TRANSPORT PROPERTIES OF GAS

- Transport properties of a perfect gas
- Diffusion in a fluid
- Measurement of
  - the diffusion coefficients,
  - Viscosity, and
  - Thermal conductivity

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A. Introduction

- ✓ **Transport properties of a substance**:
  the ability of the substance to transfer matter, energy or some other properties, from one place to another.
- ✓ **Diffusion:** matter flows in response to gradient of concentration.
- ✓ **Thermal conduction:** migration of energy because of a temperature gradient
- ✓ **Electric conduction:** migration of electric charges along an electric potential gradient
- ✓ **Viscosity:** migration of linear momentum results from a velocity gradient.
- ✓ Transport properties are expressed by **phenomenological equations** (empiric equations obtained from a summary of experiments and observations)

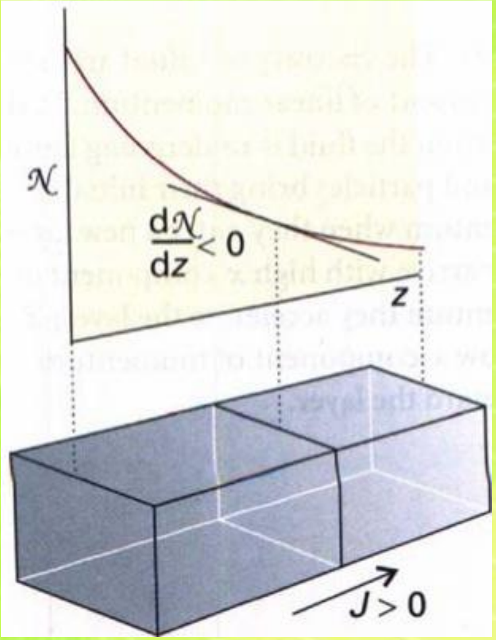
B. Phenomenological equations

- ✓ Flux, *J* represents the quantity of a property passing through a given area in a given interval of time
- ✓ Types of flux:
  - Matter flux: if the matter is flowing through the area in the interval of time > number of molecules/(m^2 s).
  - Energy flux: if energy is flowing through the area in the interval of time > J/(m^2s).
- ✓ Experimental observations on transport properties show that the flux of a property is proportional to the first derivative of a related property (gradient of the property).

B.1. Fick first law of diffusion

- ✓ the flux of matter which diffuse parallel with the direction z-ordinate in a container, is proportional to the concentration gradient.

$$J\,(matter) \propto \frac{dN}{dz}$$



N - number density of molecules
z – distance where there is a flux of matter
[J] = nr. /m^2s

- ✓ If the concentration is changing steeply with position > diffusion process is fast.
- ✓ If the concentration is uniform > flux of matter is 0 > no diffusion.

B.1. Fick first law of diffusion

- ✓ Flux is component of vector.
  - J > 0 flux towards +z-ordinate direction
  - J < 0 flux towards –z-ordinate direction
- ✓ Fick first law of diffusion for the molecules of a perfect gas:

$$J(matter) = -D\frac{dN}{dz}, \quad where\ D: diffusion\ coeff.\ (m^2 s^{-1})$$

B.2. Thermal conductivity

- ✓ The rate of thermal conduction (flux of energy associated with thermal motion) is proportional to the temperature gradientFick first law of diffusion for the molecules of a perfect gas:

$$J\,(energy) \propto \frac{dT}{dz}$$

[*J*] = *J/(m2 s) where J =*Joule

- ✓ Similar to the diffusion relation, the flux of energy due to the thermal motion is :

$$J\,(energy) = -\kappa \frac{dT}{dz}$$

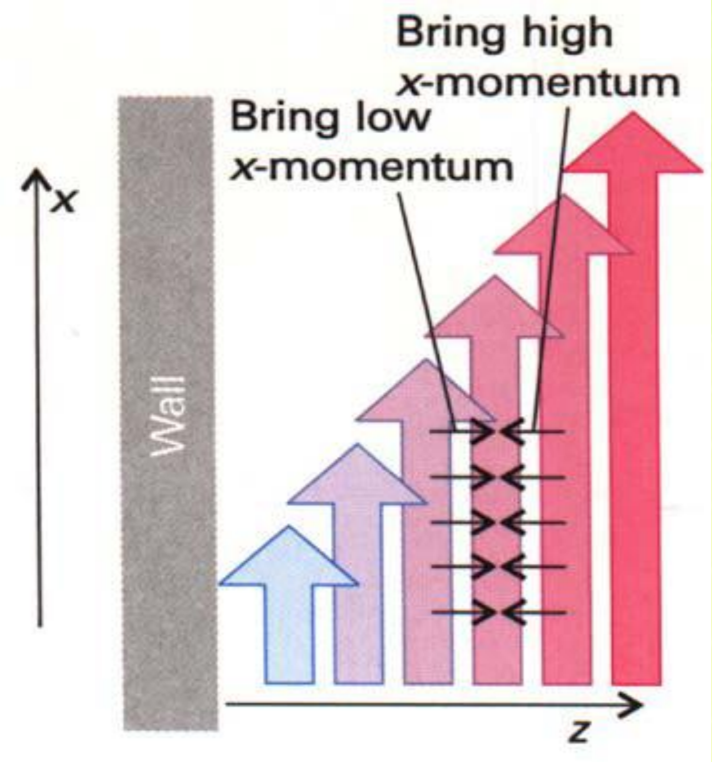
κ = *coefficient of thermal* conductivity
[κ] = *J/(K m s) where J = Joule!*

B.2. Viscosity

✓ Hypothesis: A Newtonian fluid is formed by a series of layers moving past one another, in a tube/container.
  - the layer next to the wall is stationary
  - the velocity of the succesive layers depends on the distance from the wall.

