General Meteorology

Lecture 7

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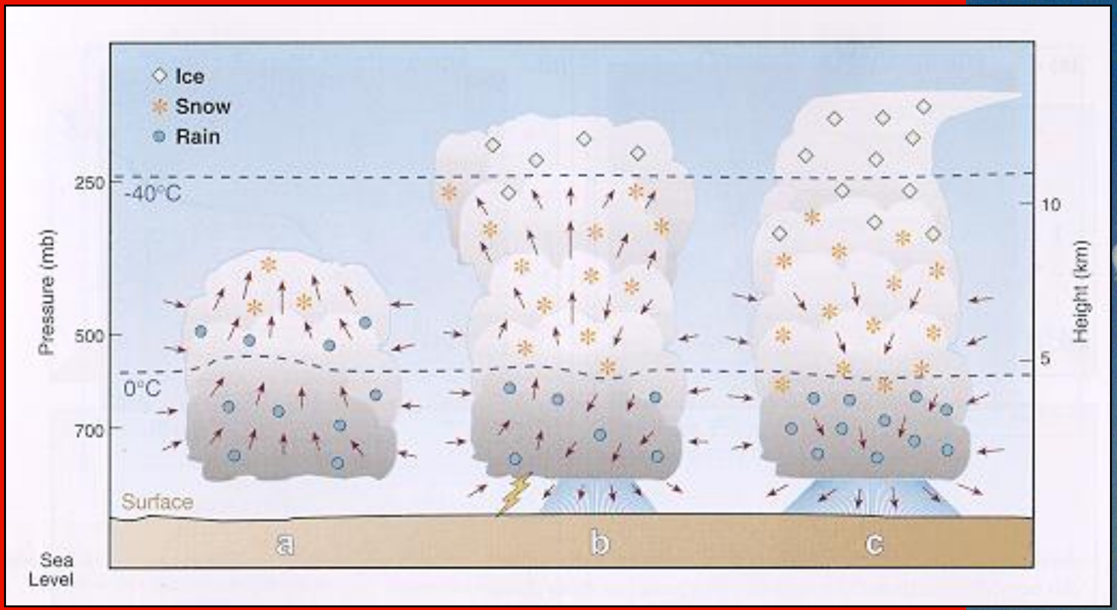
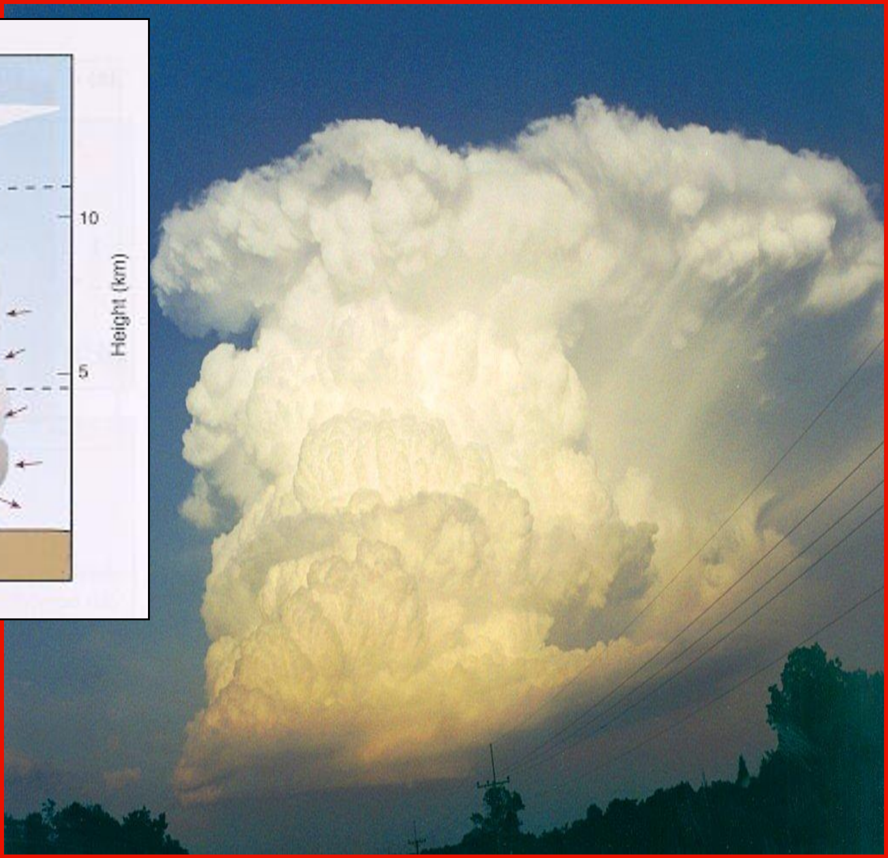
Water Vapor and its thermodynamic effects

