

Water Vapor and Humidity in the Atmosphere

Lecture 3

Vapor Pressure

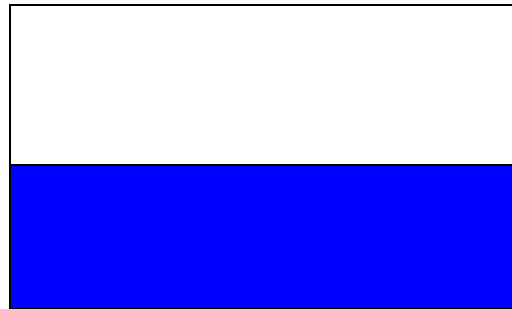
The **vapor pressure (e)** is the pressure exerted by the water vapor molecules in the air.

As the number of water vapor molecules increases, the vapor pressure increases.

Thus, evaporation of water vapor into the air increases the vapor pressure.

What is Saturation?

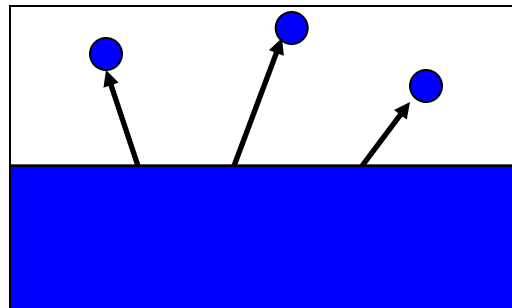
Suppose we have a closed container that is completely empty and we pump some **pure liquid water** into the bottom of the container.



Pure liquid water

What is Saturation? (Cont.)

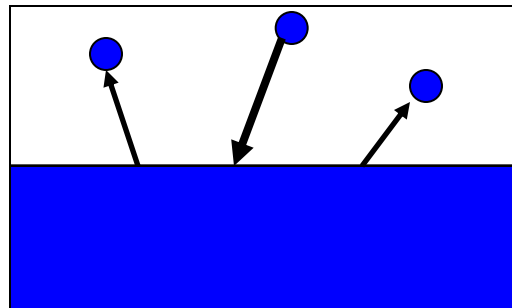
Vibrations associated with the internal energy of the water molecules at the surface will result in some molecules breaking the bonds with their neighbors and evaporating.



Pure liquid water

What is Saturation? (Cont.)

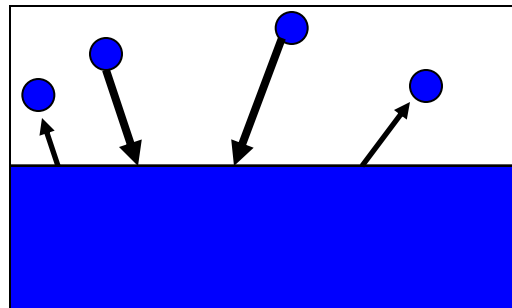
Eventually through collisions with other water vapor molecules and the sides of the container some water molecules will rebound with the surface of the liquid water.



Pure liquid water

What is Saturation? (Cont.)

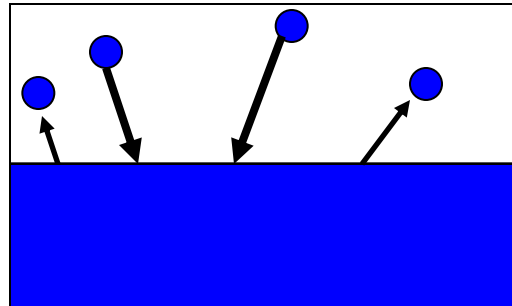
If we leave the container undisturbed and its **temperature remains constant**, eventually there will be equal numbers of water molecules entering and leaving the surface.



Pure liquid water

What is Saturation? (Cont.)

We define **saturation** as the **equilibrium condition** when **equal numbers of water molecules are entering and leaving a flat (plane) surface of pure liquid water.**



Pure liquid water

What is Saturation? (Cont.)

