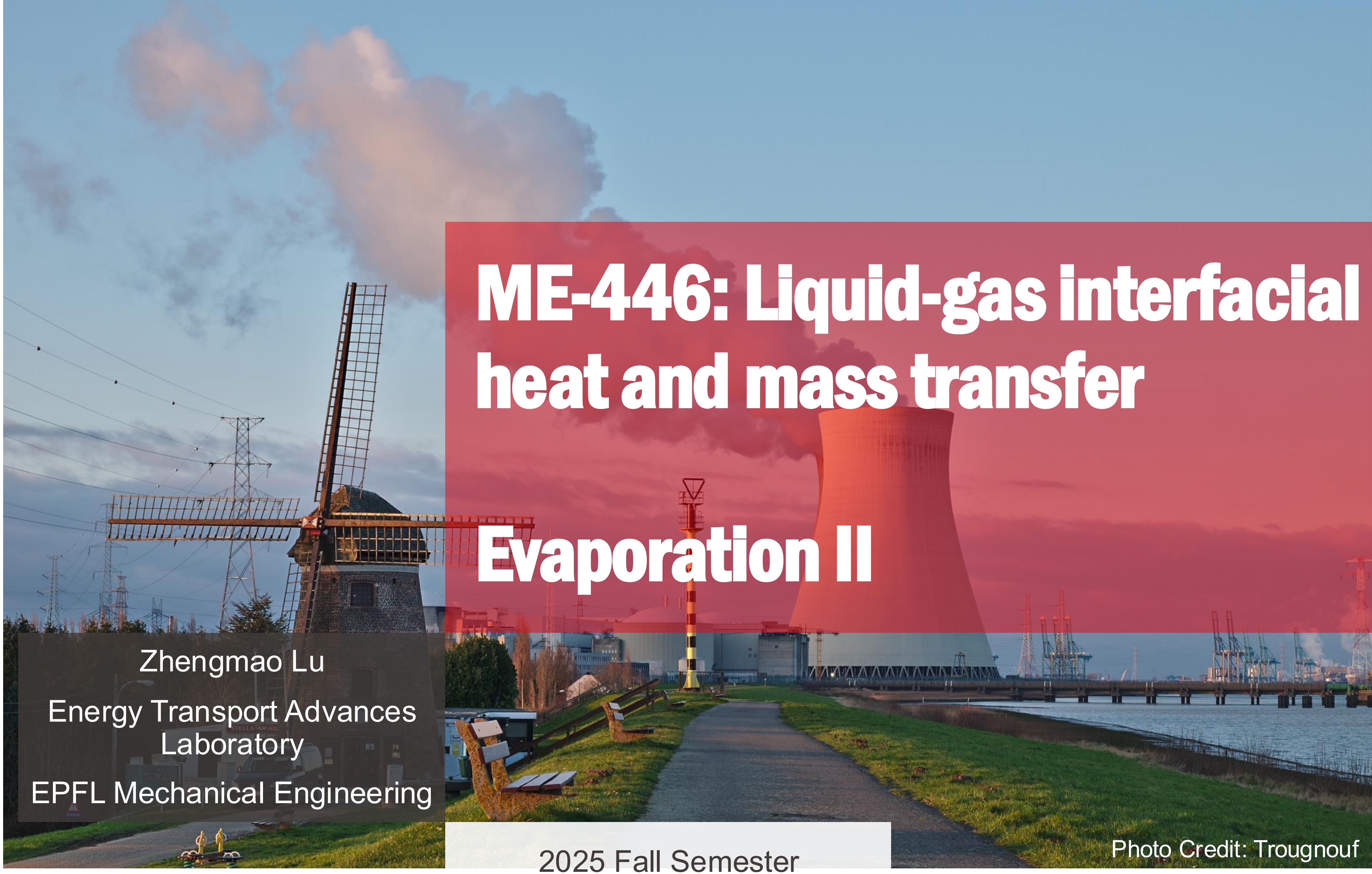
EPFL

ETA-Lab
Energy Transport Advances



ME-446: Liquid-gas interfacial heat and mass transfer

Evaporation II

Zhengmao Lu

Energy Transport Advances Laboratory

EPFL Mechanical Engineering

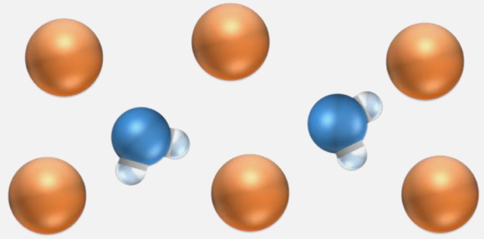
2025 Fall Semester

Photo Credit: Trougnouf

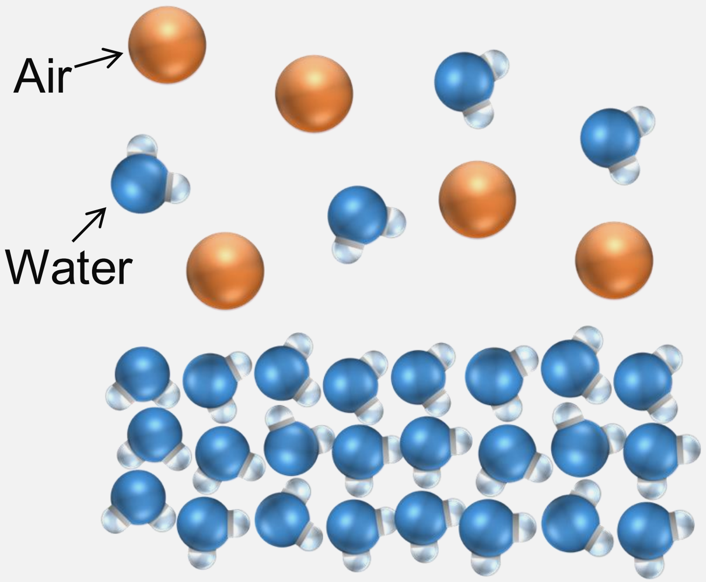
Last Week

Air → Diffusion Limited

