



*Fundamentals of Atmospheric Physics*

*Lecture 5*

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# Moisture in the atmosphere

## Indices of Water Vapor Content

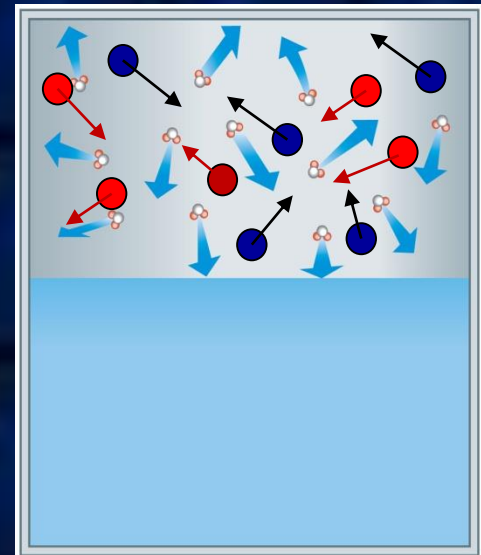
Humidity: The amount of water vapor in air

Expressed in many ways:

**Vapor pressure:** Pressure exerted on the atmosphere by water vapor

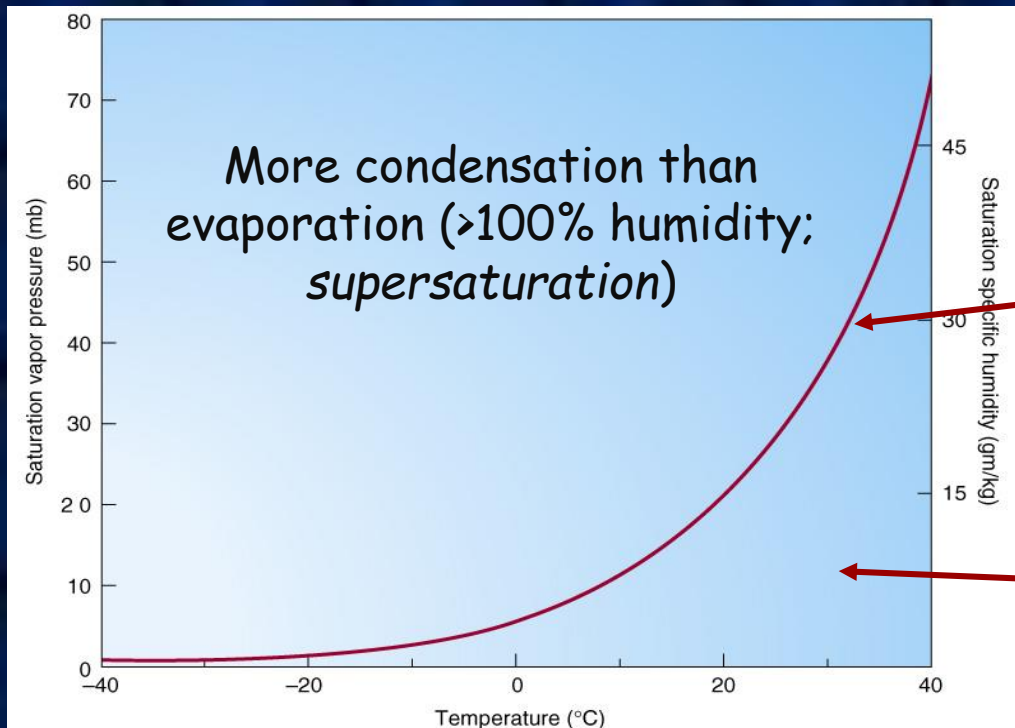
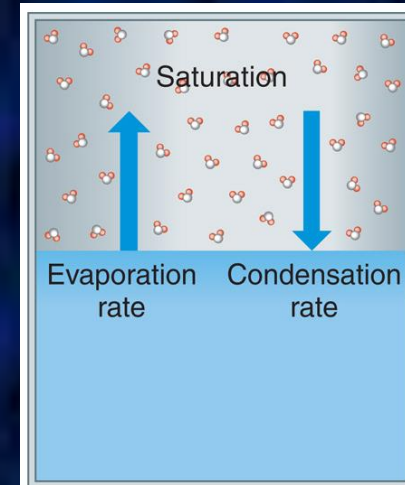
The movement of water vapor molecules exerts vapor pressure

Dependent on temperature and density



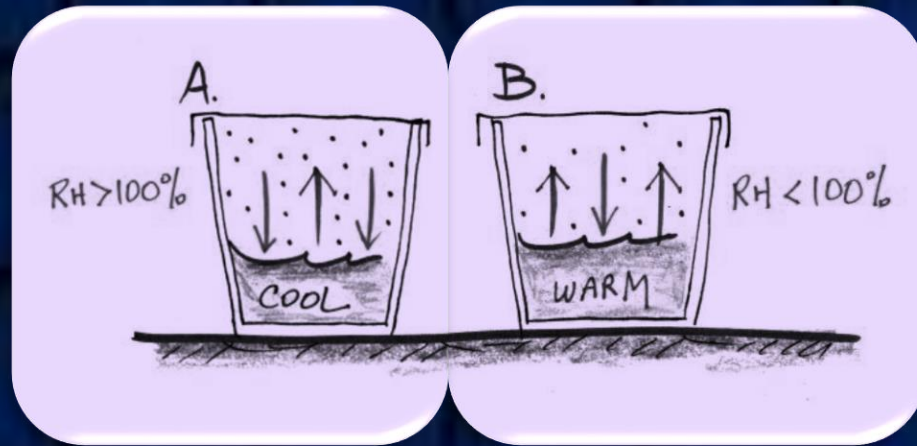
Saturation Vapor Pressure = maximum water vapor pressure possible  
(100% humidity)

