Chapter Five

Atmospheric Moisture

Water Vapor

Saturation – air that contains as much water vapor as possible (at a given temperature) such that additional water vapor would result in condensation

Unsaturated – air that contains less water vapor (at a given temperature) than possible

Supersaturation – air that contains more water vapor than possible (at a given temperature)

Vapor Pressure – The portion of total pressure exerted by water vapor

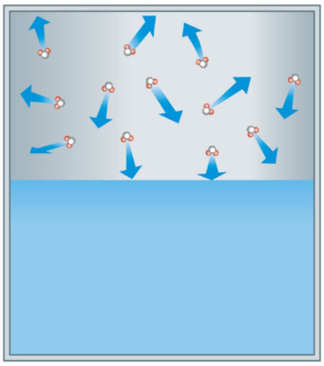
Water Vapor vs. Ice/Water

Evaporation – The transition of liquid molecules into the gaseous phase (water in a bowl disappears)

Condensation – The transition of gaseous molecules into the liquid phase (beads of water on a cold pipe)

Sublimation – The transition of solid molecules into the gaseous phase (an ice museum vanishes)

Deposition – The transition of gaseous molecules into the solid phase (frost on a cold morning)

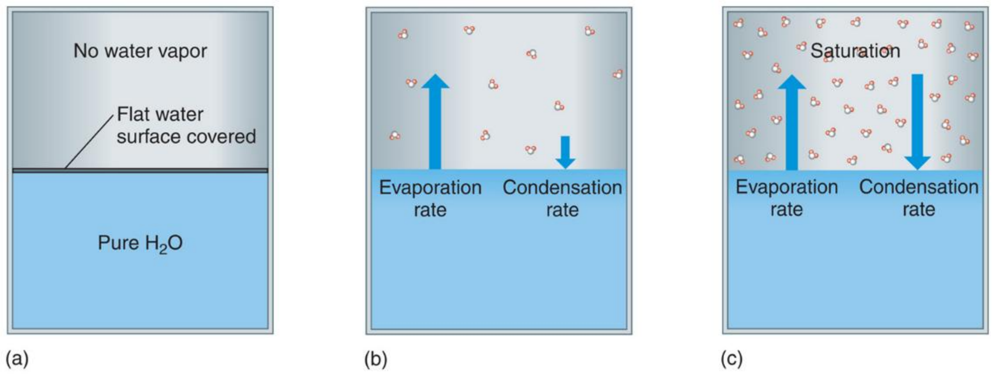


Evaporation and Condensation

2 independent, competing effects

1) Rate of evaporation depends on temperature only
2) Rate of condensation depends on vapor pressure only

Eventually → rate of evaporation = rate of condensation
Saturation (and saturation vapor pressure)