Far field (low vapor concentration)



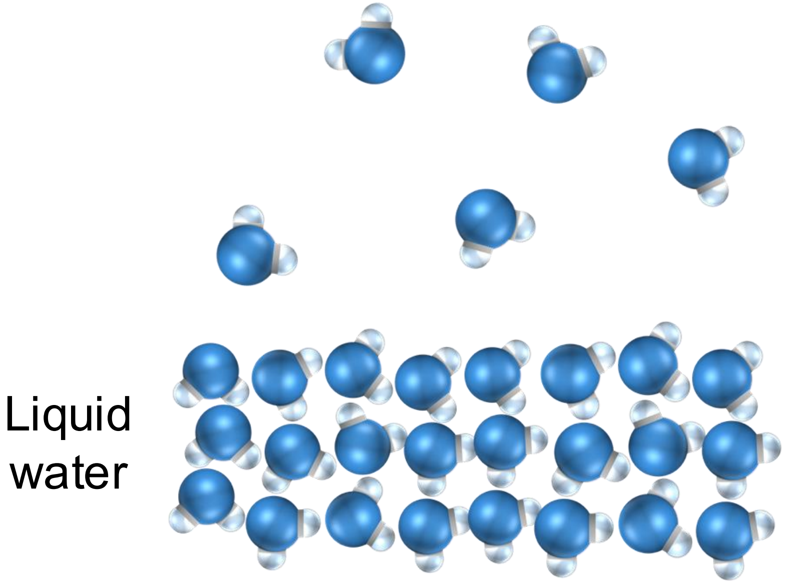
Low (high vapor concentration)



Vapor → Kinetically Limited

Far field (low pressure)

Near field (high pressure)



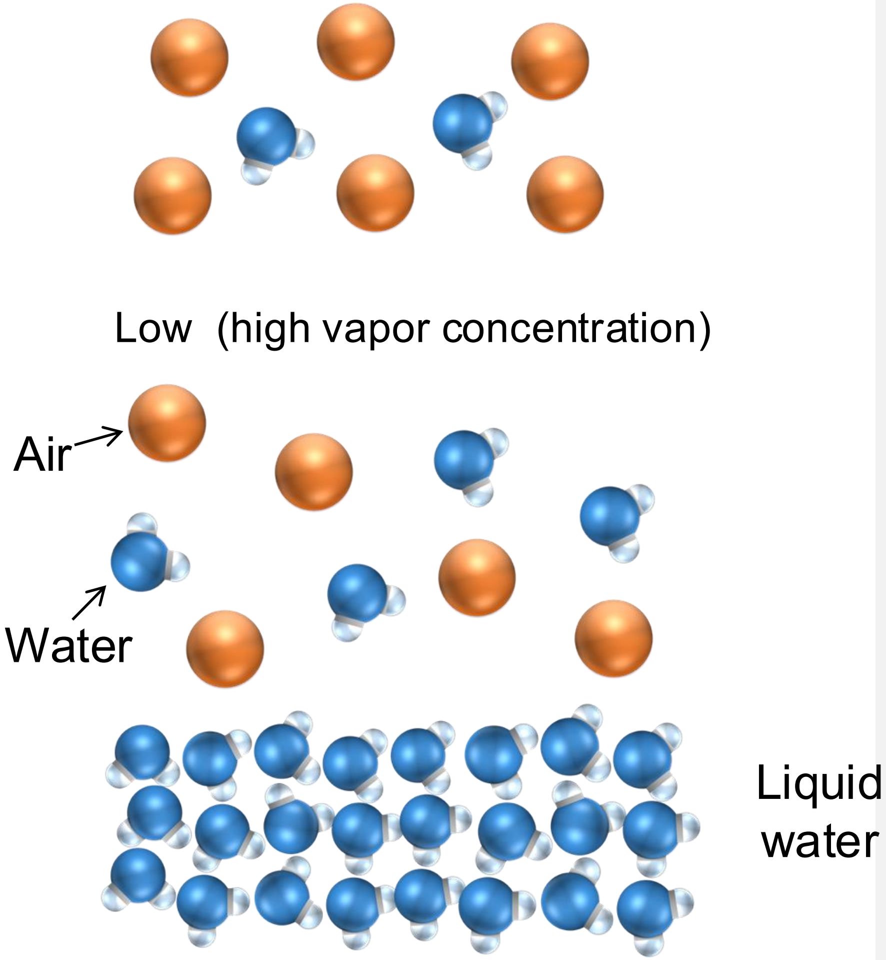
Last Week

- Fick's Law of Diffusion
  - Physical meaning of gradient and divergence operators
- Heat and mass transfer analogy
- Coffee ring effects