Evaporation equals condensation  
Saturation vapor pressure



Saturation vapor pressure

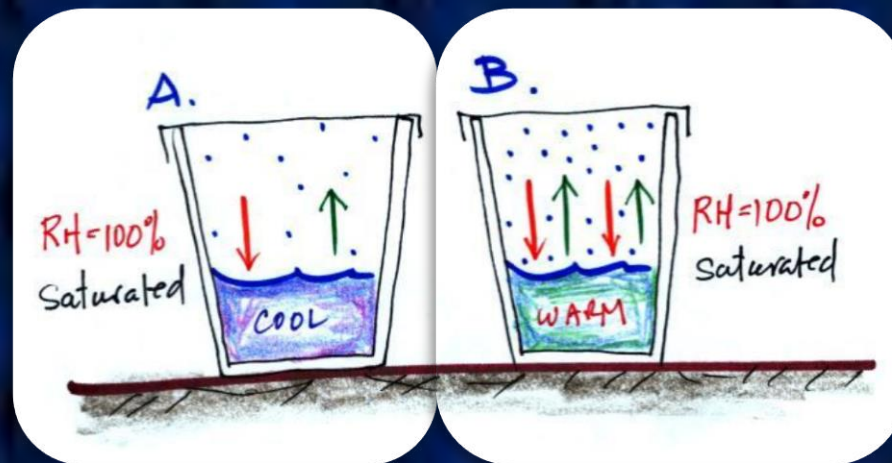
More evaporation than condensation (<100% humidity; undersaturation)



The relative humidity in Glass A is more than 100% (the air is supersaturated).

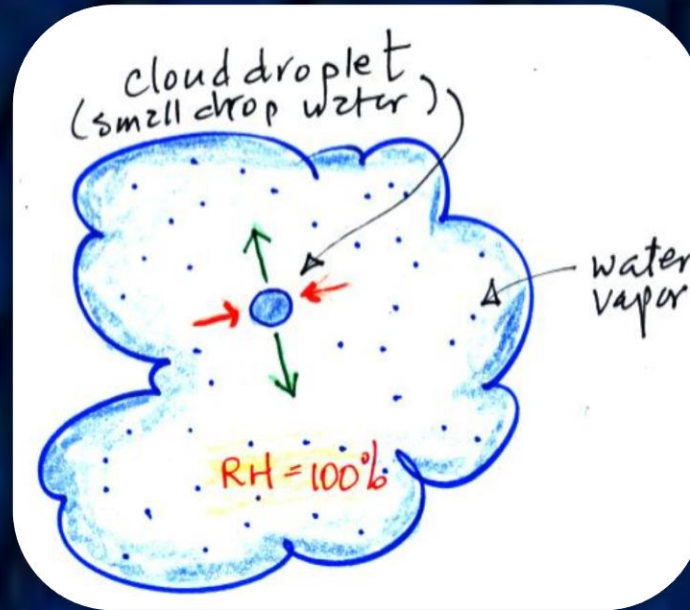
Because the rate of condensation in Glass A is greater than the rate of evaporation, the rate of condensation in Glass A will decrease.

It will continue to decrease until it is equal to the rate of evaporation.





The air inside the cloud is saturated



The rate of evaporation from the cloud droplet (2 green arrows) is balanced by an equal rate of condensation (2 orange arrows).

The  $RH = 100\%$

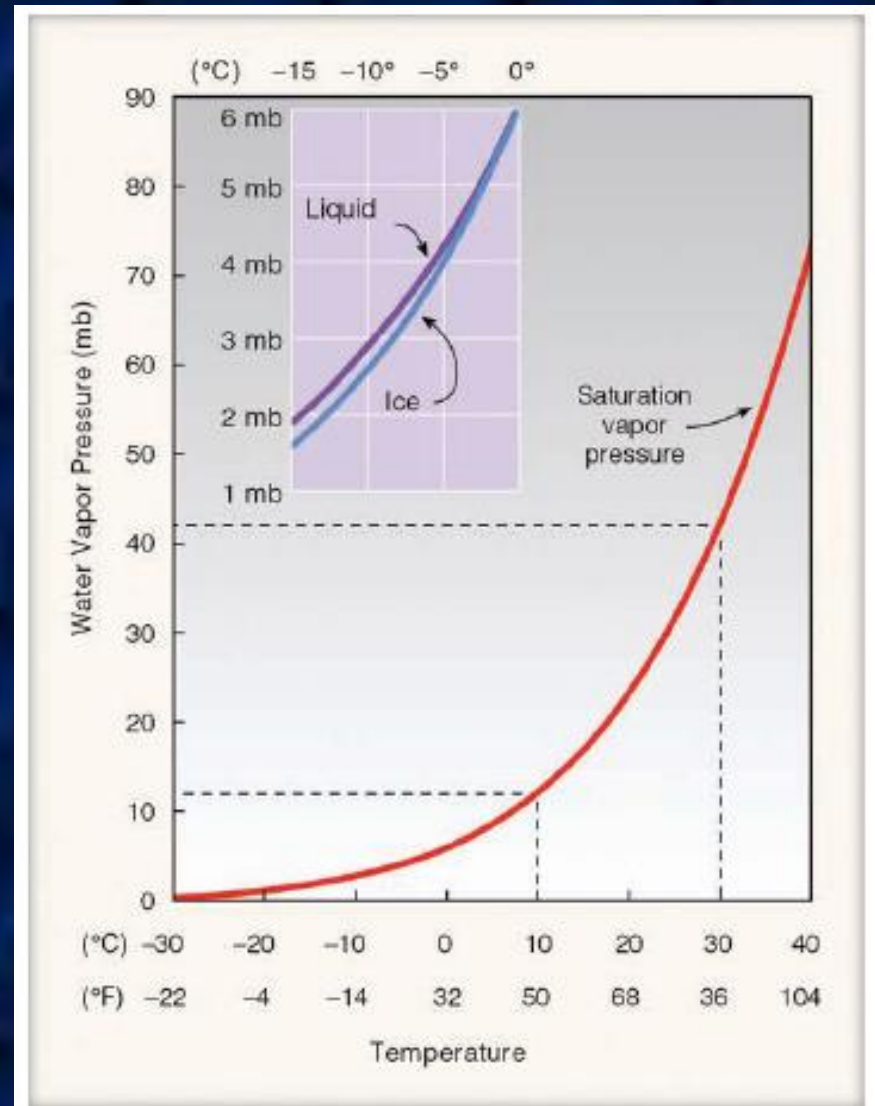
The cloud droplet won't grow any bigger or get any smaller

