General Meteorology

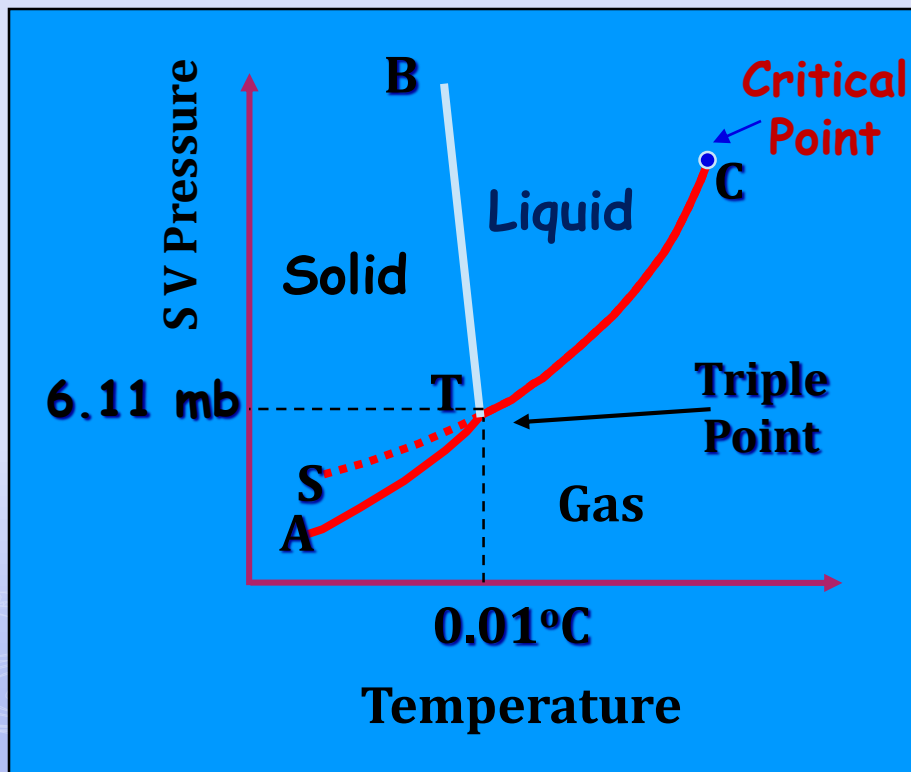## Lecture 8

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http://www.razi.ac.ir/sahraei
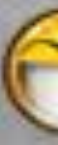
Applications of Clausius-Clapeyron Equation