Fundamental Picture of Evaporation

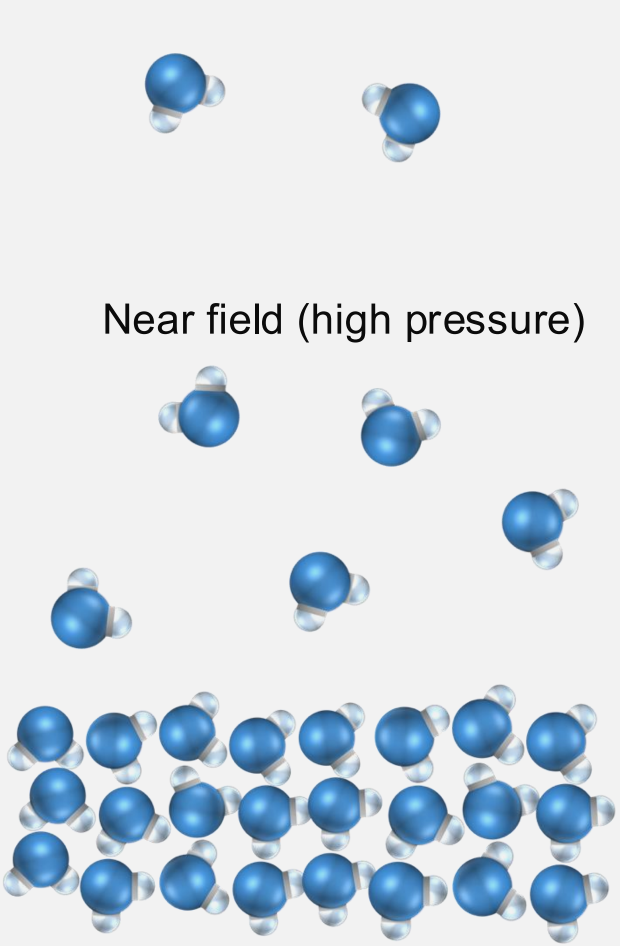
Air → Diffusion Limited

Far field (low vapor concentration)



Vapor → Kinetically Limited

Far field (low pressure)



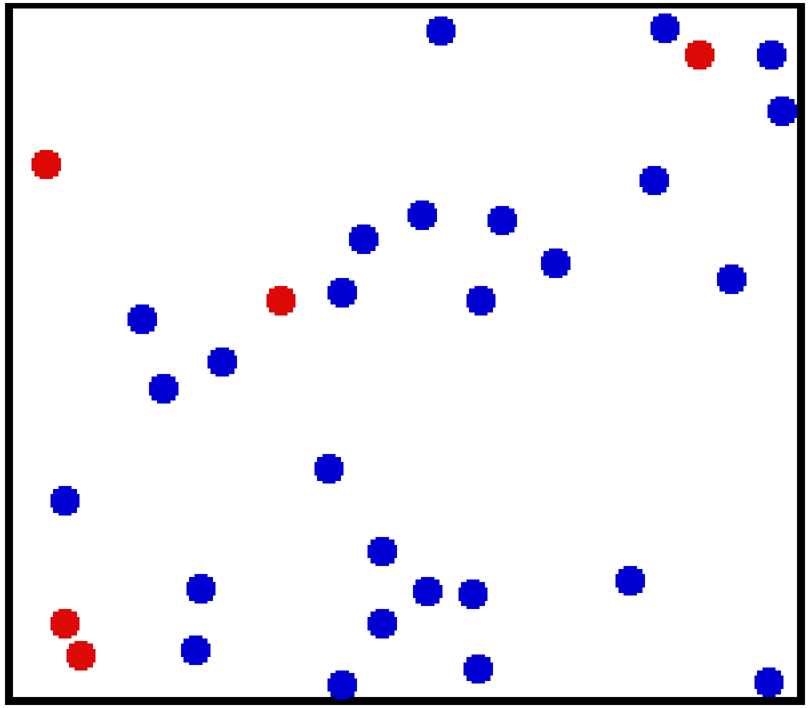
Intended Learning Objectives Today

- Understand basic assumptions of the **kinetic theory of gases**
- Relate **macroscopic quantities** to microscopic molecular motion
- Derive and understand the limit of **Schrage equation** for evaporation

Reading materials: **Carey** Chapter 4.5, Appendix I

Crash Course on Kinetic Theory of Gases

- Consider gas as **a large number of randomly moving particles** that collide with one another every now and then
- Collisions are elastic: **kinetic energy is conserved** before and after
- Between collisions, particles are not affected by any force field