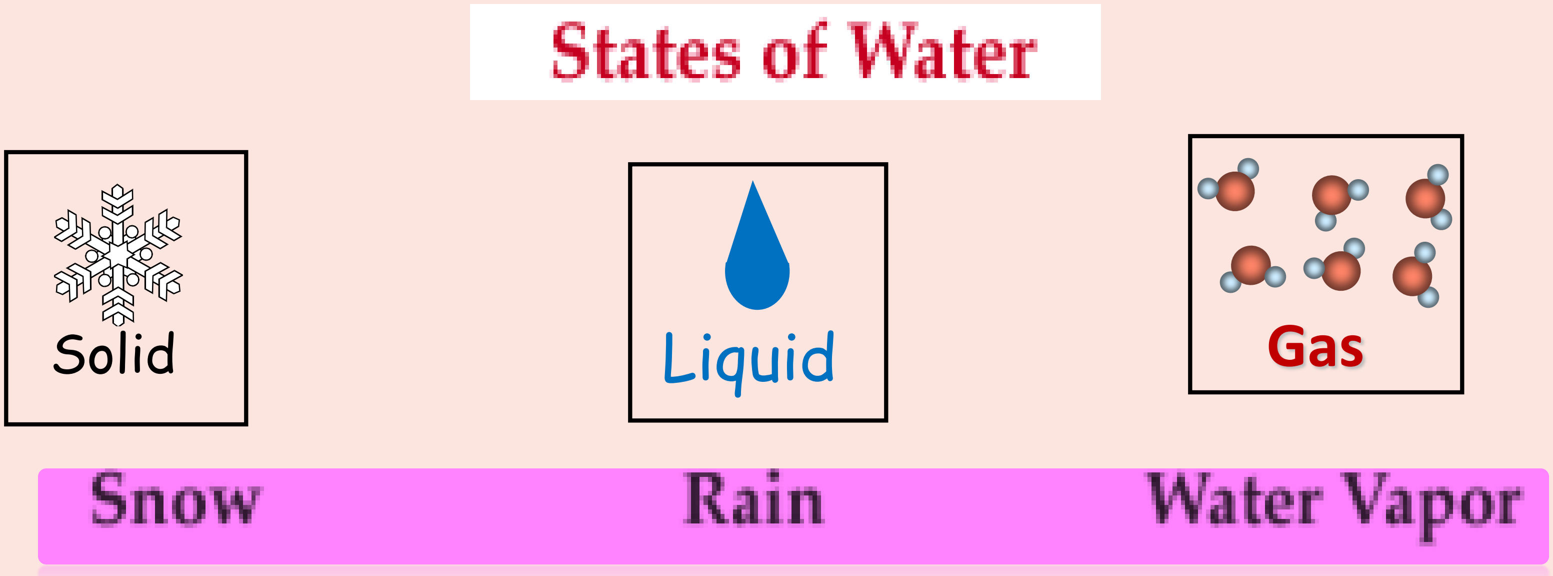




Our atmosphere contains dry air and water vapor
Clouds contain dry air, water vapor, liquid water, and ice

Water In the Atmosphere

Unique Substance



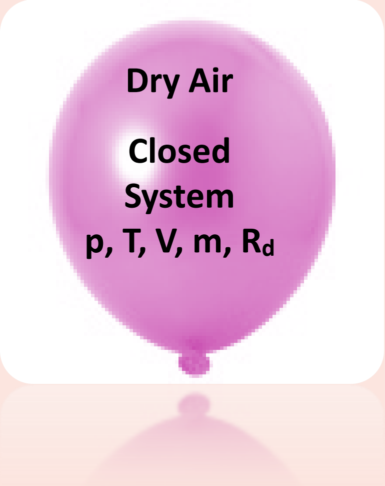
Occurs in Three Phases Under Normal Atmospheric Pressures and Temperatures

Gaseous State

Variable 0 – 4%

System: Any specific sample of matter
(Examples: an "air parcel" or the air within a balloon)

- Thus far we have worked exclusively dry air only closed system
(no mass exchange, but some energy exchange)



- What about water vapor?