$$\frac{de_s}{dT} = \frac{L_{12}}{(\alpha_2 - \alpha_1)T}$$

$$\frac{de_s}{dT} = \frac{L_{wv}}{T(\alpha_v - \alpha_w)}$$

$$\frac{de_s}{dT} = \frac{L_{iv}}{T(\alpha_v - \alpha_i)}$$

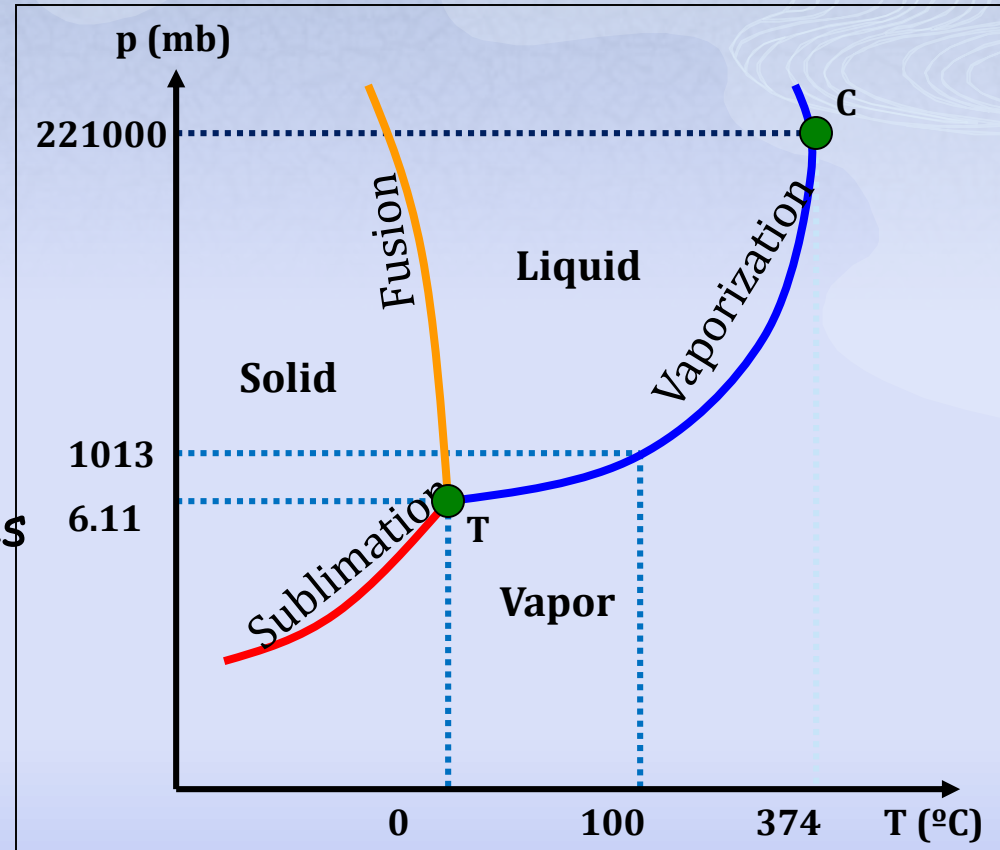$$\frac{de_s}{dT} = \frac{L_{iw}}{T(\alpha_w - \alpha_i)}$$

Water in Equilibrium

Three Standard Equilibrium States:

Vaporization: Gas ↔ Liquid

Fusion: Liquid ↔ Ice

Sublimation: Gas ↔ Solid

• Each of these equilibrium states occur at certain temperatures and pressure

• Thus we can construct an equilibrium phase change graph for water

Provides the mathematical relationship (i.e., the equation) that describes **any** equilibrium state of water as a function of temperature and pressure.