# SATURATION VAPOUR PRESSURE

Saturation vapor pressure depends primarily on the air temperature.

## Exponential relationship

When water and ice both exist below freezing at the same temperature, the saturation vapor pressure just above water is greater than the saturation vapor pressure over ice.



## Mixing Ratio

Mixing ratio ( $r$ ) - The ratio of the mass of water vapor to the mass of dry air in a sample.

$$r = \frac{m_v}{m_d}$$

Usually expressed in g/kg, but most correct when unitless (i.e.kg/kg).  
Typical range = 0-25 g/kg.

$$r = \frac{m_v / v}{m_d / v} = \frac{\rho_v}{\rho_d}$$



$$e = \rho_v R_v T$$

$$P - e = \rho_d R_d T$$

$$r = \frac{\frac{e}{R_v T}}{\frac{P - e}{R_d T}} = \frac{R_d}{R_v} \frac{e}{P - e}$$

$$\frac{R_d}{R_v} = \frac{R^* / M_d}{R^* / M_v} = \frac{M_v}{M_d} = \varepsilon \cong 0.622$$

$$r = \varepsilon \frac{e}{p - e} \approx \varepsilon \frac{e}{p}$$



## *Saturation Mixing Ratio*

$$r_s = \varepsilon \frac{e_s}{p - e_s}$$

# Measures of Water Vapor Content in the Air

## Absolute Humidity

mass of water vapor/volume of air

gr/m<sup>3</sup>

# Relative Humidity

Relative Humidity (RH) -Ratio of mixing ratio to its saturation value  
Expressed in percent