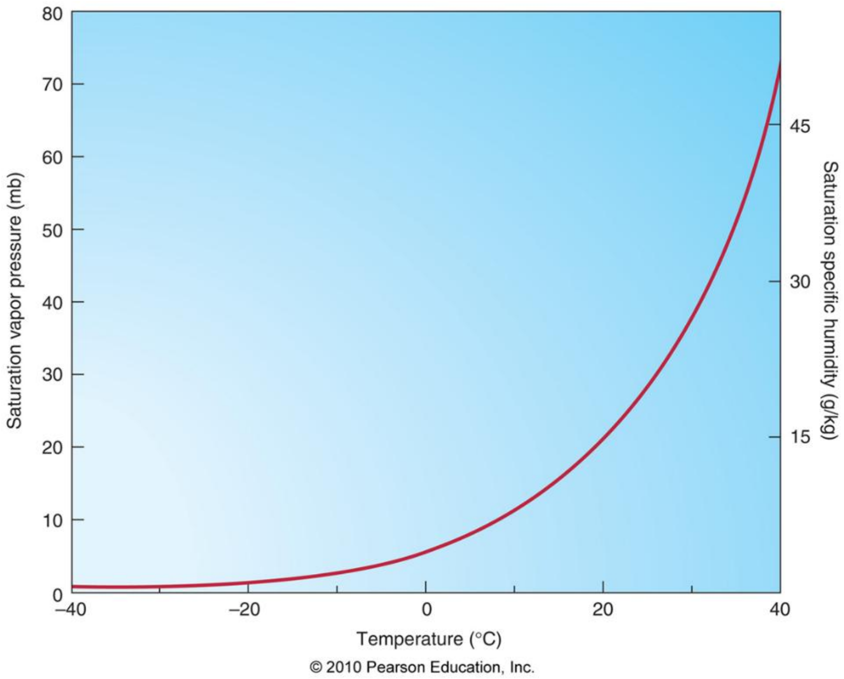
Vapor Pressure

Key ideas:

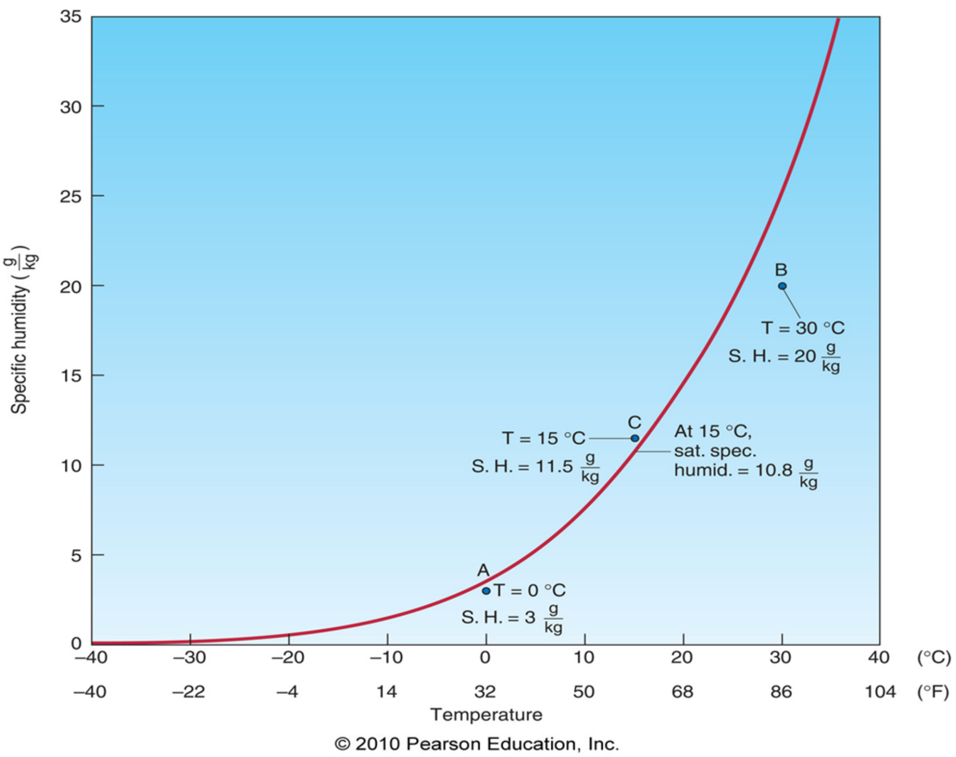
1) Vapor pressure indicates how much water vapor is in the air

2) Saturation vapor pressure indicate how much water vapor could be in the air (depends on temperature)

Saturation Vapor Pressure



Seeing your breath is explained by this curve (as is teakettle steam and steam fog)



Useful Indices of Atmospheric Water Vapor Content

- **Vapor pressure** – the portion of total pressure exerted by water vapor (mb)

- **Saturation vapor pressure** – the vapor pressure at saturation (mb)
- **Specific humidity** – the mass of water vapor in a given mass of air (g/kg)

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

- **Saturation specific humidity** – the specific humidity at saturation (g/kg)

- **Mixing ratio** – the mass of water vapor per mass of dry air (g/kg)