Water in Equilibrium

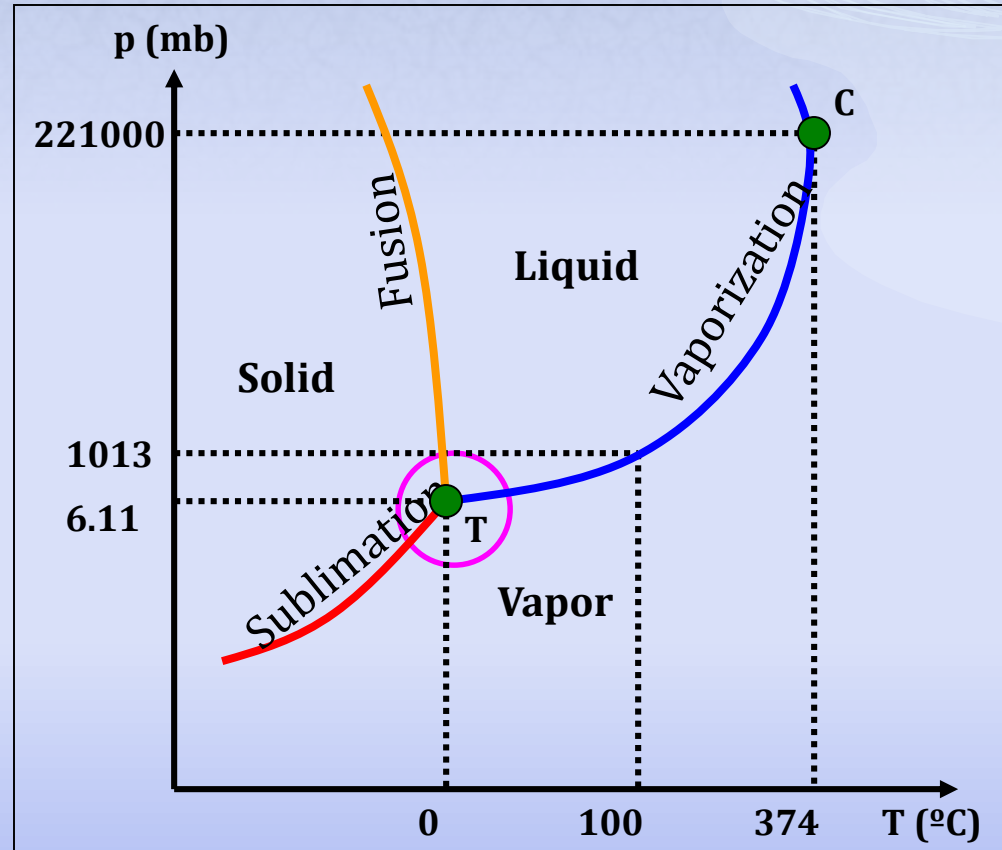**One Unique Equilibrium State:**

• It is possible for all three phases
to co-exist in an equilibrium at a
   single temperature and pressure

• Called the **Triple Point**

$$p_v = p_w = p_i$$

$$T_v = T_w = T_i$$

$$p = 6.11 \ mb$$

$$T = 273.16 \ K$$

Water in Equilibrium

Critical Point:

- Thermodynamic state in which liquid and gas phases can co-exist in equilibrium at the highest possible temperature

$$T_c = 374^o C$$

$$p_c = 221,000 \ mb$$

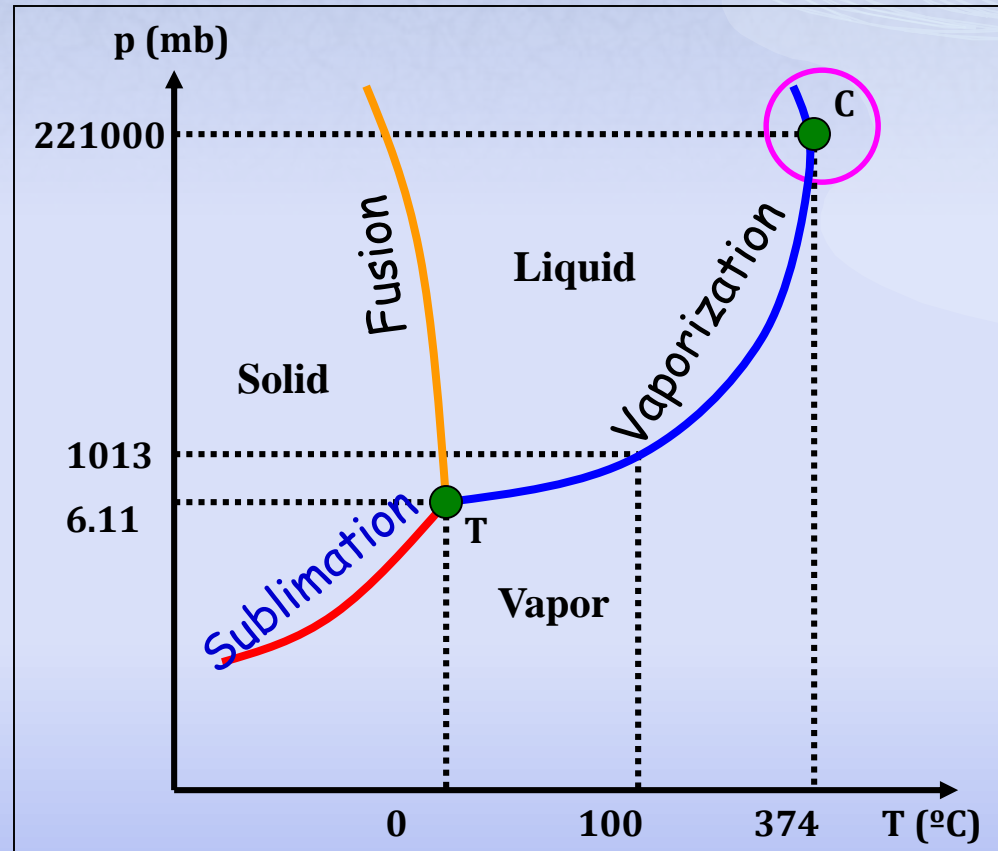- Above this temperature, water can **NOT** exist in the liquid phase