$$RH = \frac{\text{Actual Amount}}{\text{Amount if Saturated}} \times 100 \%$$

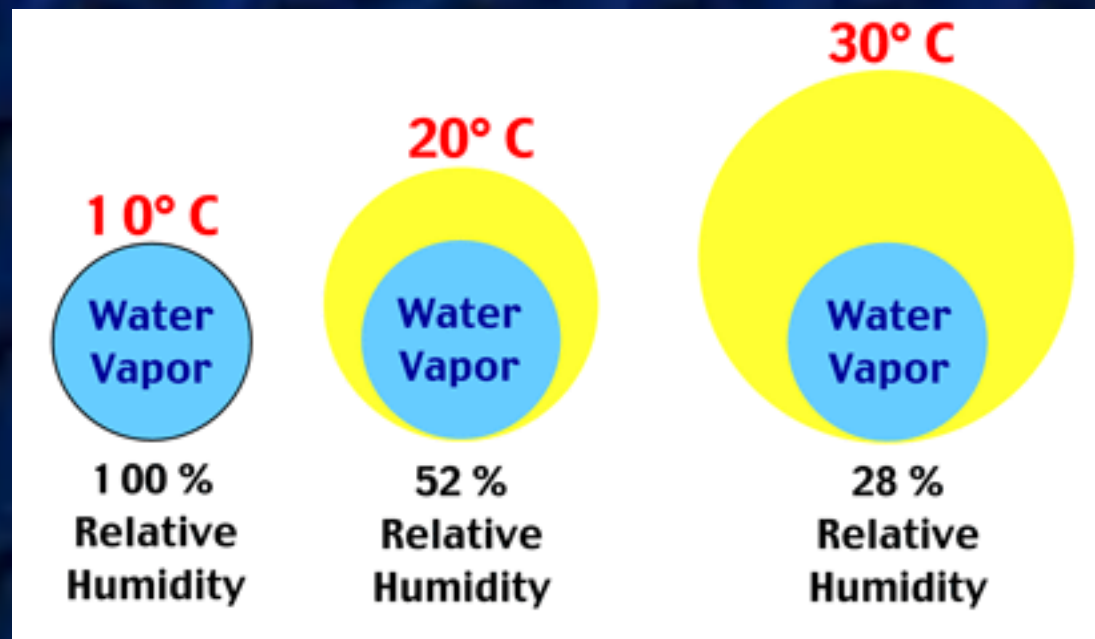
*Amount if Saturated = Max. Capacity*

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

RH = 100% means air is saturated

RH > 100% is supersaturated air



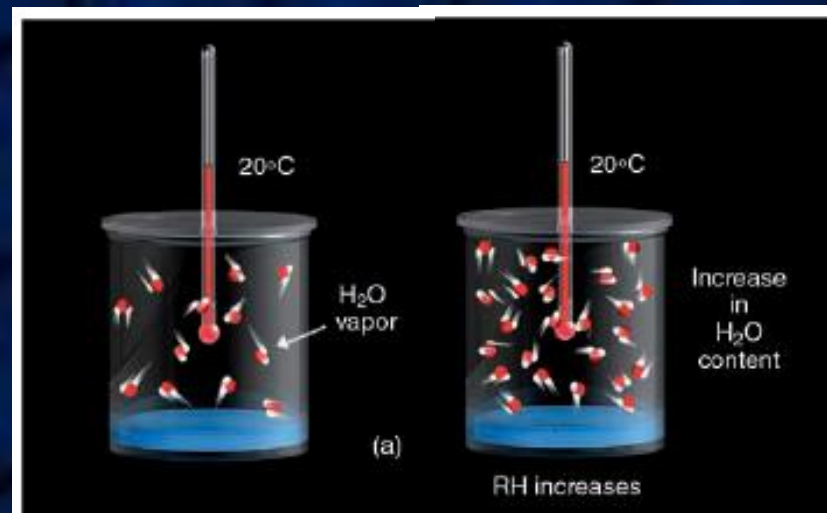


# Changing Relative Humidity

How do we alter a location's relative humidity?

*Change the water vapor content*

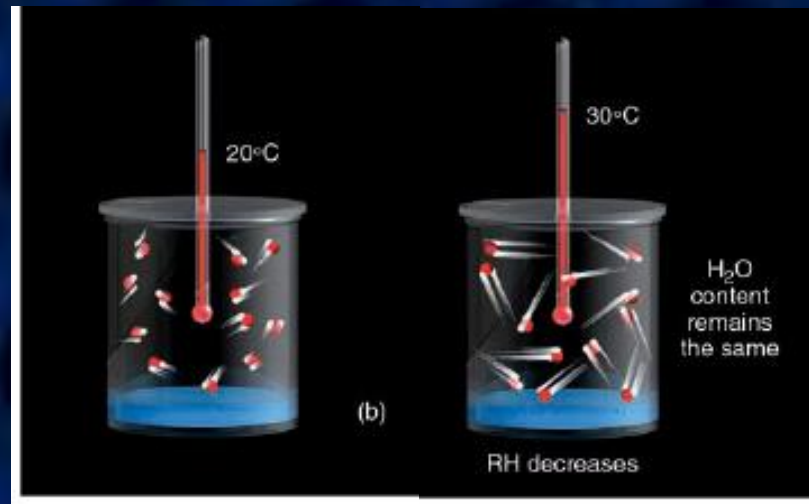
Increase w.v. content  $\Rightarrow$  raise actual vapor pressure  $\Rightarrow$  relative humidity increases



## Change the air temperature

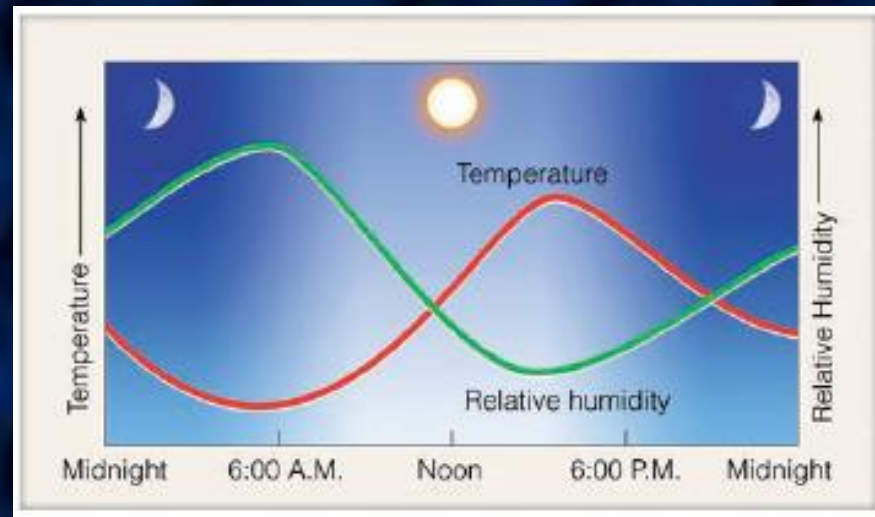
Increase temperature  $\Rightarrow$  increase saturation vapor pressure  
 $\Rightarrow$  relative humidity decreases