Credit: A. Greg

Velocity Distribution Function

The fraction of (or the probability of finding) molecules with Cartesian velocities (u, v, w) in the ranges u to $u + du$, v to $v + dv$, w to $w + dw$ in a unit volume is

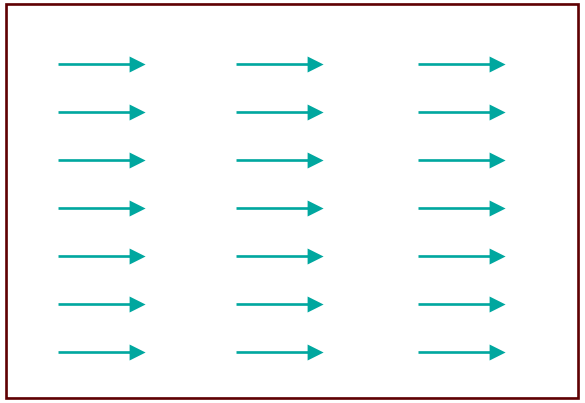
Velocity Distribution Function

Average Properties

Temperature in Kinetic Theory

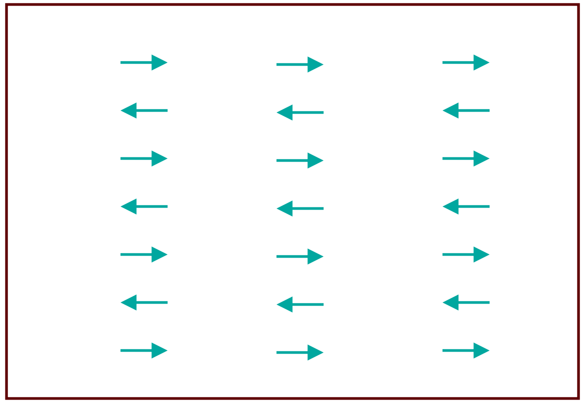
Pop quiz

Situation A



All molecules moving in the same direction at 10 m/s

Situation B



Half of the molecules moving in one direction 5 m/s and the other half moving in the opposite direction at 5 m/s

Scan the QR code with your device
Or go to **echo360poll.eu**

Enter Code

luepfl

In which case is the temperature higher

A. $T_A > T_B$

B. $T_A < T_B$

C. $T_A = T_B$

D. I don’t really know

Maxwell-Boltzmann Distribution

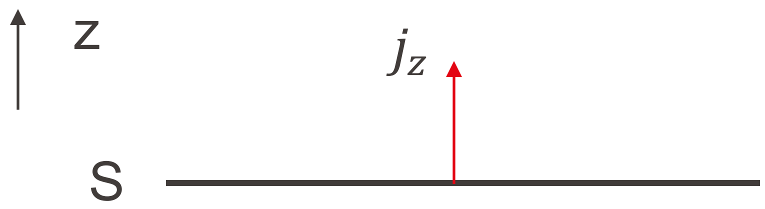
Maxwell-Boltzmann Distribution

Maxwell-Boltzmann Distribution

Drifted M-B Distribution

In the case that the vapor is moving at a bulk velocity (u_0, v_0, w_0), but otherwise is in equilibrium, we can take the frame of reference that moves at the bulk vapor velocity.

Mass Flux Across a Surface

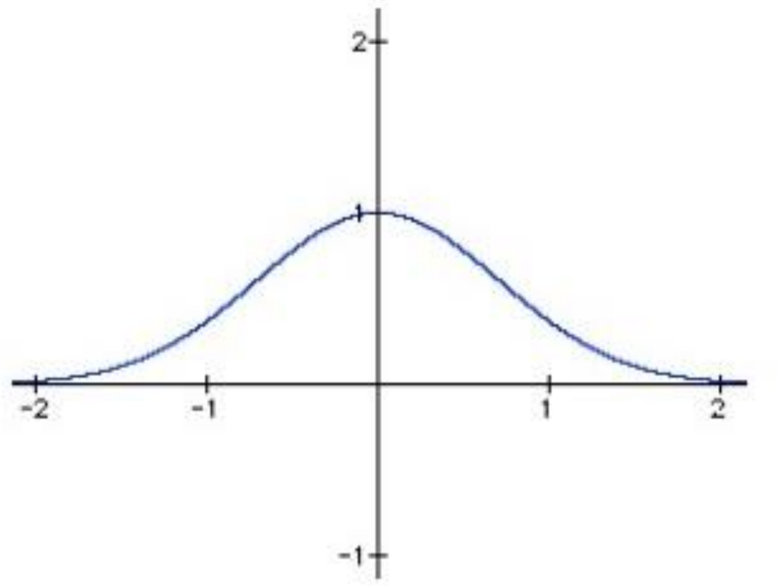


How to determine the molecular flux across a surface if the velocity distribution function is known

