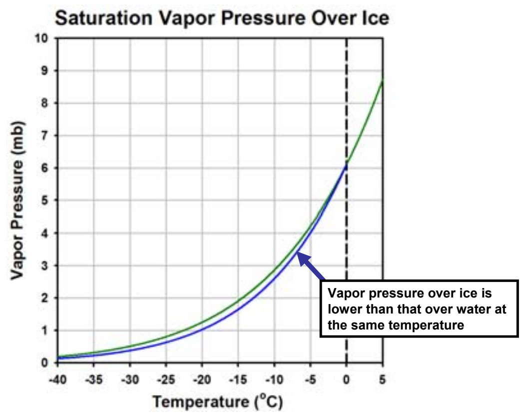
Saturation

- An example of equilibrium
- As many molecules evaporate from the surface as condense upon it.
- By Dalton's law, vapor exerts a pressure that is determined only by its density & temperature since we know the gas constant for water.
- At saturation, this Vapor Pressure depends only on temperature.
- And we have the Clausius-Clapyron equation that lets us calculate it.



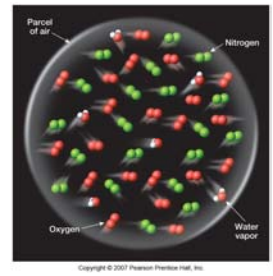
Saturation Vapor Pressure Over Water





Humidity is a Measure of Water Vapor Content of Air

- We think of air in "parcels," say a cubic meter or a kilogram
- Vapor pressure is one measure of humidity
- Vapor pressure can take on any value between zero and saturation for the given temperature, or just a bit more.
- But there are other measures
  - Water vapor per unit mass or volume
  - Or ratio between amount of water vapor and amount at saturation



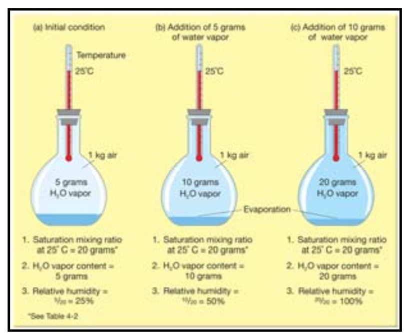
Relative and Absolute Humidity

- Absolute humidity is amount of water vapor per unit volume, or the water-vapor density
- Relative is the ratio of the density of water vapor actually in the air to what it could hold at saturation, keeping the temperature the same

$$\text{Absolute Humidity} = \rho_v = \frac{e_w}{R_v T},$$

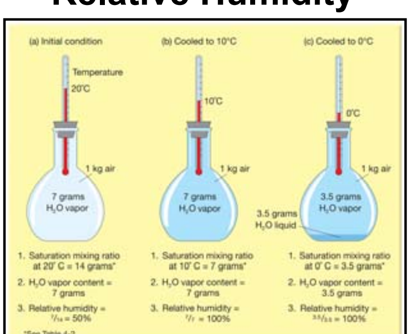
$$\text{Relative Humidity} = 100 \times \frac{\rho_w}{\rho_{ws}} = 100 \times \frac{e_w / R_v T}{e_{ws} / R_v T} = 100 \times \frac{e_w}{e_{ws}}$$

Relative Humidity



Changes with Added Moisture

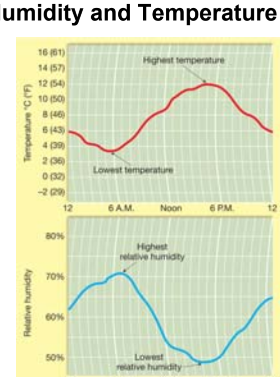
Relative Humidity



Changes with Temperature

Daily Cycle of Relative Humidity and Temperature

- There is generally not a lot of local evaporation
- RH rises overnight as the temperature falls
- Largest RH near dawn
- RH falls during the day
- Minimum near sunset
- During a prolonged period of light winds over a moist surface, RH will be higher on successive days



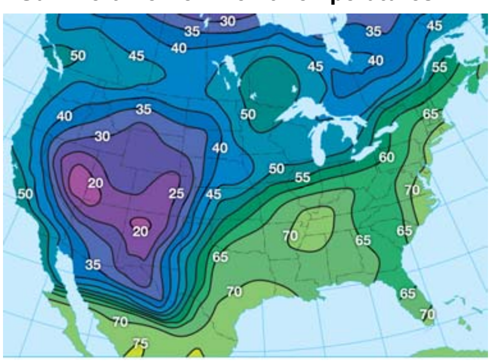
Dew and Frost Points

- ***Dew Point*** (TD or T_d) is the temperature where the existing vapor pressure is the saturation vapor pressure
- ***Frost Point*** is like dew point but for temperatures < 0°C using saturation over ice
- ***Dew Point Depression*** is the difference between the dew point and the temperature = *T - TD*
- They can be used to compute relative humidity (RH)