- What about the combination of dry air and water vapor?

- What about the combination of dry air, water vapor, and liquid/ice water?

$$p\alpha = R_d T$$

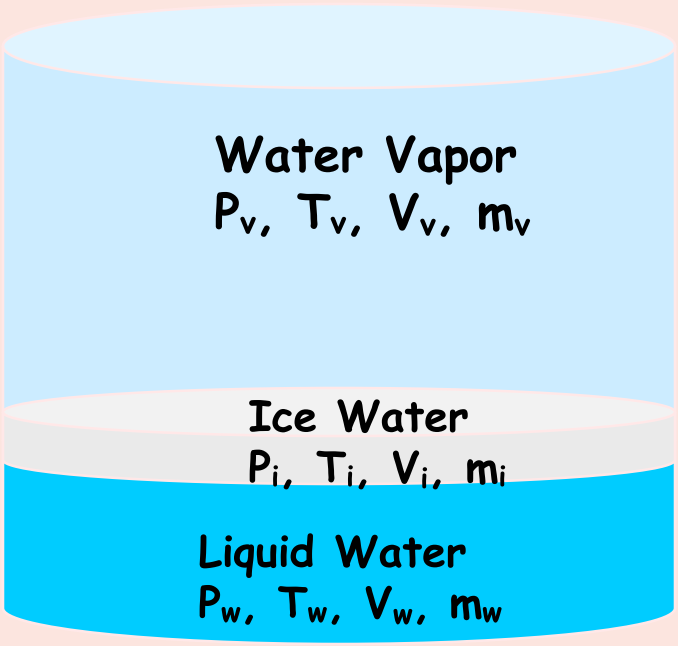
$$dq = c_v dT + pd\alpha$$

$$ds = \frac{dq_{rev}}{T}$$

Review of Systems

Heterogeneous Systems:

- Comprised of a single component in multiple phases or multiple components in multiple phases
  - Water (vapor, liquid, ice)
- Each component or phase **<u>must</u>** be defined by its own set of state variables



Thermodynamic Properties of Water

Single Gas Phase (Water Vapor):

- Can be treated like an ideal gas when it exists in the absence of liquid water or ice (i.e. like a homogeneous closed system):

$$\boxed{p_v = \rho_v R_v T_v} \qquad \boxed{e\alpha_v = R_v T_v}$$

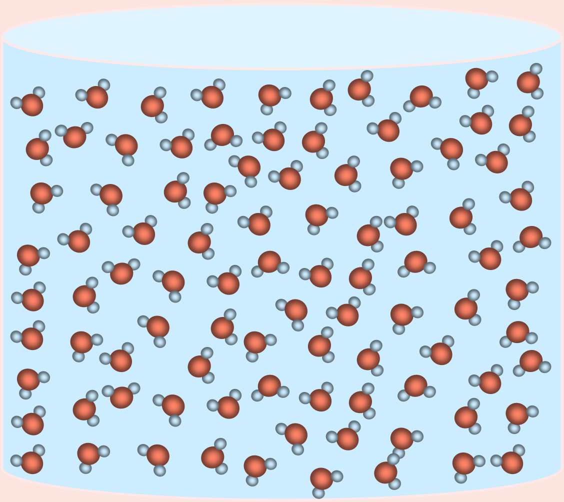
$$R_v = \frac{R^*}{M} = \frac{8314}{18} = 461.5 \ Jkg^{-1}k^{-1}$$

p_v = Partial pressure of water vapor
(called **vapor pressure**)

ρ_v = Density of water vapor (or **vapor density**)
(The mass of the H_2O molecules)
(per unit volume)