j_z : the rate at which molecules pass through surface S per unit area

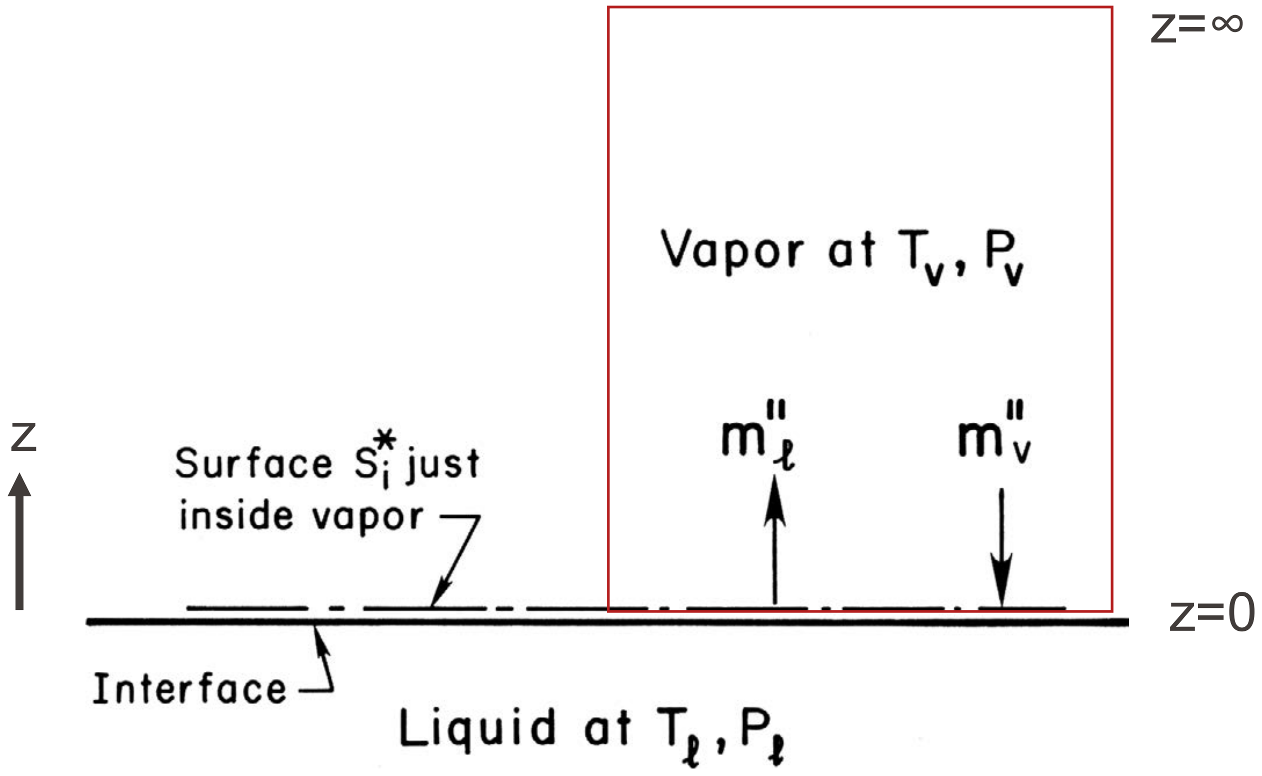
What matters is velocity distribution in the direction perpendicular to the surface

One Way Mass Flux



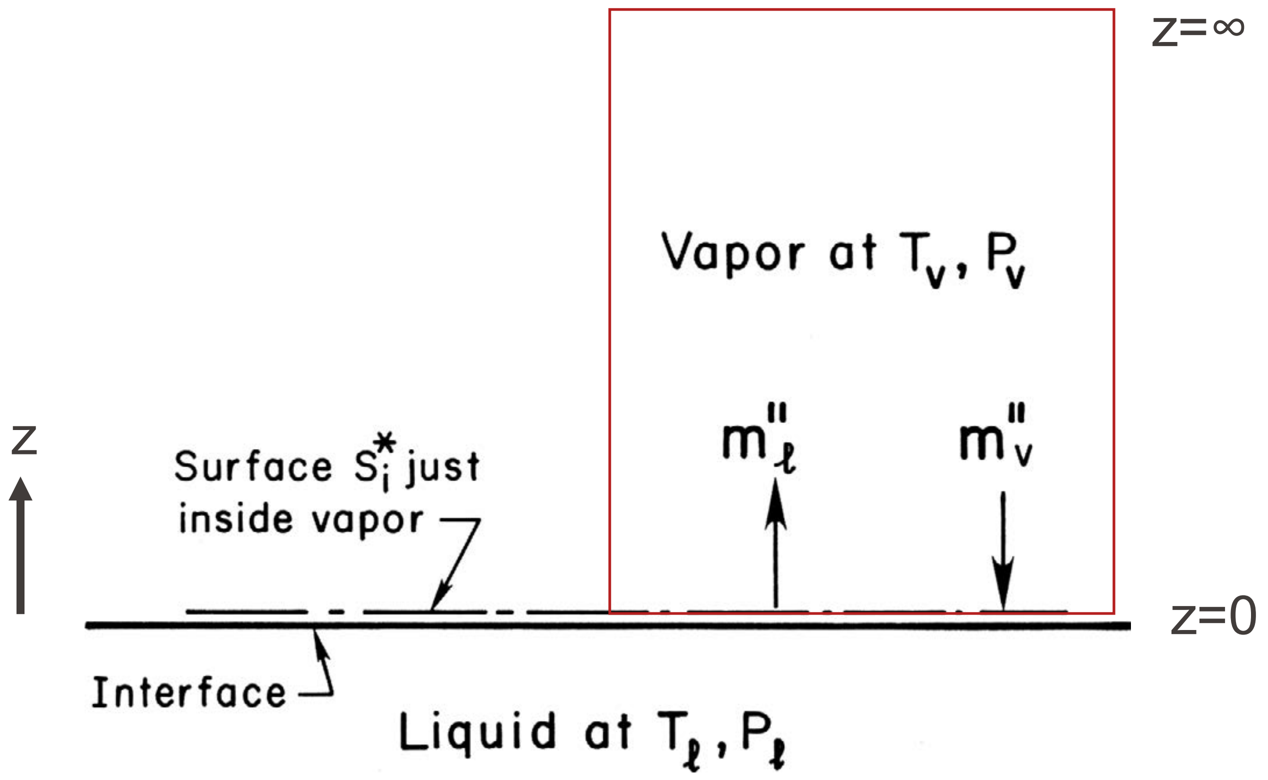
With symmetric velocity distribution such as M-B, although the net molecular flux is zero is zero, there are two one-way molecular fluxes negating each other.