Other Atmospheric Gases:

$$O_2 \quad \rightarrow \quad T_c = -119^o C$$

$$N_2 \quad \rightarrow \quad T_c = -147^o C$$

$$CO_2 \quad \rightarrow \quad T_c = 31^o C$$

Computing saturation vapor pressure for a given temperature:

Version 1:   Assumes constant latent heat of vaporization (L = constant)
                    Less accurate at extreme temperatures

$$\frac{de_s}{dT} = \frac{L_{wv}}{(\alpha_v - \alpha_L)T}$$

$$e_s\,\alpha_v = R_v T$$

$$\frac{de_s}{dT} = \frac{L_{wv}\,e_s}{R_v T^{\,٢}}$$

$$e_{sw}\,(mb) = 6.11\ exp\left[\frac{L}{R_v}\left(\frac{1}{273.15} - \frac{1}{T(K)}\right)\right]$$

Saturated Adiabatic Lapse Rate

Temperature Changes Inside Clouds

Two processes occur simultaneously inside clouds that affect the temperature.

(1) Rising air expands, does work and cools;

(2) Condensation releases latent energy which is then stored as internal energy and warms the air inside the cloud.

Normally, the cooling due to the work of expansion is greater than the warming associated with the release of latent energy and its conversion to internal energy.

Thus, as air rises inside a cloud it still gets **colder**, but it does so at a slower rate than the Dry Adiabatic Lapse rate.

The rate at which rising air inside a cloud cools is called the **Saturated Adiabatic Lapse Rate (SALR).**

The Saturated Adiabatic Lapse Rate (SALR)

The derivation of the equation for the SALR begins with a form of the First Law of Thermodynamics

$$d q = c_p \, dT - \alpha \, dp$$

In this case the energy gained, **dq**, is equal to the latent energy released when water vapor condenses inside the cloud.

$$d q = -L_{vw} \, dq_v$$

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

where
L$_{wv}$ is the latent heat of vaporization, and

dq$_v$ is the change of specific humidity of the air parcel when water vapor condenses

Substitute for **dq** in the First Law of thermodynamics to get

$$-L_{vw}\,dq_v = c_p\,dT - \alpha\,dp$$

Add **−c$_p$dT + L$_{vw}$dq$_v$** to both sides to get

$$-c_pdT = -\alpha dp + L_{vw}dq_v$$

Divide by **c$_p$dz** to get

$$\frac{-c_p\,dT}{c_p\,dz} = \frac{-a\,dp}{c_p\,dz} + \frac{L_{vw}\,dq_v}{c_p\,dz}$$

$$\frac{-dT}{dz} = \frac{-dp}{c_p\,\rho\,dz} + \frac{L_{vw}\,dq_v}{c_p\,dz}$$

Since **α = 1/ρ**

$$g = \frac{-dp}{\rho\,dz}$$

$$\frac{-dT}{dz} = \frac{g}{c_p} + \frac{L_{vw} \, dq_v}{c_p \, dz} = \Gamma_s$$

SALR = cooling due to work of expansion **+** warming due to latent energy released during condensation

The SALR is always *less* than the DALR because the cooling caused by adiabatic expansion *is partially offest by the release of latent energy during condensation.*

The SALR is a variable.