Saturation does not mean that air is holding all the water vapor it can!

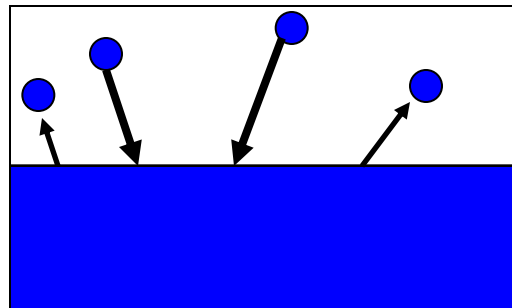
Air is mostly empty space. If there were no dust or other nuclei for water to condense on, then we could evaporate much more water vapor into the air before it started to condense into liquid water.

Saturation Vapor Pressure

The vapor pressure of the air when the saturation equilibrium exists is called the **saturation vapor pressure (e_s)**.

Saturation Vapor Pressure and Temperature

If we **increase the temperature of the water**, then the molecules will have more internal energy and will be vibrating faster.



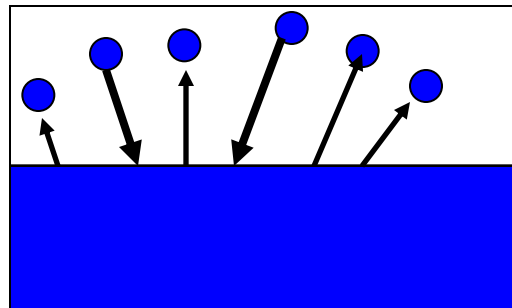
Add energy, increase temperature, molecules vibrate faster

Pure liquid water

Saturation Vapor Pressure and Temperature (Cont.)

More molecules will break free and evaporate from the surface and the vapor pressure will increase.

Add energy, increase temperature, molecules vibrate faster

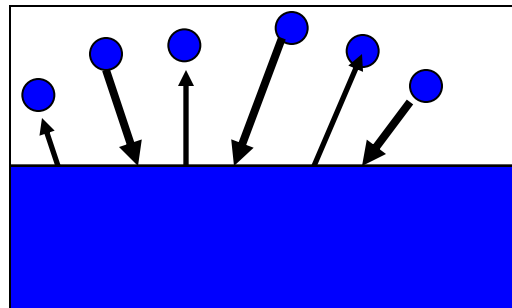


More molecules evaporate and the vapor pressure increases.

Pure liquid water

Saturation Vapor Pressure and Temperature (Cont.)

If we stop increasing the **temperature**, then the system will eventually reach a **new equilibrium** when equal numbers of molecules are entering and leaving the surface again.



Add energy, increase temperature, molecules vibrate faster

More molecules evaporate and the vapor pressure increases.

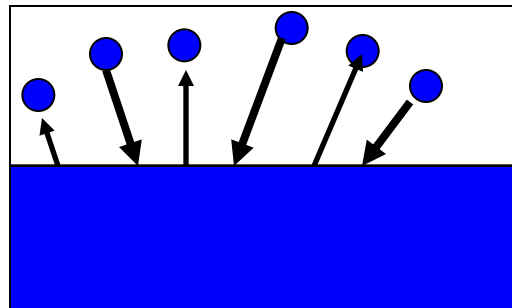
Pure liquid water

Saturation Vapor Pressure and Temperature (Cont.)

There will be a higher saturation vapor pressure when this new equilibrium is reached.

The new equilibrium occurs at a higher saturation vapor pressure.

Add energy, increase temperature, molecules vibrate faster



More molecules evaporate and the vapor pressure increases.