Warm = faster molecules = less likely to condense = lower RH

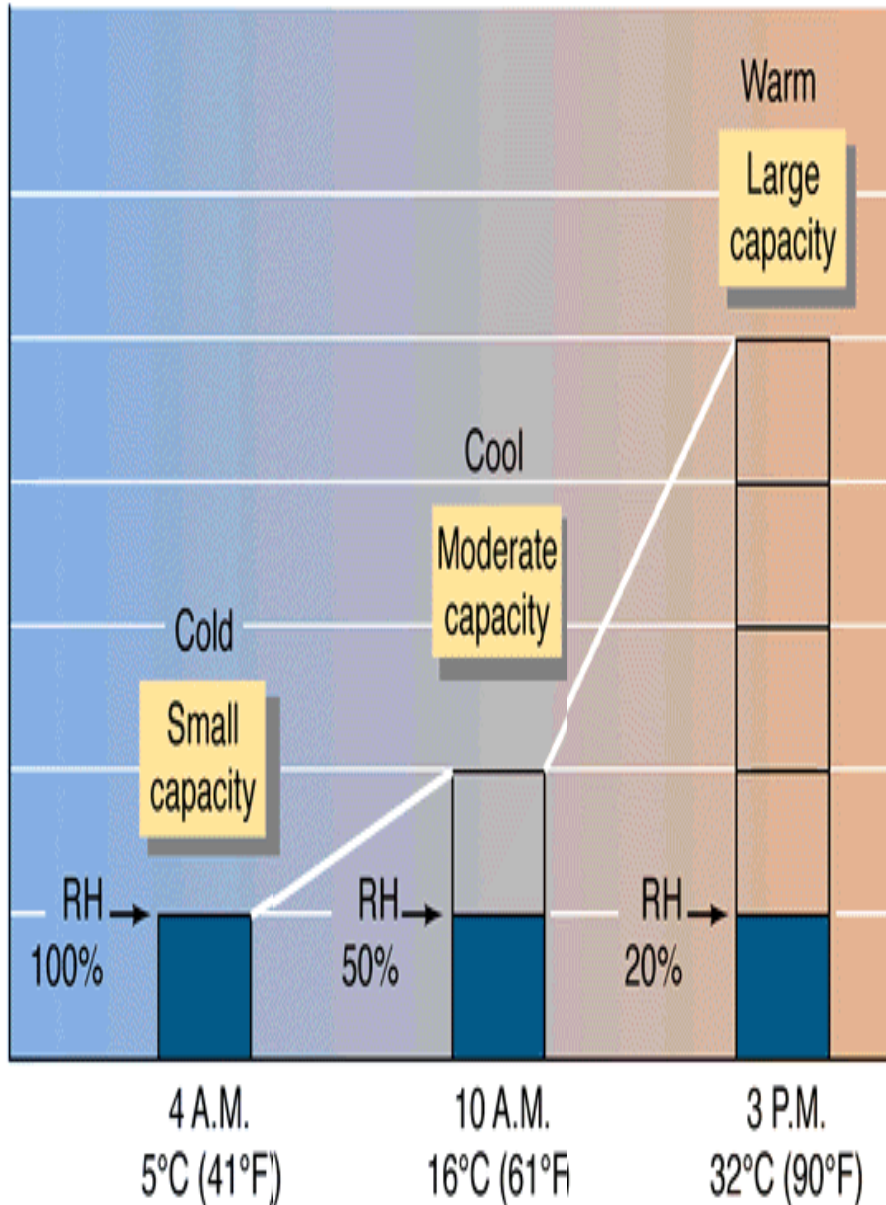




Since water vapor content generally does not vary much during an entire day, changing air temperature primarily regulates the daily variation in relative humidity



During day, relative humidity and temp. have inverse relationship



4 am :

$$T = 5^{\circ}\text{C}$$

$$\text{actual} = 7\text{ g/kg}$$

$$\text{capacity} = 7\text{ g/kg}$$

$$\text{RH} = 7 / 7 \times 100 = 100\%$$

10 am :