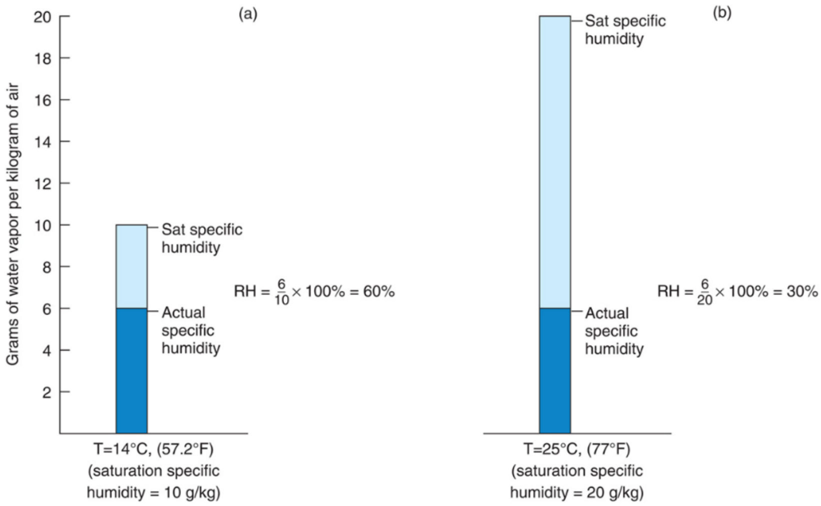
$$r = \frac{m_d}{m_v}$$

- **Saturation mixing ratio** - the mixing ratio at saturation (g/kg)
- **Relative humidity** – the amount of water vapor in the air relative to the maximum possible amount of water vapor in the air (%)