T_v = Temperature of the water vapor

R_v = Gas constant for water vapor
(Based on the mean molecular weights)
(of the constituents in water vapor)



$$dq = c_v dT + pd\,\alpha$$

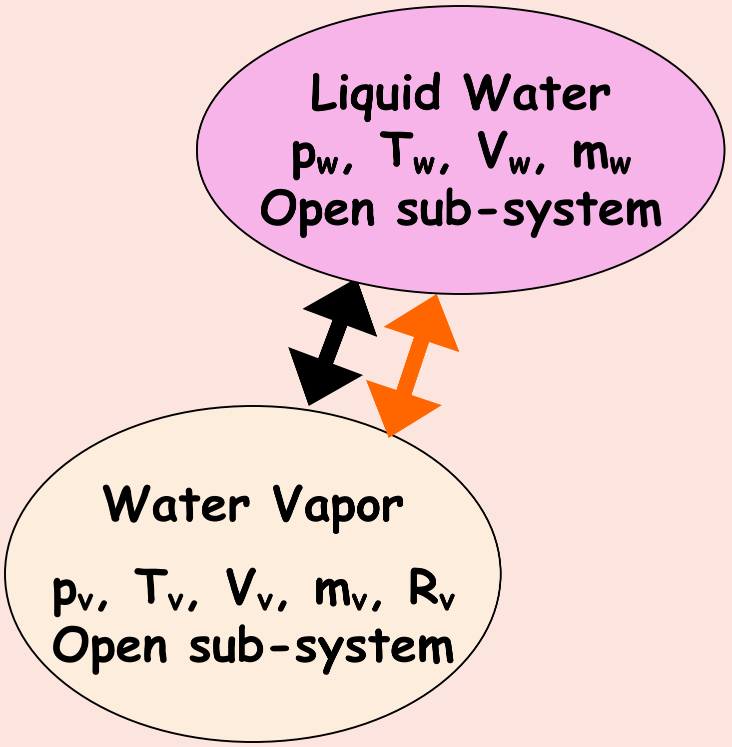
$$ds = \frac{dq_{rev}}{T}$$

Thermodynamic Properties of Water

Multiple Phases:

- Can NOT be treated like an ideal gas when water vapor **co-exists** with either liquid water, ice, or both:

$$p_v = \rho_v R_v T_v \qquad p_w = \rho_w R_w T_w$$



- This is because the two sub-systems can exchange mass between each other when an equilibrium exists

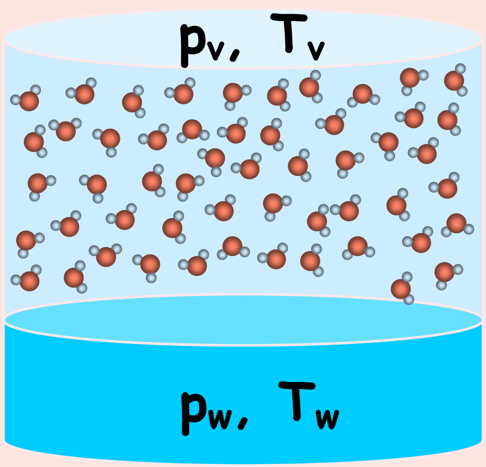
- This violates the Ideal Gas Law

Water in Equilibrium

Multiple Phases:

- When an equilibrium exists, the thermodynamic properties of each phase are equal:

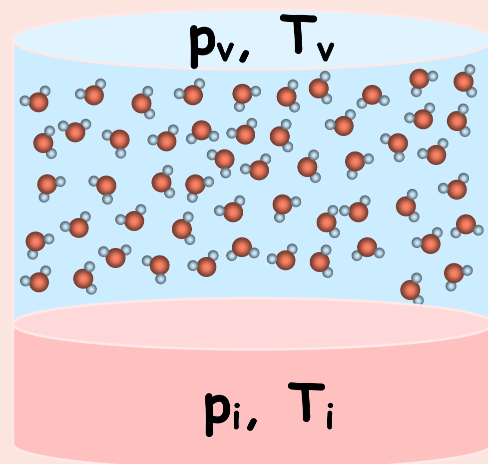
Vapor and Liquid



$$p_v = p_w$$

$$T_v = T_w$$

Vapor and Ice

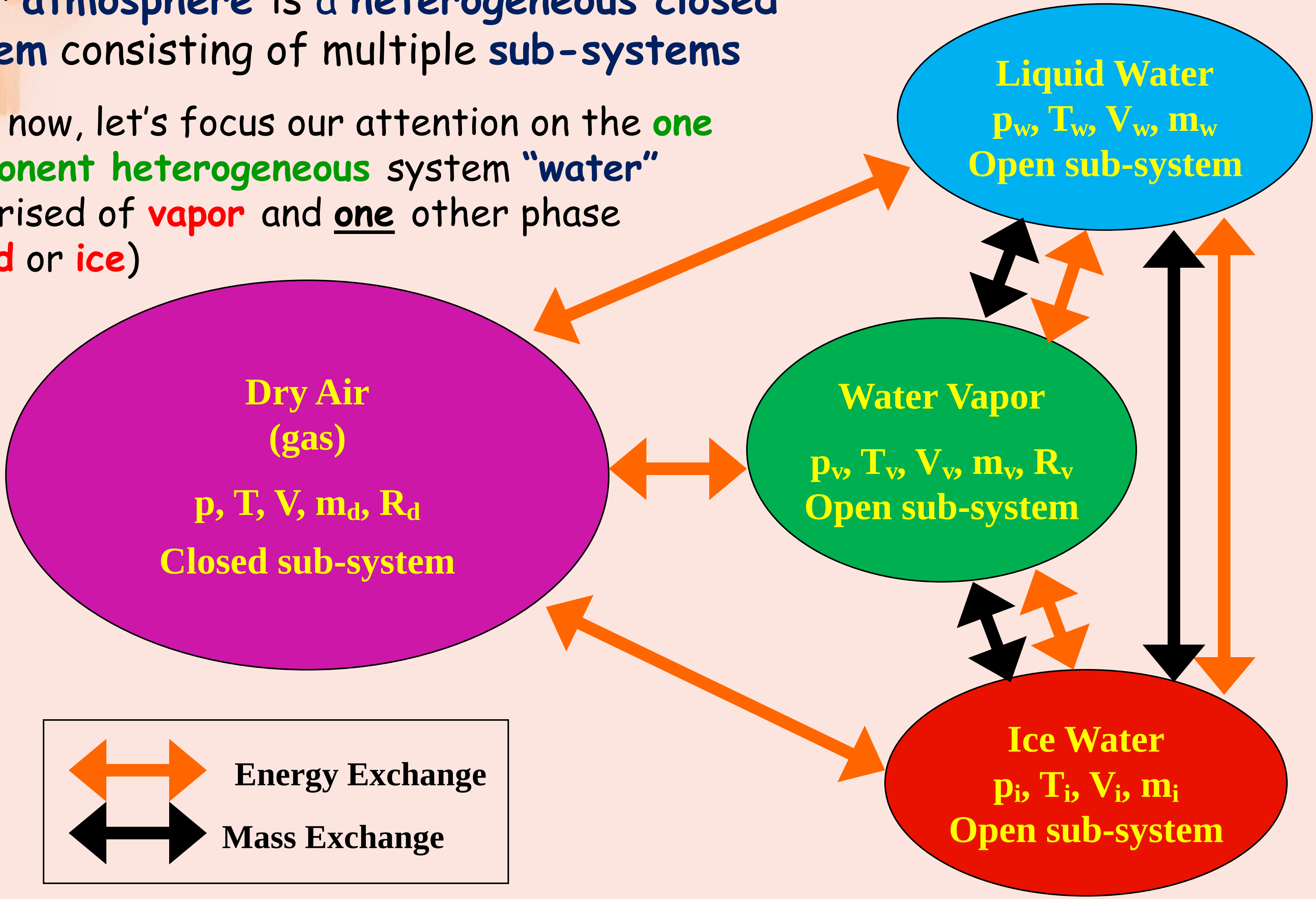


$$p_v = p_i$$

$$T_v = T_i$$

Review of Systems

- Our **atmosphere** is a **heterogeneous closed system** consisting of multiple **sub-systems**
- For now, let's focus our attention on the **one component heterogeneous** system **"water"** comprised of **vapor** and **one** other phase (**liquid** or **ice**)