The magnitude of the SALR is determined by *the amount of water vapor that condenses.*

Moist Adiabatic Rate
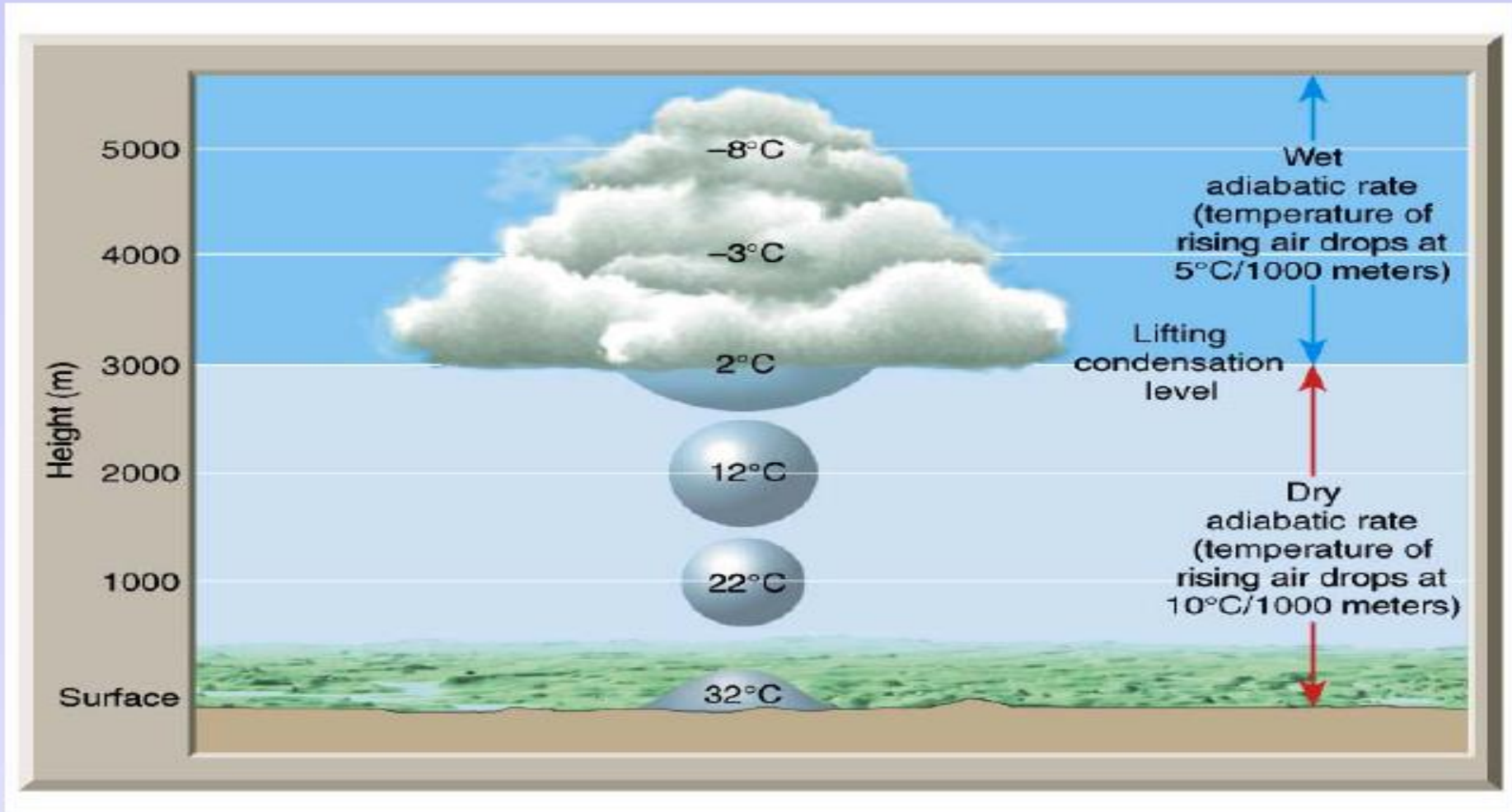
LCL: the level in the atmosphere at which an unsaturated air parcel lifted dry adiabatically would become saturated.