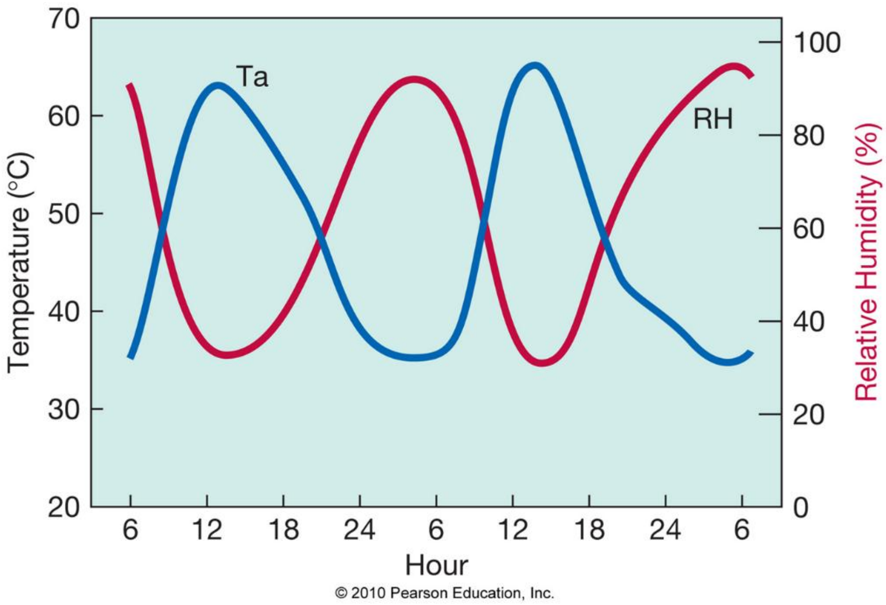
$$RH = \frac{q}{q_s} \times 100\%$$

q = specific humidity

q_s = saturation specific humidity

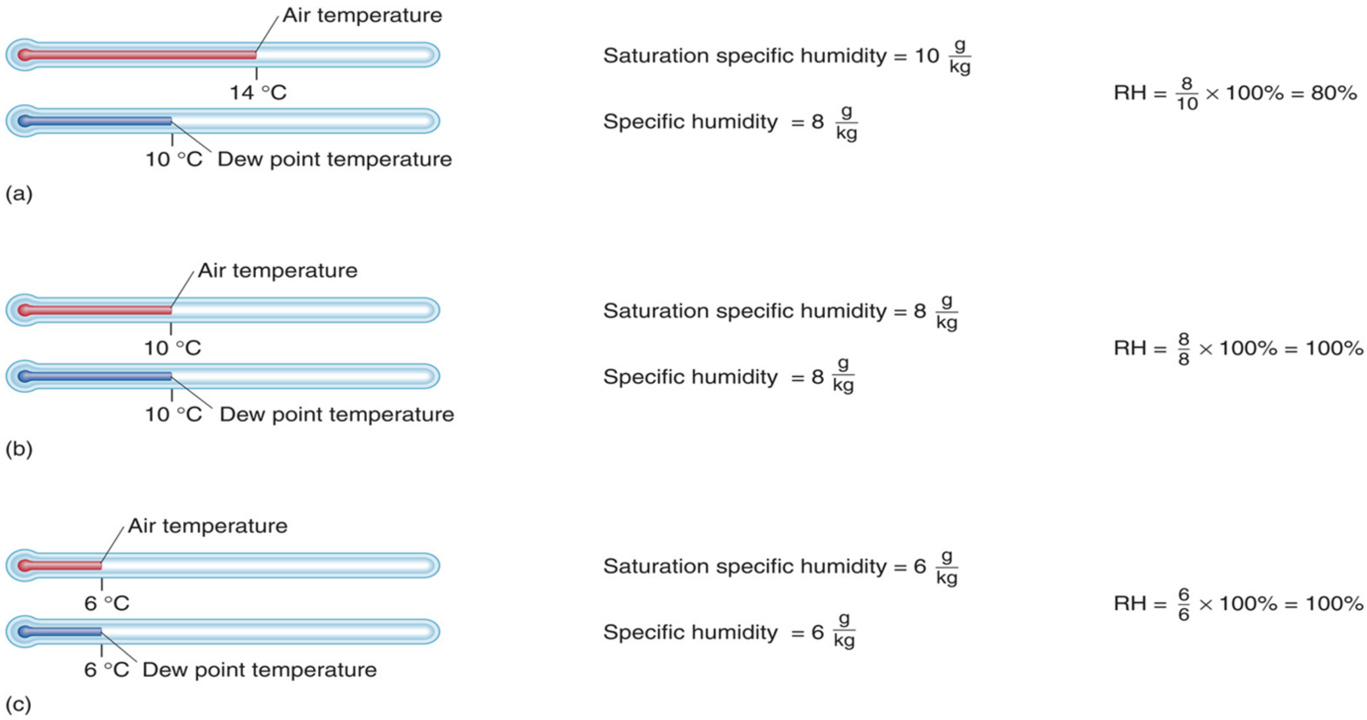


Interesting tidbits
RH doesn't tell you the amount of water vapor in the air
RH does tell you the "evaporative" power of the air
Explains why people need humidifiers indoors in cold climates



Dew Point – the temperature to which air must be cooled to reach saturation

- The dew point tells you how much water is in the air
- The dew point reveals the "evaporative" power of the air through the dew point depression



Dew Point – Exposing a Myth

Have you ever heard somebody say, "It's 35 degrees with 100% humidity"?

They're lying!!!

Here's Why

- Dew points are equal to or less than the temperature of their water source
- The highest dew points occasionally hit 30

<u>A hot, muggy day</u>

Air temperature = 30^{o}C

Dew point = 28^{o}C

Saturation specific humidity at 30^{o}C air temperature = 30 g/kg

Specific humidity at 28^{o}C dew point = 24 g/kg

RH = 24/30 x 100 = 80%

= 67% if Td is 25^{o}C

How much water vapor does exist?