$$T = 16^{\circ}\text{C}$$

$$\text{actual} = 7\text{ g/kg}$$

$$\text{capacity} = 14\text{ g/kg}$$

$$7 / 14 \times 100 = 50\%$$

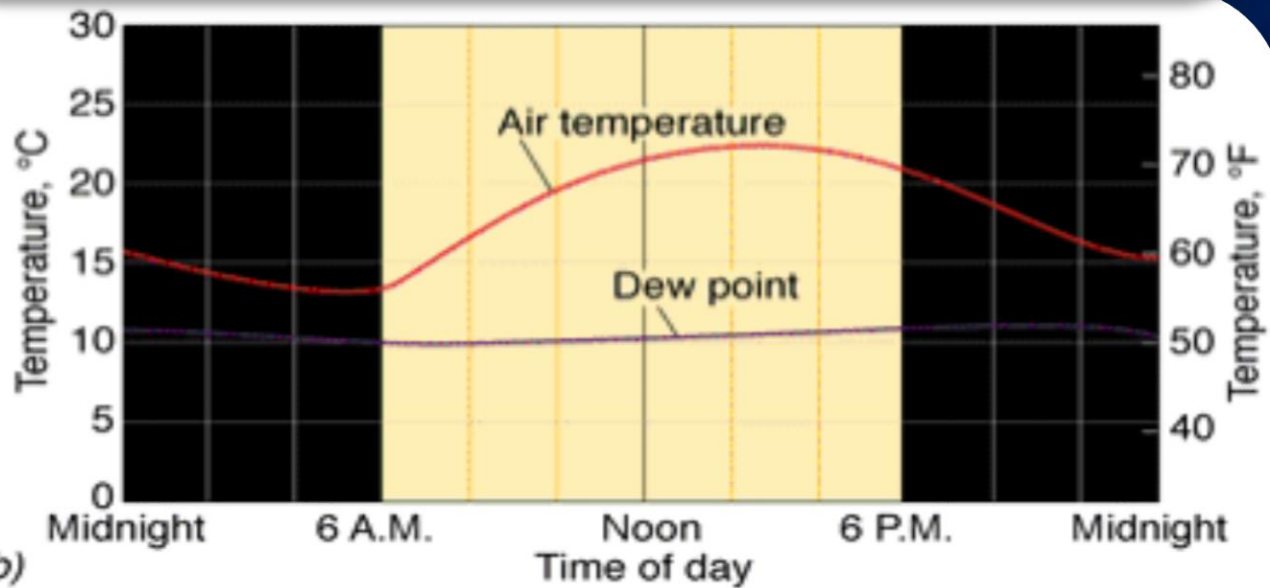
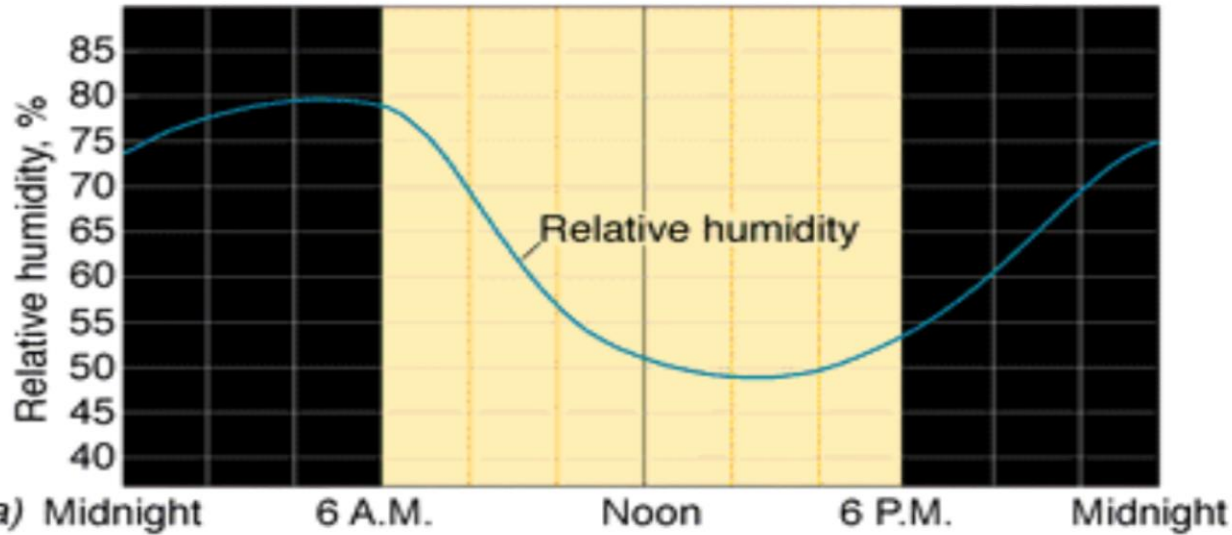
3 pm :

$$T = 32^{\circ}\text{C}$$

$$\text{actual} = 7\text{ g/kg}$$

$$\text{capacity} = 35\text{ g/kg}$$

$$7 / 35 \times 100 = 20\%$$



Data from National Weather Service.



## Specific Humidity

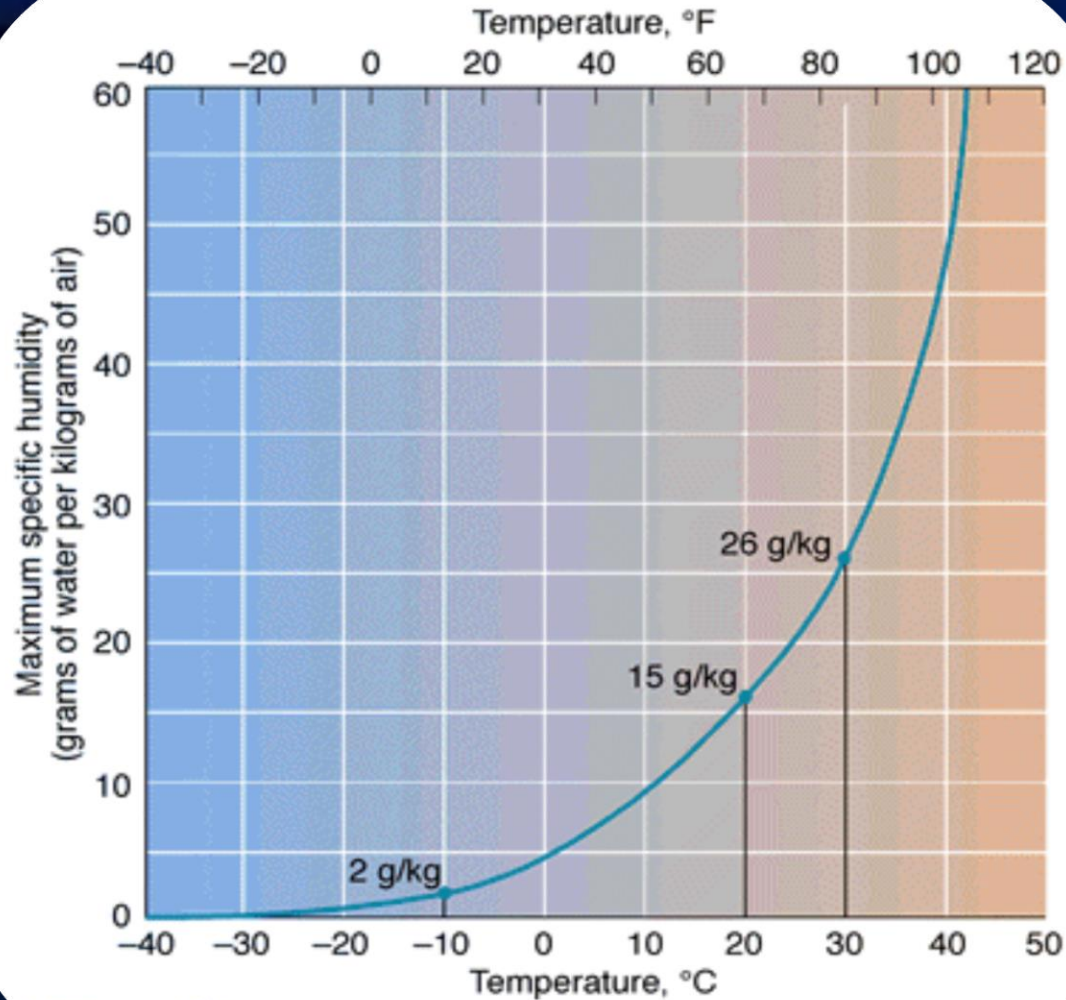
Specific humidity ( $q$ ) - mass of water vapor per unit mass of moist air.  
similar to  $r$ , but slightly smaller values. (g/kg)