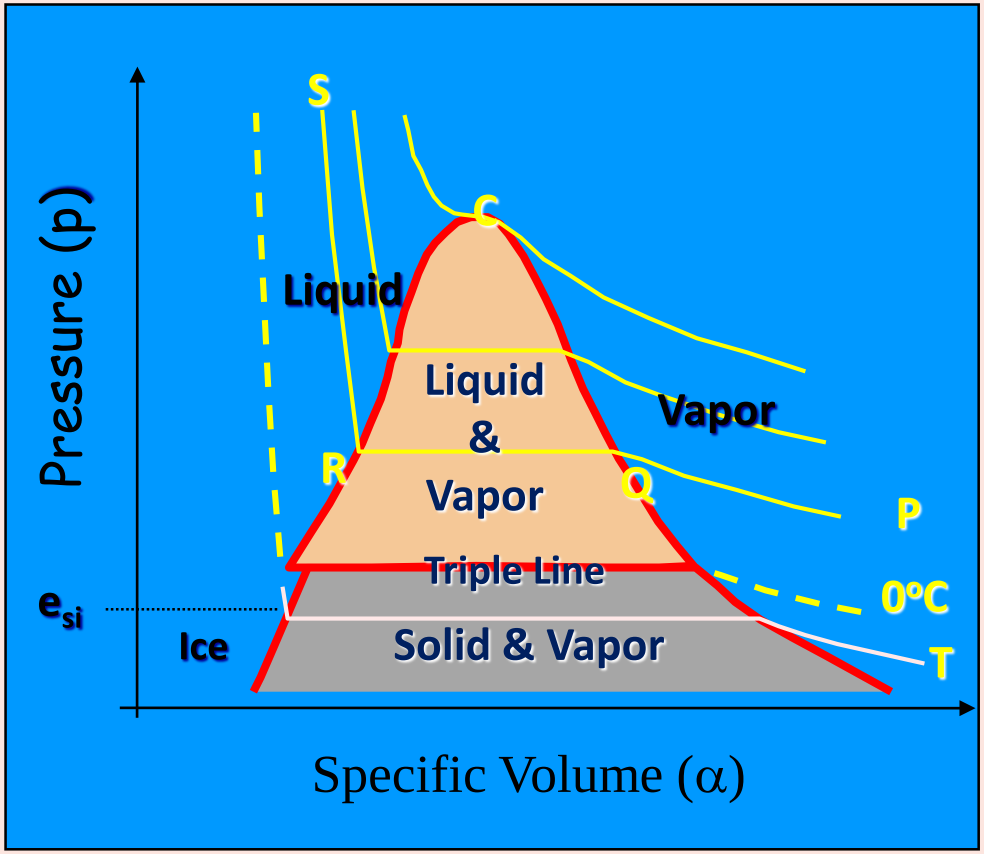


سه حالت آب

هرگاه بخار آب از حالت میعان یا تبلور دور باشد مثلا در شرف تبدیل به آب یا یخ نباشد تقریبا مانند گاز ایده آل رفتار می کند

Phase Change (p- α Diagram)