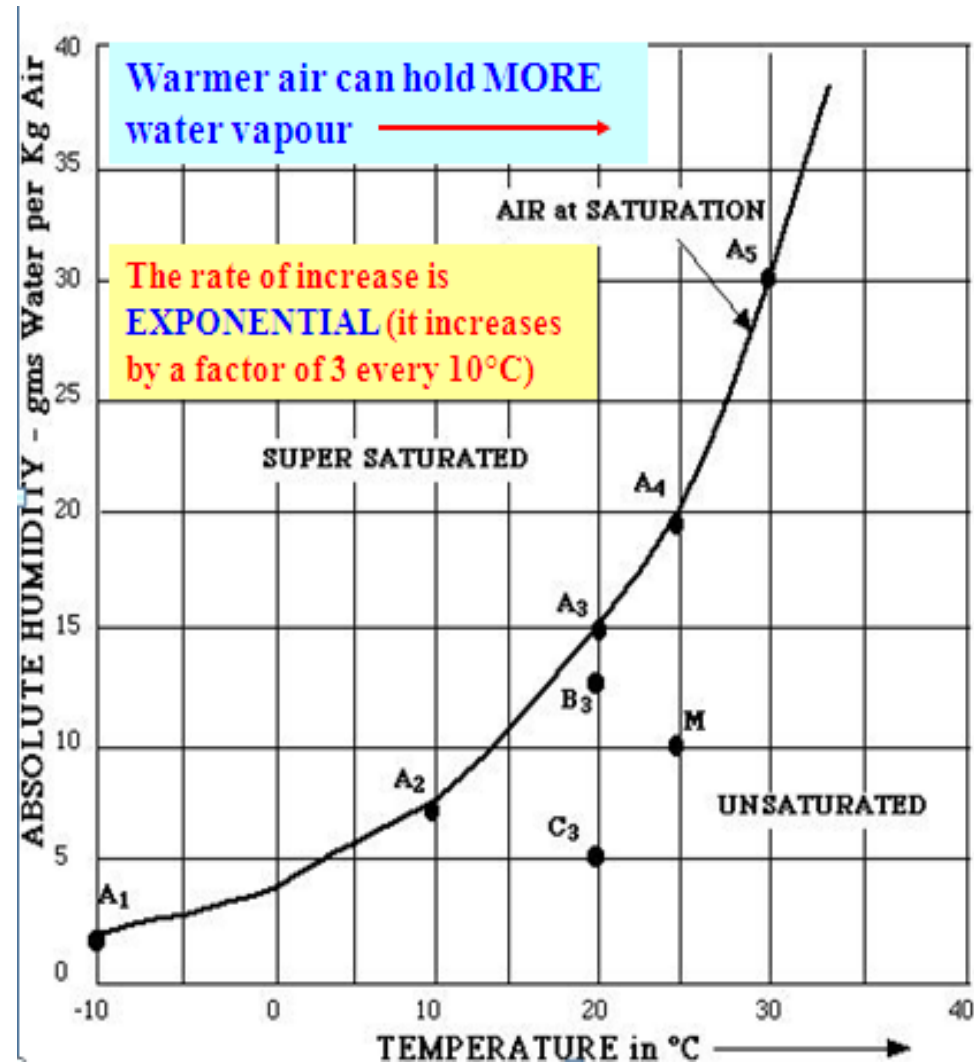
Pure liquid water

Saturation Vapor Pressure and Temperature (Cont.)

Thus, the saturation vapor pressure **increases** when the **temperature increases**.

The saturation vapor pressure at 273.15 K (0°C) is 611 Pa (6.11 mb).

- ◆ **Points A 1-5 are all at 100% relative humidity. B3 is 80%, C3 is 33%, M is 50%.**
- ◆ **For air at temperature and humidity of B3, C3 and M to reach saturation (100% relative humidity) it must either**
 - ◆ **ADD WATER VAPOUR** **OR**
 - ◆ **BE COOLED**



The Clausius-Clapeyron Equation

The **Clausius-Clapeyron** equation is the equation that relates saturation vapor pressure to temperature.