$$q = \frac{m_v}{m_v + m_d}$$

$$q = \frac{\rho_v}{\rho_v + \rho_d} = \varepsilon \frac{e}{p - (1 - \varepsilon)e} \approx \varepsilon \frac{e}{p}$$

Warm air can "hold more water" than cold air

Line is maximum (capacity) specific humidity



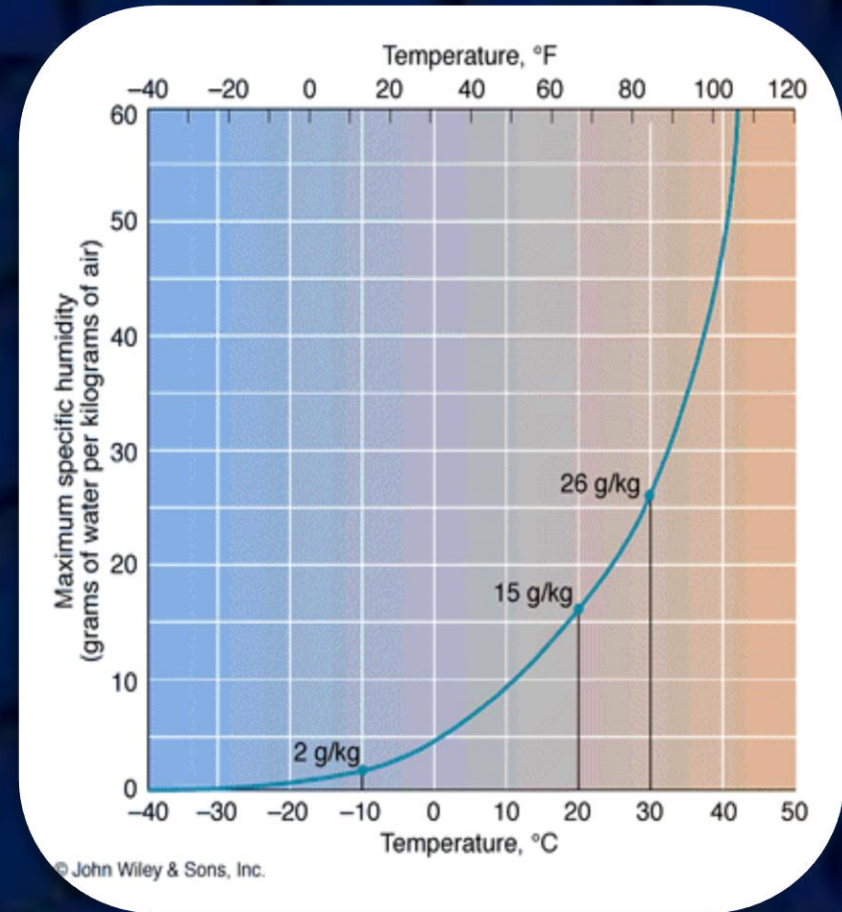
## Calculating RH from specific humidity:

If temperature = 25 °C and actual sp. hum. is 5 g/kg, what is RH?

Solution:

1. Use graph to find capacity amount.

2.  $RH = (5/20) \times 100 = 25\%$

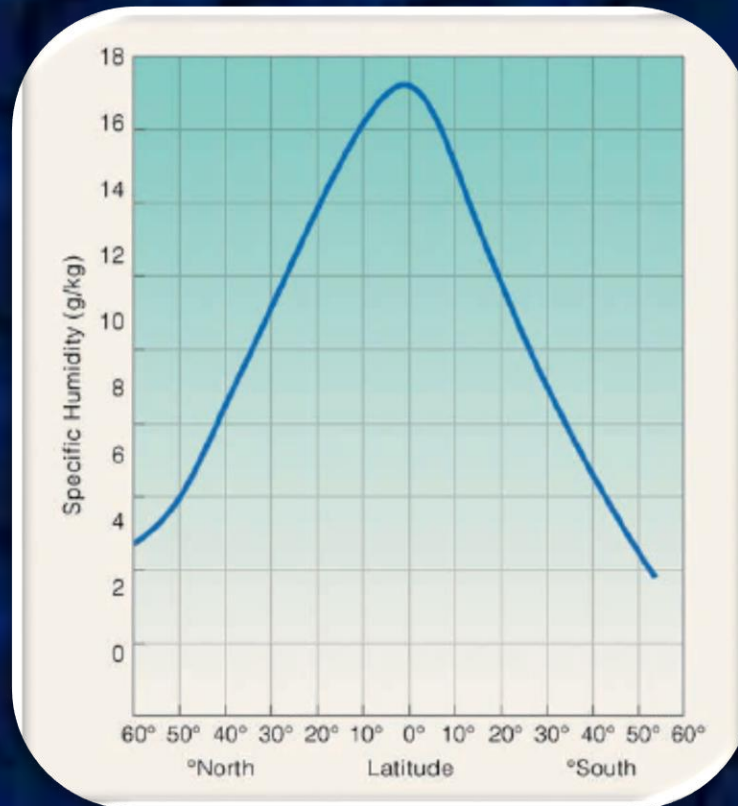




## Figure shows how specific humidity varies with latitude

The average specific humidity is highest in the warm, muggy tropics.