- At a given temperature, air can contain an amount of water vapor equal to or less than the amount at saturation
- Dewpoint reveals how much water does exist in air

Moisture Variables

1) **Vapor pressure**
2) **Specific humidity, mixing ratio**
3) **Relative humidity**
4) **Dew point**

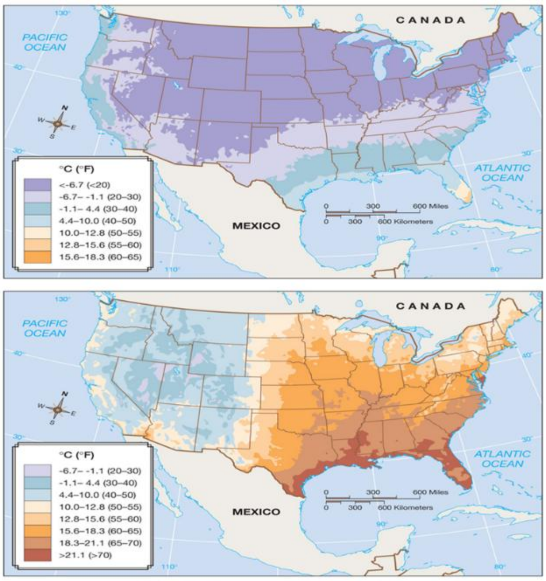
Unsaturated air	Saturated air
Vapor pressure = 14mb	Vapor pressure = 21mb
Saturation Vapor pressure = 21mb	Saturation Vapor pressure = 21mb
Specific humidity = 9 g/kg	Specific humidity = 16 g/kg
Saturation specific humidity = 16 g/kg	Saturation specific humidity = 16 g/kg
Mixing ratio = 9 g/kg	Mixing ratio = 16 g/kg
Saturation mixing ratio = 16 g/kg	Saturation mixing ratio = 16 g/kg
Relative humidity = 56%	Relative humidity = 100%
Dew point = 11oC	Dew point = 20oC

Dew Point – a Forecasting Tool

The dew point is frequently used to forecast nighttime low temperatures – Why?

1) Latent heat release during condensation
2) Absorption and re-emission of longwave radiation by cloud droplets

Distribution of Water Vapor



Measuring Humidity

Sling psychrometer – a pair of thermometers, one with moist cotton around the bulb, that are "slung" around until the wet bulb temperature is reached

Wet bulb temperature (T_W) – the temperature air would have if water was evaporated into it until saturation was reached

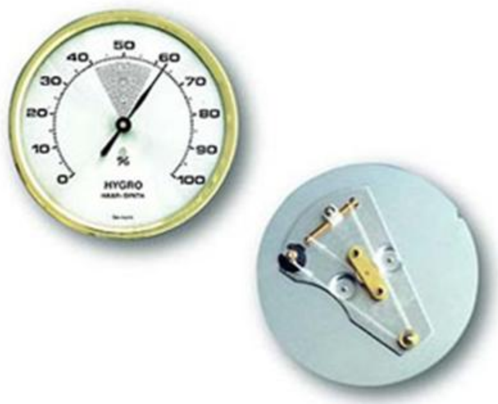
- Tw is always equal to or less than T
- Tw is always equal to or greater than the dew point

Wet bulb depression – the difference between the temperature and the wet bulb temperature

- The wet bulb depression is large for dry air
- The wet bulb depression is small for moist air
- The wet bulb depression is zero for saturated air

Aspirated psychrometers – like a sling psychrometer, but has a fan instead of having to be "slung"

Hair hygrometer – measures humidity based on the expansion and contraction of a strand of hair