Molecules move between layers and bring a x-component of linear momentum they have in their original layer (initial layer) to the layer in which they move (final layer).

The final layer is accelerated or retarded, dependng on the linear momentul of the molecule.



B.2. Viscosity

- ✓ Viscosity: net retarding effect of molecules to different layers.
- ✓ It depends on the transfer of x-component of linear momentum (flux in the z-ordinate direction) into the layer of interest.

$$J(x - component - momentum) \propto \frac{dv_x}{dz}$$

- ✓ Similar to the diffusion relation, the flux of energy due to the thermal motion is :

$$J(x - comp - momentum) = -\eta \frac{dv_x}{dz}$$

η = coefficient of viscosity (or viscosity)
[η] = kg/(m s) or Poise (P),
1P = 10^{-1} kg/m s

Thermal conductivity and viscosity

	$\kappa/(J\,K^{-1}\,m^{-1}\,s^{-1})$	$\eta/(\mu P)^{\dagger}$	
	273 K	273 K	293 K
Ar	0.0163	210	223
CO_2	0.0145	136	147
He	0.1442	187	196
N_2	0.0240	166	176

Transport properties of a perfect gas

Coefficient of thermal conductivity, κ:

$$\kappa = \frac{1}{3}\lambda \bar{c} C_{v,m}[A]$$

λ - mean free path of particles
ć - mean speed of the particles in a gas
[*A*] - *molar concentration of the gas* molecules
$C_{v,m}$ – molar heat capacity at V constant.

- ✓ λ decreases as the pressure in the gas is increasing
- ✓ λ decreases as the molar concentration of the gas is increasing

$\kappa \neq f(pressure)$

- ✓ *κ is higher for gases with a high heat capacity because a gradient of* temperature corresponds to a higher variation of energy.

Viscosity – perfect gas

✓ **Viscosity, η**

$$\eta = \frac{1}{3} M \lambda \bar{c} [A]$$

λ - mean free path of particles
ć - mean speed of the particles in a gas
[*A*] - *molar concentration of the gas* molecules
M – molar mass of molecules

✓ ć increases when the temperature increases ($T^{1/2}$) → viscosity is increasing as temperature increases (for gases).

✓ λ decreases as the pressure in the gas is increasing
✓ [*A*] *increases as the molar concentration of the gas is* increasing

$\eta \neq f(pressure)$

Transport properties for gases

	$\langle v \rangle$ ($m\,s^{-1}$)	λ (10^{-9} m)	$d = 2r$ (10^{-9} m)	η ($10^{-6}\,kg\,m^{-1}s^{-1}$)	Λ ($10^{-3}\,J\,K^{-1}\,m^{-1}s^{-1}$)	c_V ($10^{3}\,J\,K^{-1}\,kg^{-1}$)	$\eta \cdot c_V / \Lambda$
He	1202	179.8	0.200	18.6	140.5	3.11	0.41
Ne	535	100	0.234	29.8	46.5	0.618	0.40
Ar	380	63.5	0.286	21.0	16.2	0.314	0.41
Kr	263	50	0.318	23.4	8.7	0.149	0.40
Xe	210			21.2	5.2	0.095	0.39
H_2	1693	112.3	0.218	8.42	169.9	10.04	0.50
N_2	454	60.0	0.316	16.7	24.3	0.736	0.51
O_2	425	64.7	0.296	18.09	24.6	0.649	0.48
Cl_2	286	28.7	0.370	12.3	7.65	0.342	0.55
CO	454	58.4	0.380	16.8	23.6	0.741	0.53
CO_2	362	39.7	0.460	13.8	14.4	0.640	0.61
NH_3	583	44.1		9.76	21.5	1.67	0.76
C_2H_4	454	34.5		9.33	17.0	1.20	0.65

Transport properties for gases

Property	Transported quantity	Simple kinetic theory	UNIT
Diffusion	Matter	$D = \frac{1}{3}\lambda\bar{c}$	$m^2\ s^{-1}$
Thermal conductivity	Energy	$\kappa = \frac{1}{3}\lambda\bar{c}C_{V,m}[A] = \frac{\bar{c}C_{V,m}}{3\sqrt{2}\sigma N_A}$	$J\ K^{-1}\ m^{-1}\ s^{-1}$
Viscosity	Linear momentum	$\eta = \frac{1}{3}\lambda\bar{c}m\mathcal{N} = \frac{m\bar{c}}{3\sqrt{2}\sigma}$	$kg\ m^{-1}\ s^{-1}$

Diffusion coefficients for various media

Substance and diffusion medium	T / K	D / cm^2s^{-1}
H_2 in H_2	65 192 296	1.01×10^{-1} 6.73×10^{-1} 1.65
Xe in Xe	194 273	2.57×10^{-2} 4.80×10^{-2}
H_2 in air	301	0.7
I_2 in air	303	8.50×10^{-2}
NaCl in H_2O Na^+	298	1.25×10^{-5}
NaCl in H_2O Cl-	298	1.78×10^{-5}
ethanol in H_2O	298	1.08×10^{-5}
Ag in Cu (6.55 mol%)	900 1000	1.38×10^{-11} 1.57×10^{-10}
Cu in Zn (75 mol%)	1005 1150	2.29×10^{-9} 1.02×10^{-8}

P=1 bar

Thank You