The Clausius-Clapeyron Equation (Cont.)

$$e_s = 611 \text{ Pa } e_{xp}^{(Lv/Rv)[(1/273.15K) - (1/T)]}$$

where

e_s is the saturation vapor pressure in Pa

Lv is the latent heat of vaporization

Rv is the gas constant for water vapor

T is the temperature in Kelvins

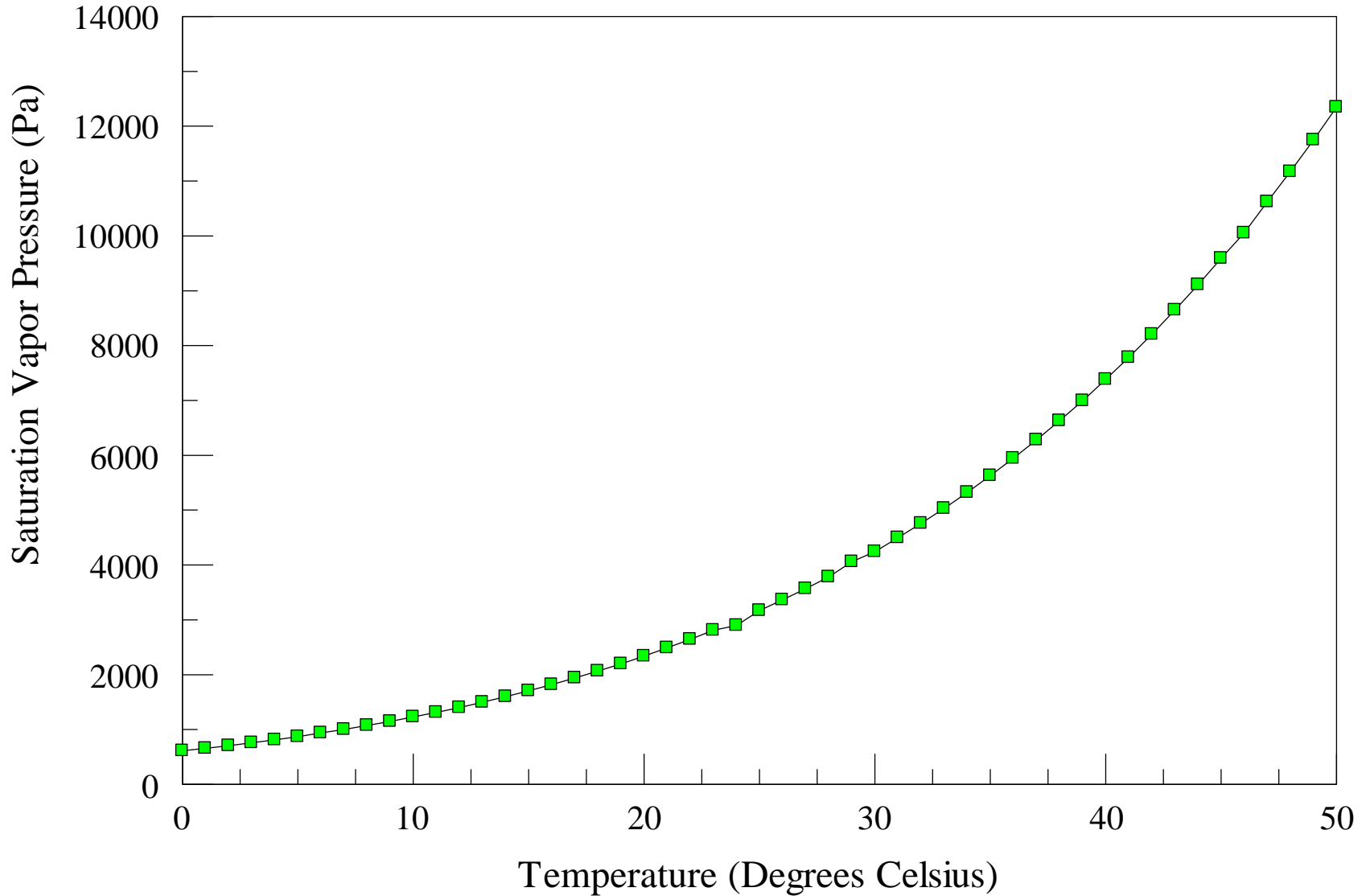
e_{xp} is the base of the natural logarithms