Condensation in the Atmosphere

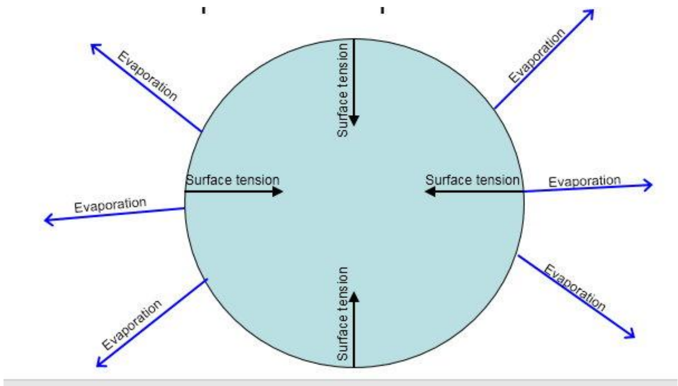
- Condensation is how clouds and fog form
- Condensation occurs when air cools below its dew point
- Condensation requires the presence of atmospheric aerosols

Nucleation – the formation of an airborne water droplet by condensation

Homogeneous nucleation – the formation of water droplets by random collisions of water vapor molecules in the absence of aerosols

- Surface tension "squeezes" the water droplet, forcing rapid evaporation
- ~400% saturation needed for cloud formation!!!

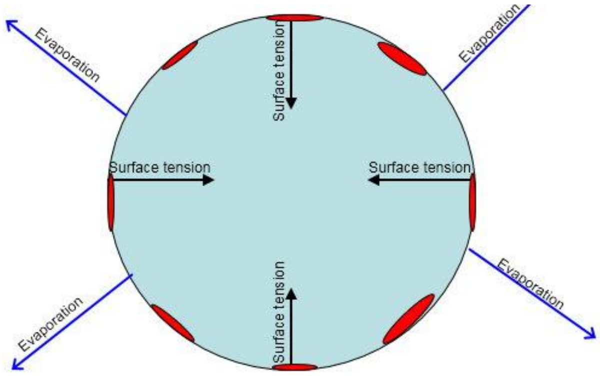
A microscopic water droplet



Heterogeneous nucleation – the formation of water droplets onto aerosols (condensation nuclei)

- Aerosols dissolve in water
- Occurs near saturation
- Can also occur with large, insoluble aerosols (curvature not a strong effect)

A microscopic water droplet (with dissolved aerosol)



Ice Nuclei

Ice nucleii – ice look-a-like aerosols on which ice forms at saturation

- Ice nucleation depends on temperature
  0^{o}C > T > -4^{o}C no ice nucleation
  -4^{o}C > T > -10^{o}C little ice nucleation
  -10^{o}C > T moderate ice nucleation
- The result is that supercooled water exists as fog and clouds at temperatures between 0^{o}C and -10^{o}C
- Below -10^{o}C there is a mix of supercooled water and ice

Cloud- and fog-forming condensation results from cooling in two forms

- Diabatic cooling – heat is removed from the air by its surroundings (example – nighttime cooling of surface air)
- Adiabatic cooling – no heat is exchanged between the air and its surroundings (example – rising air)

Adiabatic Cooling

1st Law of Thermodynamics:

Energy is conserved

Heat added must equal work done plus a change in internal energy (temperature)

$$\Delta H = dw + dq$$

However, no heat is exchanged between air and its surroundings with adiabatic processes

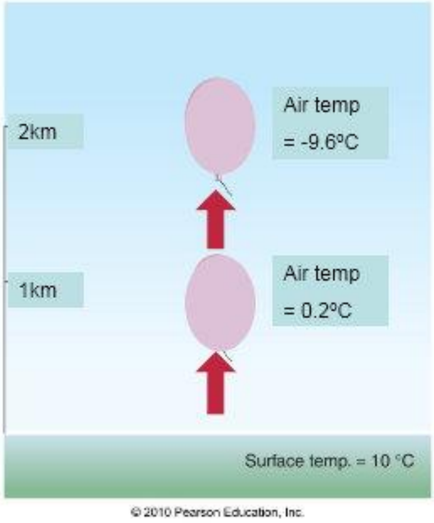
Work done must equal change in temperature ($0 = dw + dq$ or $dw = -dq$)