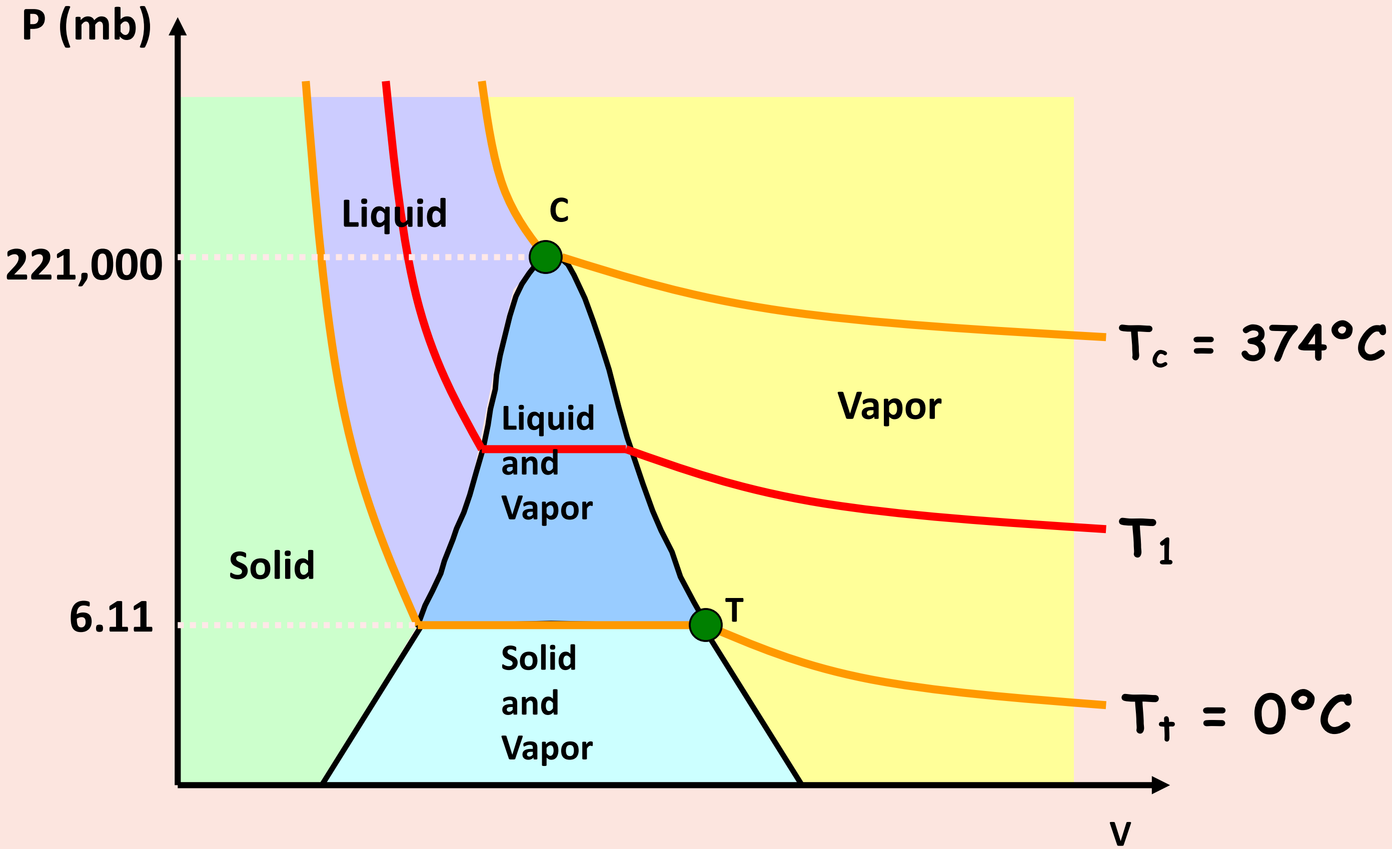
- Triple Line
  - T = 273.16K
  - p = 6.11 mb
- Critical Point
  - T = 374 °C
  - p = 221000 mb



Water vapor obeys the
Ideal Gas Law at higher temperatures

Amagat-Andrews Diagram

Equilibrium Phase Changes on P-V Diagrams:

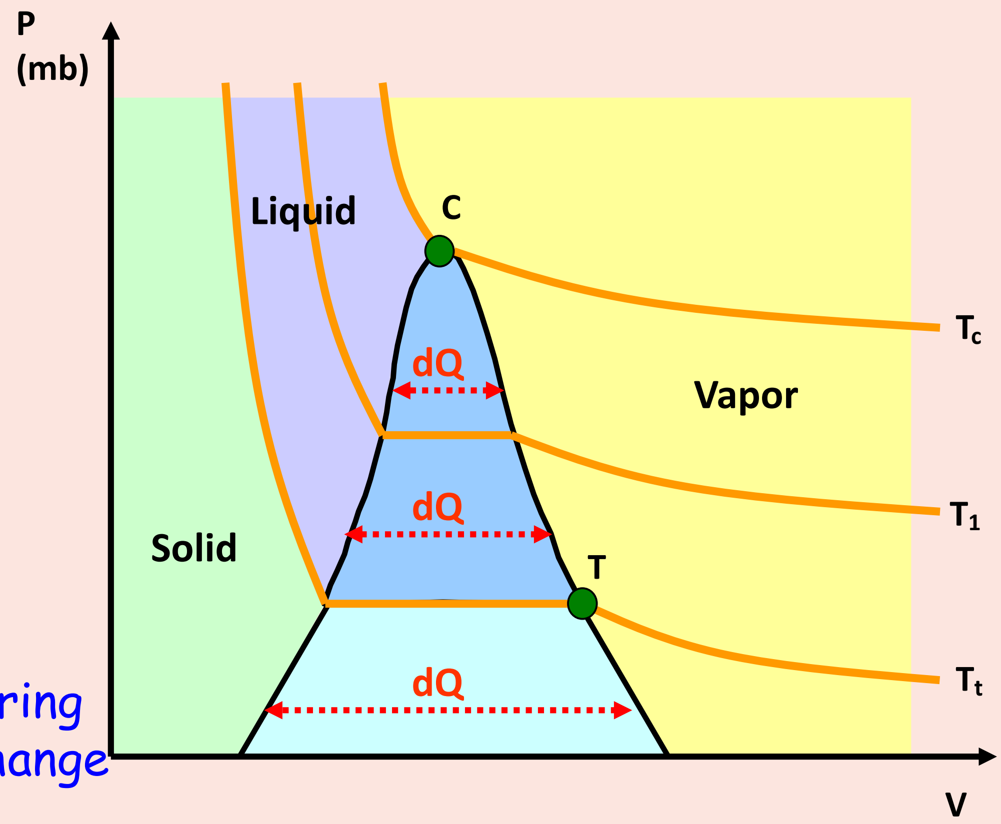


Latent Heats during Phase Changes

- **Liquid and Vapor**

<u>Isobaric Process</u>

- Heat (**dQ**) added or removed from the system
- Temperature constant
- Volume changes



- Heat absorbed (or given away) during an isobaric and isothermal phase change

$$L = dQ$$

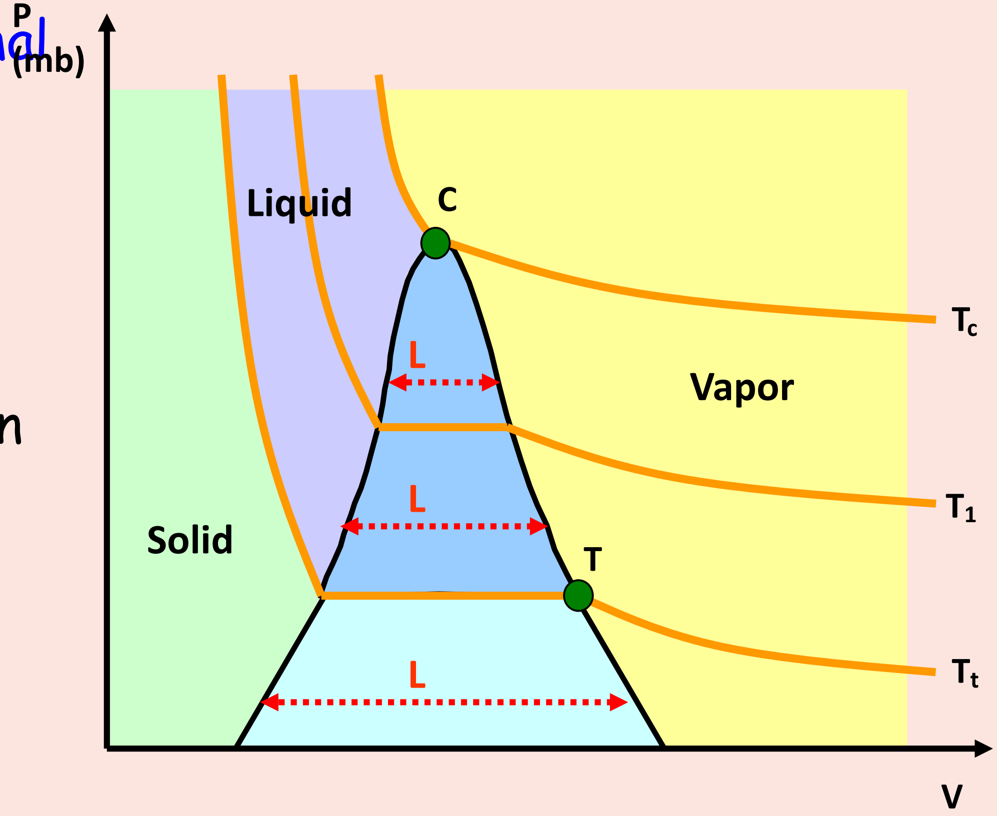
Definition of Latent Heat (L):

- Heat absorbed (or given away) during an isobaric and isothermal phase change

- Magnitude varies with temperature

- However, the range of variation is very small for the range of pressures and temperatures observed in the troposphere

- Assumed **constant** in practice



$$L = dQ = \text{constant}$$

Phase Changes of Water- Latent Heat