The Clausius-Clapeyron Equation (Cont.)

$$L_v = 2.5 \times 10^6 \text{ J kg}^{-1}$$

$$R_v = 461 \text{ J kg}^{-1} \text{ K}^{-1}$$

Saturation Vapor Pressure Over a Liquid Surface



Saturation Vapor Pressure over Ice

The bonds between adjacent molecules are stronger in an ice surface than they are **in a liquid surface.**

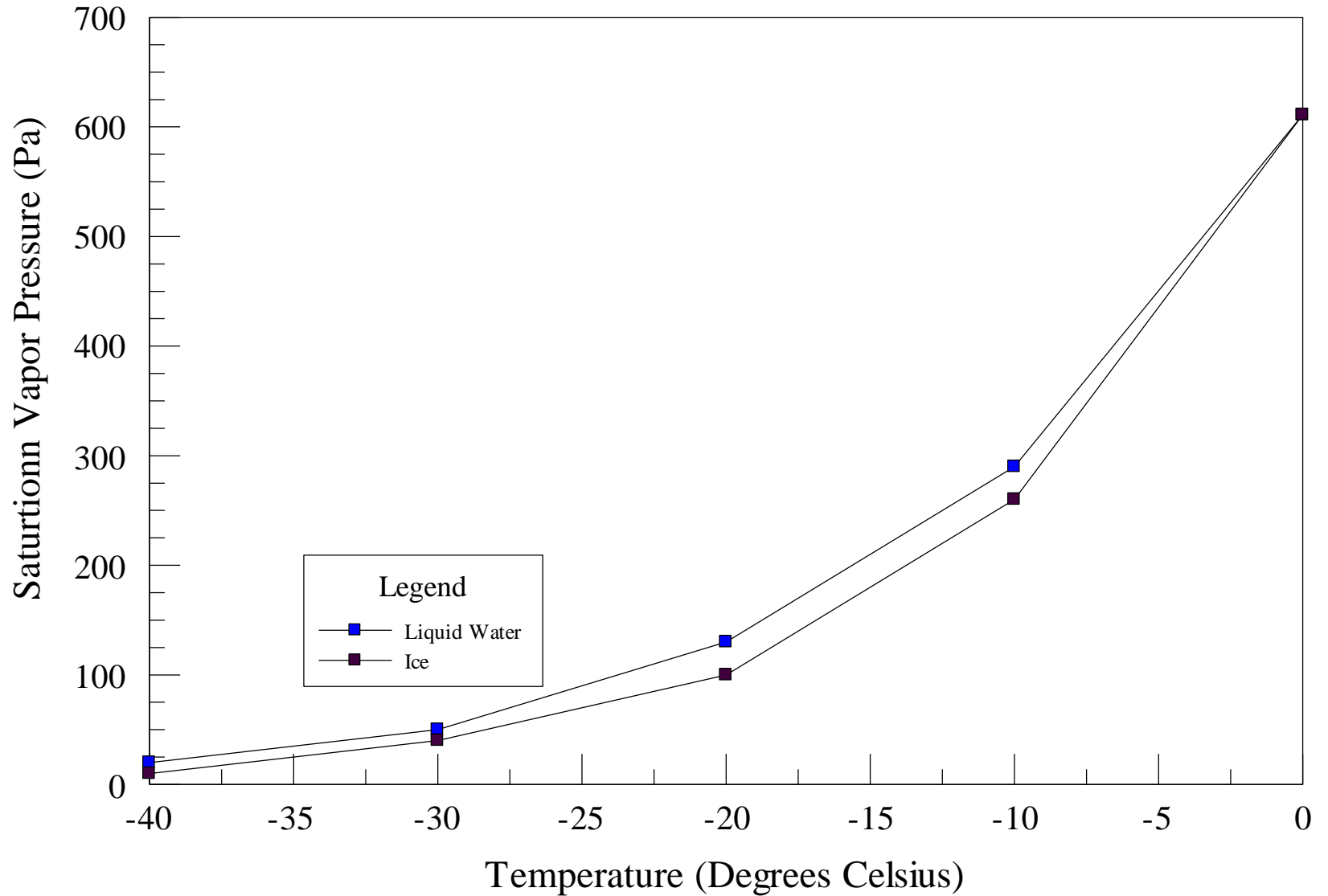
Thus at the same temperature **fewer molecules will escape from an ice surface** than from a **liquid surface.**