Liquid-Vapor Interfacial Transport

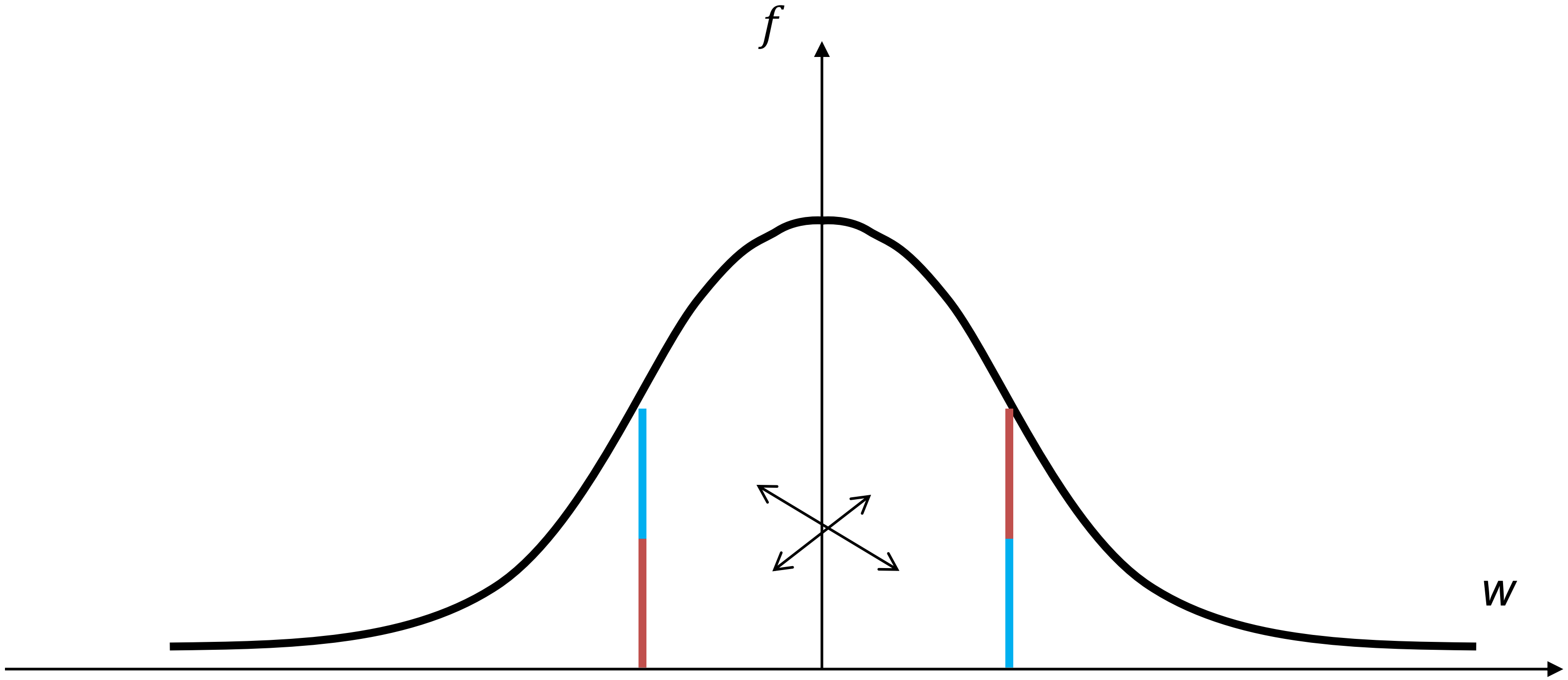


z-direction opposite to Figure 4.10 in Carey

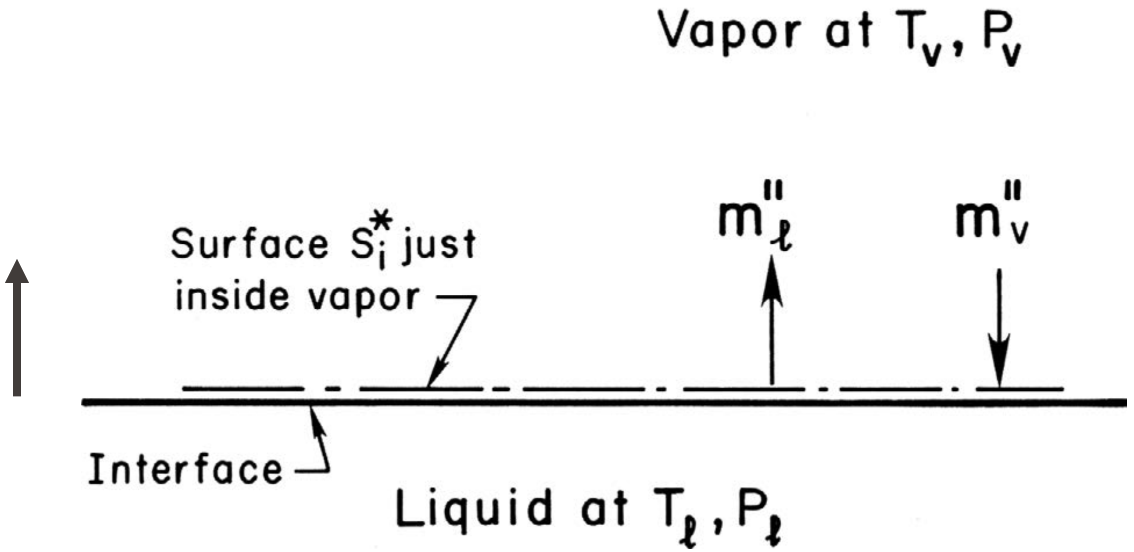
Liquid-Vapor Interfacial Transport