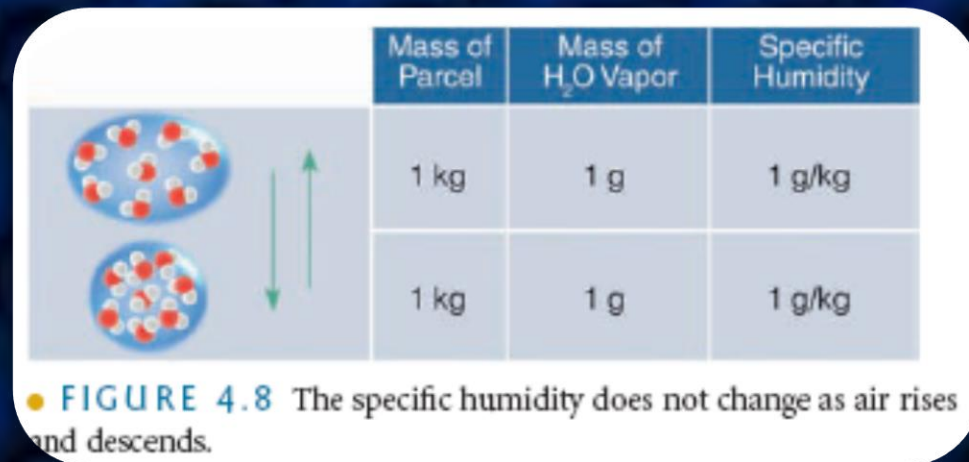
As we move away from the tropics, it decreases, reaching its lowest average value in the polar latitudes.



The specific humidity and mixing ratio of an air parcel remain constant as long as water vapor is not added to or removed from the parcel.

This happens because the total number of molecules (and, hence, the mass of the parcel) remains constant, even as the parcel expands or contracts.

Since changes in parcel size do not affect specific humidity and mixing ratio, these two concepts are used extensively in the study of the atmosphere.



**Dew Point** = Temperature above freezing at which saturation occurs  
(i.e., dew forms)

**Frost Point** = Temperature where saturation occurs below the  
freezing point (i.e., frost forms)



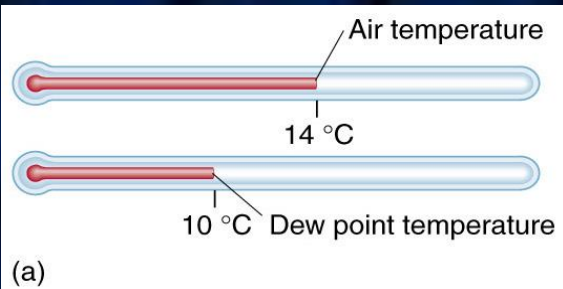
deposition



condensation



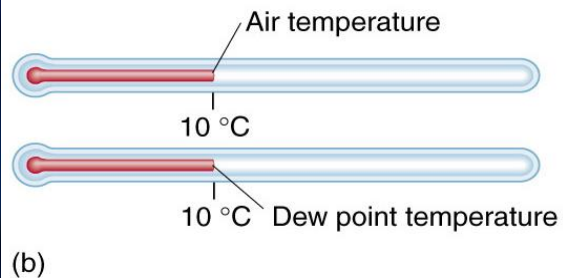
# When the air temperature drops to the dewpoint, the relative humidity is 100%



$$\text{Saturation specific humidity} = 10 \frac{\text{g}}{\text{kg}}$$

$$\text{Specific humidity} = 8 \frac{\text{g}}{\text{kg}}$$

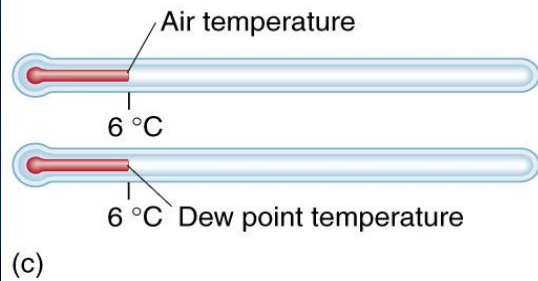
$$\text{RH} = \frac{8}{10} \times 100\% = 80\%$$



$$\text{Saturation specific humidity} = 8 \frac{\text{g}}{\text{kg}}$$

$$\text{Specific humidity} = 8 \frac{\text{g}}{\text{kg}}$$

$$\text{RH} = \frac{8}{8} \times 100\% = 100\%$$



$$\text{Saturation specific humidity} = 6 \frac{\text{g}}{\text{kg}}$$

$$\text{Specific humidity} = 6 \frac{\text{g}}{\text{kg}}$$

$$\text{RH} = \frac{6}{6} \times 100\% = 100\%$$