Saturation Vapor Pressure over Ice (Cont.)

Therefore **the saturation vapor pressure over ice is lower than the saturation vapor pressure over liquid water.**

This difference in saturation vapor pressure between water and ice plays an important role in the way we think precipitation forms.

Comparison of Saturation Vapor Pressure over Ice and Liquid Surfaces



ABSOLUTE HUMIDITY:

- Absolute humidity is a measure of the actual amount of water vapor (moisture) in the air, regardless of the air's temperature.
- expressed as grams of water vapor per cubic meter volume of air.
- The higher the amount (weight) of water vapor per kilogram, the higher the absolute humidity.

RELATIVE HUMIDITY

- The **relative humidity** is the ratio of the amount of water vapor actually in the air compared to the amount of water vapor required for saturation at that particular temperature and pressure.

Relative Humidity (Cont.)

$$RH = (e/e_s) \times 100\%$$

where

RH is the relative humidity

e is the vapor pressure

e_s is the saturation vapor pressure

Relative Humidity Example

If the vapor pressure is 1200 Pascals and the saturation vapor pressure is 2000 Pascals, what is the relative humidity?

$$\text{RH} = (1200 \text{ Pa} / 2000 \text{ Pa}) \times 100\%$$

$$\text{RH} = 60\%$$

Saturation of Air

There are two ways for air to become saturated.

- (1) evaporate more water vapor into it**
- (2) decrease the temperature**

(1) Evaporating Water Until Air Is Saturated

When water evaporates, the vapor pressure increases. If water evaporates until the vapor pressure is equal to the saturation vapor pressure, then the air is saturated.

(1) Evaporating Water Until Air Is Saturated (Cont.)

In our previous example $e = 1200$ Pa and $e_s = 2000$ Pa. If water evaporated until e was equal to 2000 Pa, then

$$\text{RH} = (2000 \text{ Pa} / 2000 \text{ Pa}) \times 100\%$$

$$\text{RH} = 100 \%$$

and the air would be saturated.

(1) Evaporating Water Until Air Is Saturated (Cont.)

Several types of **fog** form when water evaporates into the air until it becomes saturated.

(2) Decreasing the Temperature of Air Until it Becomes Saturated

As we saw earlier, the saturation vapor pressure is a function of the **temperature**.

If the **temperature decreases**, then the saturation vapor pressure decreases.

If the saturation vapor decreases until it is equal to the vapor pressure, then the air is saturated.

(2) Decreasing the Temperature of Air Until it Becomes Saturated

(Cont.)

In our earlier example $e = 1200$ Pa and $e_s = 2000$ Pa. If the temperature decreased until e_s was equal to 1200 Pa, then

$$\text{RH} = (1200 \text{ Pa} / 1200 \text{ Pa}) \times 100\%$$

$$\text{RH} = 100 \%$$

and the air would be saturated.

(2) Decreasing the Temperature of Air Until it Becomes Saturated

(Cont.)

Dew, many types of **fog**, and **clouds** form when the temperature decreases until air becomes saturated.