Evaporation/Condensation Coefficient



Hertz-Knudsen Equation



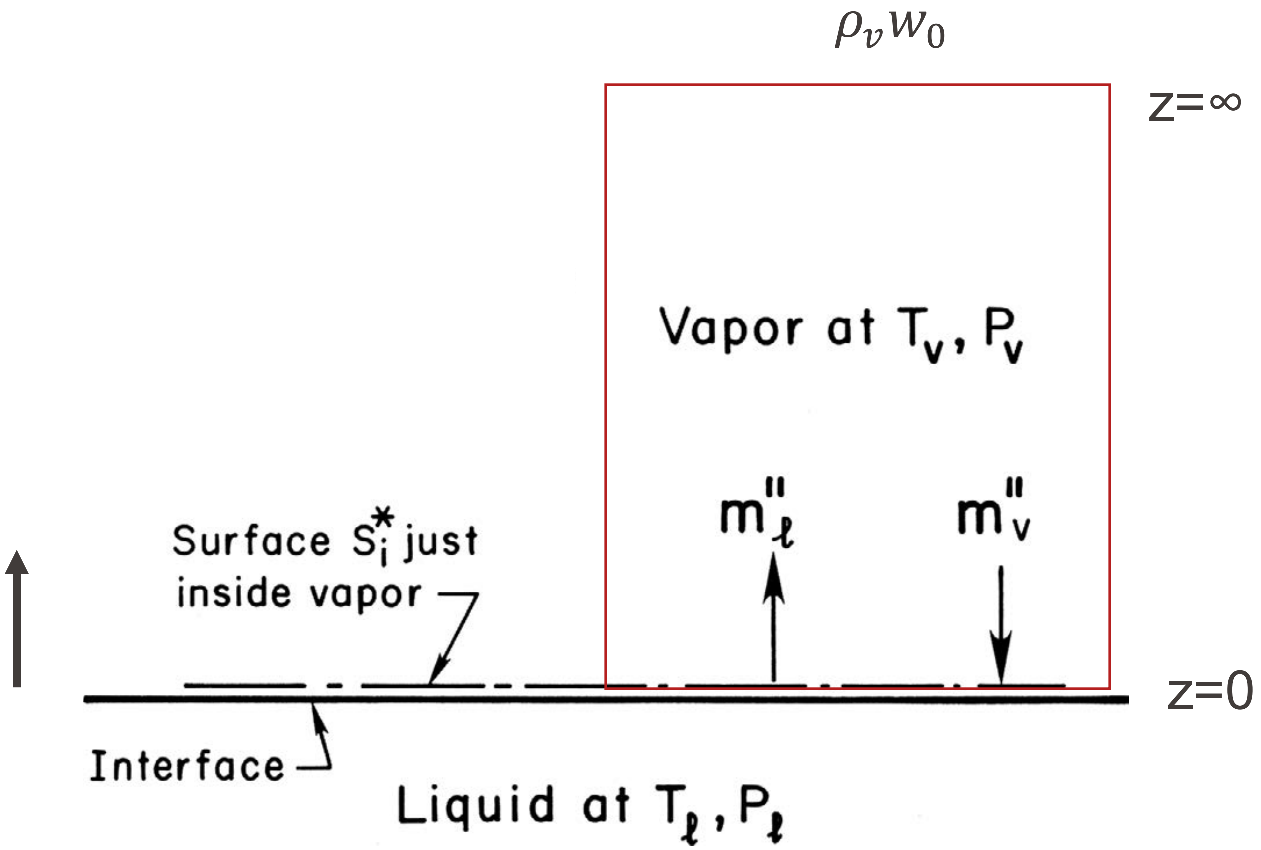
$$|m_v''| = \rho_v \left(\frac{k_B T_v}{2\pi m}\right)^{\frac{1}{2}}$$