Adiabatic Cooling and Warming

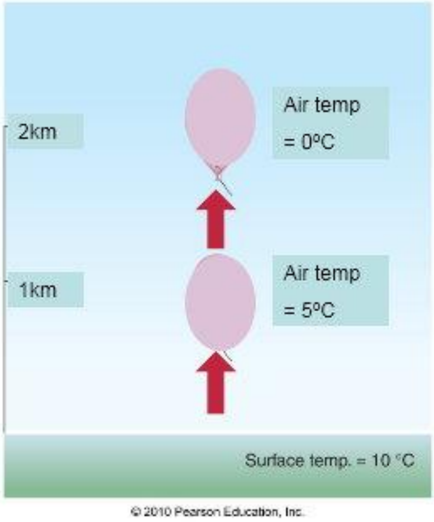
- Dry adiabatic lapse rate – the rate at which unsaturated air cools (warms) as it rises (sinks)
  = 9.8ºC/km (constant)
- Moist adiabatic lapse rate – the rate at which saturated air cools (warms) as it rises (sinks)

  ~ 5ºC/km (variable)

  Less than the dry adiabatic lapse rate???

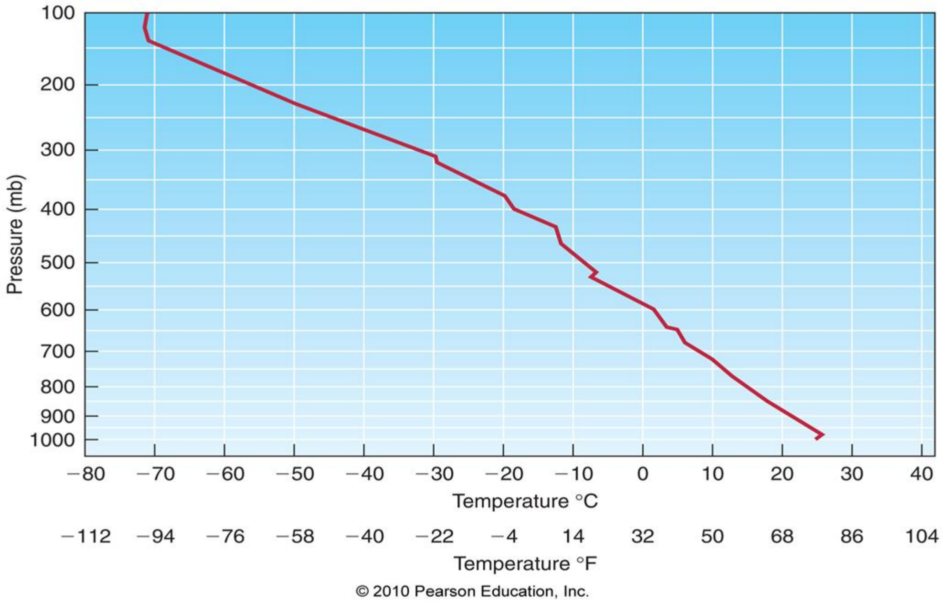


Unsaturated Air (9.8ºC/km)



Saturated Air (5ºC/km)

Environmental lapse rate – the rate at which still air changes with height



Types of Condensation

Dew – condensation of water vapor onto the ground or objects on the ground

Frost – deposition of water vapor onto the ground or objects on the ground

Frozen dew – condensation that freezes

Fog – condensation of water vapor onto airborne aerosols, forming a cloud in contact with the ground

Clouds – condensation of water vapor onto airborne aerosols aloft

Dew

(a)

Frost

(b)

Fog

- **Radiation fog** – fog that forms overnight due to the cooling of air in contact with the ground
  Associated with temperature inversions
- **Advection fog** – fog that forms when warm, moist air moves over a cool surface and cools
- **Upslope fog** – fog that forms due to the cooling of air as it rises up a gentle slope
- **Steam fog** – fog that forms when warm, moist air mixes with cooler air
- **Precipitation fog** – fog that forms when rain evaporates and adds water vapor to ambient air, which then condenses

Advection fog

Steam fog