$$e_w = e_{ws}(T_d), \text{ or } \quad e_i = e_{is}(T_f),$$

$$\mathrm{RH} = 100 \times \frac{e_{ws}(T_d)}{e_{ws}(T)}$$

Summertime Dew Point Temperatures



T_d greater than 70°F is dangerous

TABLE 4-A Heat index

Air Temperature (°F)	Relative Humidity (%) 40	45	50	55	60	65	70	75	80	85	90	95	100	With prolonged exposure and/or physical activity
110	136													**Extreme danger** Heat stroke or sunstroke highly likely
108	130	137												
106	124	130	137											
104	119	124	131	137										
102	114	119	124	130	137									**Danger** Sunstroke, muscle cramps, and/or heat exhaustion likely
100	109	114	118	124	129	136								
98	105	109	113	117	123	128	134							
96	101	104	108	112	116	121	126	132						
94	97	100	102	106	110	114	119	124	129	135				**Extreme caution** Sunstroke, muscle cramps, and/or heat exhaustion possible
92	94	96	99	101	105	108	112	116	121	126	131			
90	91	93	95	97	100	103	106	109	113	117	122	127	132	
88	88	89	91	93	95	98	100	103	106	110	113	117	121	
86	85	87	88	89	91	93	95	97	100	102	105	108	112	**Caution** Fatigue possible
84	83	84	85	86	88	89	90	92	94	96	98	100	103	
82	81	82	83	84	84	85	86	88	89	90	91	93	95	
80	80	80	81	81	82	82	83	84	84	85	86	86	87	

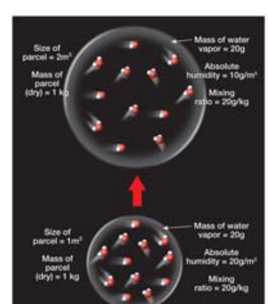
Mixing Ratio

- Ratio of the density of vapor to that of dry air
- If there is no condensation or evaporation, mixing ratio stays constant following a parcel
- <u>Saturation</u> mixing ratio does change as a function of pressure because
  - The amount of dry air changes,
  - Although the amount of water vapor stays constant when the temperature (or dewpoint) is fixed

$$q = \frac{\rho_v}{\rho_d} = \frac{\dfrac{e}{R_v T}}{\dfrac{p-e}{R_d T}} = \frac{\dfrac{M_w e}{R^* T}}{\dfrac{M_d(p-e)}{R^* T}} = \frac{M_w}{M_d}\frac{e}{p-e} = 0.622\frac{e}{p-e}$$

Conservative Properties

- In meteorology, properties of an air parcel that stay the same as it undergoes a transformation are said to be ***<u>"conservative"</u>***
- The volumes of vapor and of dry air change by the same amount when the pressure changes
- Dew point, absolute humidity, relative humidity are not conservative in pressure changes



PROBLEM

If the pressure is 1000 hPa, the temperature is 20oC, and the dew point is 10 oC, what are the following quantities?

a. Dewpoint depression ___________,

b. Vapor pressure ___________,

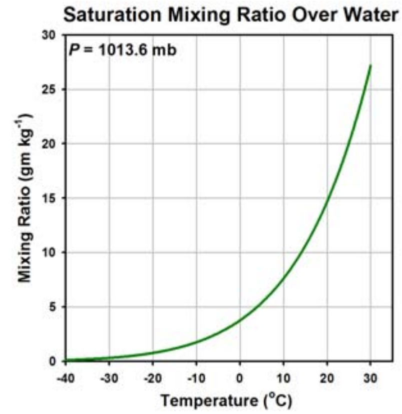
c. Saturation vapor pressure___________,

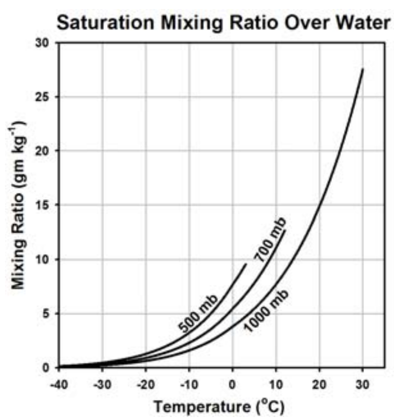
d. Actual mixing ratio ___________,

e. Saturation mixing ratio ___________,

f. Relative humidity ___________.

T°C	*es*(*T*)
0	6.11
5	8.72
10	12.27
15	17.04
20	23.37
25	31.67
30	42.43





Sling Psychrometer

- Two thermometers mounted on a frame
- One has a wet "sock" over it's bulb
- Observer whirls the instrument in a circle
- Wet bulb thermometer cools to the wetbulb temperature
- *T > Tw > Td*
- Dew point can be calculated with tables or a special diagram
- Electronic sensors use substances whose resistance or capacitance changes with humidity

Summary

- Know what the ***Hydrologic Cycle*** is and the proportions of global water in oceans, ice caps, runoff, ground water and in the air. Don't memorize percents.
- Know what specific heat is and the general ratios between specific heats of liquid water, ice, vapor, dry air and rock.
- Know what ***Latent Heat*** is and be able to use it in calculations
- Don't use no stinkin' calories
- Know the definitions of ***Evaporation, Condensation, Melting, Freezing, Sublimation***, and ***Deposition***
- Be able to describe the different molecular organizations of ice, liquid water, and vapor
- Understand the concept of ***Saturation***
- Understand how vapor pressure over liquid water varies with temperature
- Memorize the vapor pressure doubles for every 10°C increase in temepratrue rule
- Know that vapor pressure over ice is less than that over liquid water between 0° and -40°C
- Know how to calculate **Dew Point, Relative Humidity, Vapor Pressure, Dew-Point Depression, Mixing Rato,** and **Saturation Mixing Ratio**, given one quantity, the pressure and a table of saturation mixing ratios as a function of temperature
- Know what "conservative" means and that mixing ratio is a conservative property during pressure changes
- Know how heat and humidity affect human comfort, including a understanding of Heat Index
- Know how humidity is measured with a ***Sling Psychrometer***