$$m_l'' = \hat{\sigma}_e m_e'' + (1 - \hat{\sigma}_c)|m_v''|$$

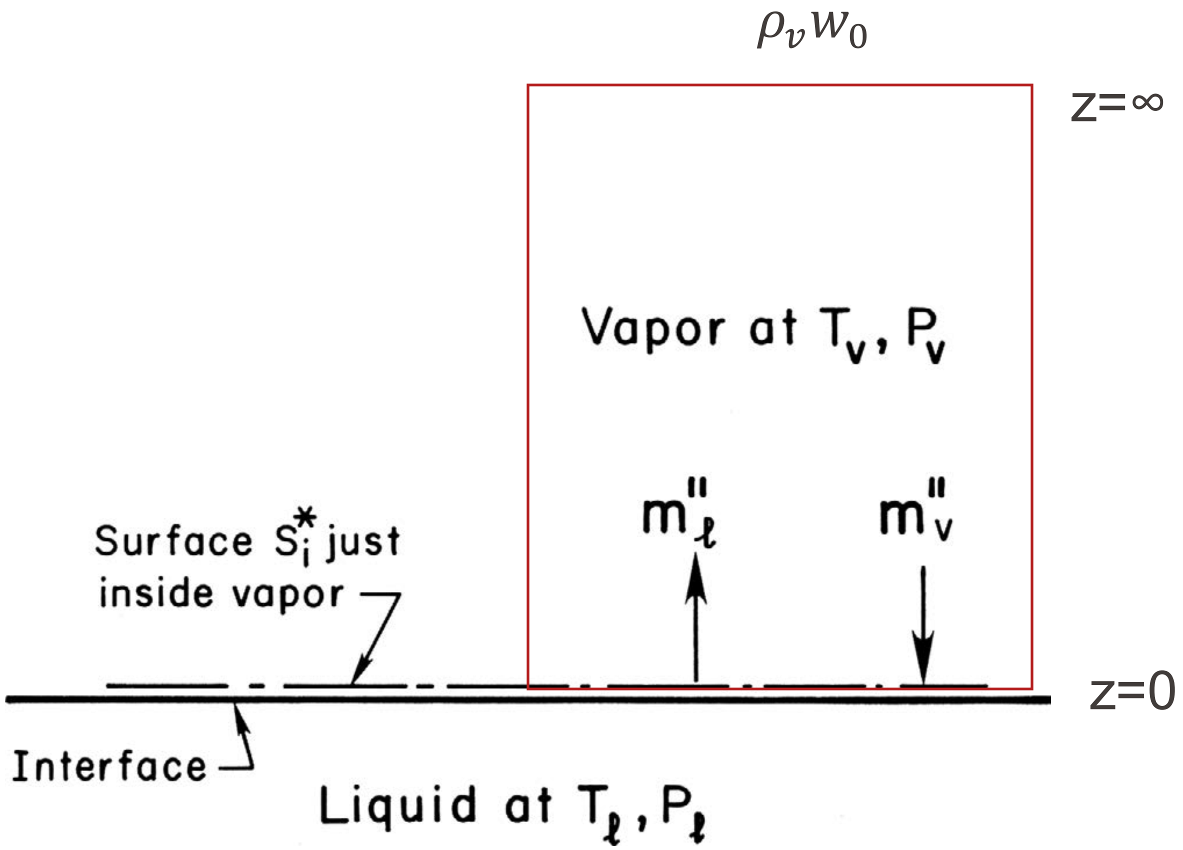
$$m_{net}'' = m_l'' - m_v'' = \hat{\sigma}_e m_e'' - \hat{\sigma}_c |m_v''|$$

$$[m_{net}'']_{\mathrm{HK}} = \hat{\sigma}_e \rho_e \left(\frac{k_B T_l}{2\pi m}\right)^{\frac{1}{2}} - \hat{\sigma}_c \rho_v \left(\frac{k_B T_v}{2\pi m}\right)^{\frac{1}{2}}$$

Schrage Equation



Mass Balance



Schrage Equation

When $\frac{1}{2}mw_0^2 \ll k_B T_v$, the evaporation heat flux can be written in a closed form

Backup Blank Slide

Summary

- Understand basic assumptions of the **kinetic theory of gases**
- Relate **macroscopic quantities** to microscopic molecular motion
- Derive and understand the limit of **Schrage equation** for evaporation

Reading materials: **Carey** Chapter 4.5, Appendix I