# Mass Transfer: Diffusion

## Introduction to mass transfer

Prof. Dr.-Ing. Reinhold Kneer

Prof. Dr.-Ing. Dr. rer. pol. Wilko Rohlfs

HEATQUIZ

UNIVERSITY OF TWENTE.

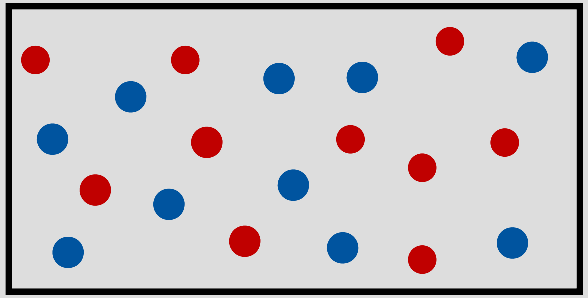
Lehrstuhl für Wärme- und Stoffübertragung

RWTH AACHEN UNIVERSITY

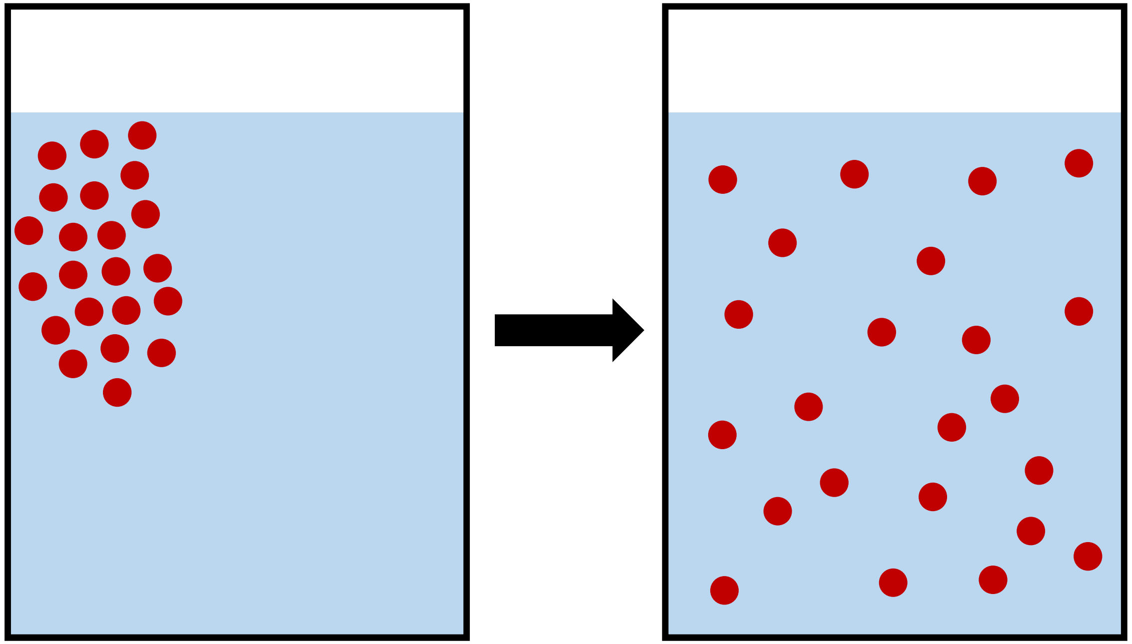
# Learning goals

## Learning goals:

- Understand the basics of mass diffusion
- Understand diffusion in gaseous binary mixture
- Learn about Fick's law
- Learn to draw the concentration profile of one-dimensional equimolar diffusion in binary gas mixtures at rest



# Random and undirected physical process of concentration equalization



[1]

[1] https://mrgranato.files.wordpress.com/2018/09/tea-diffusion.jpg



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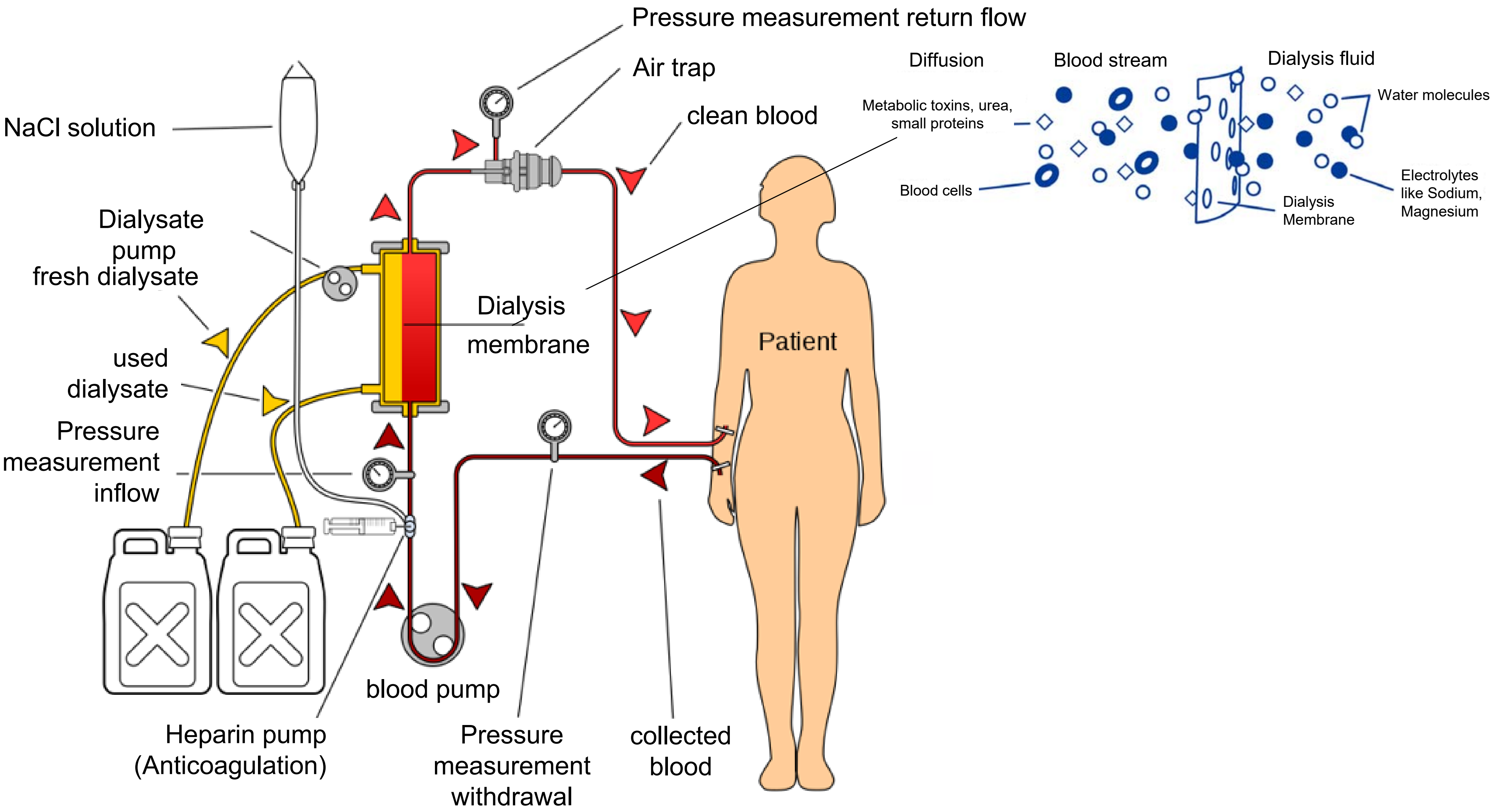
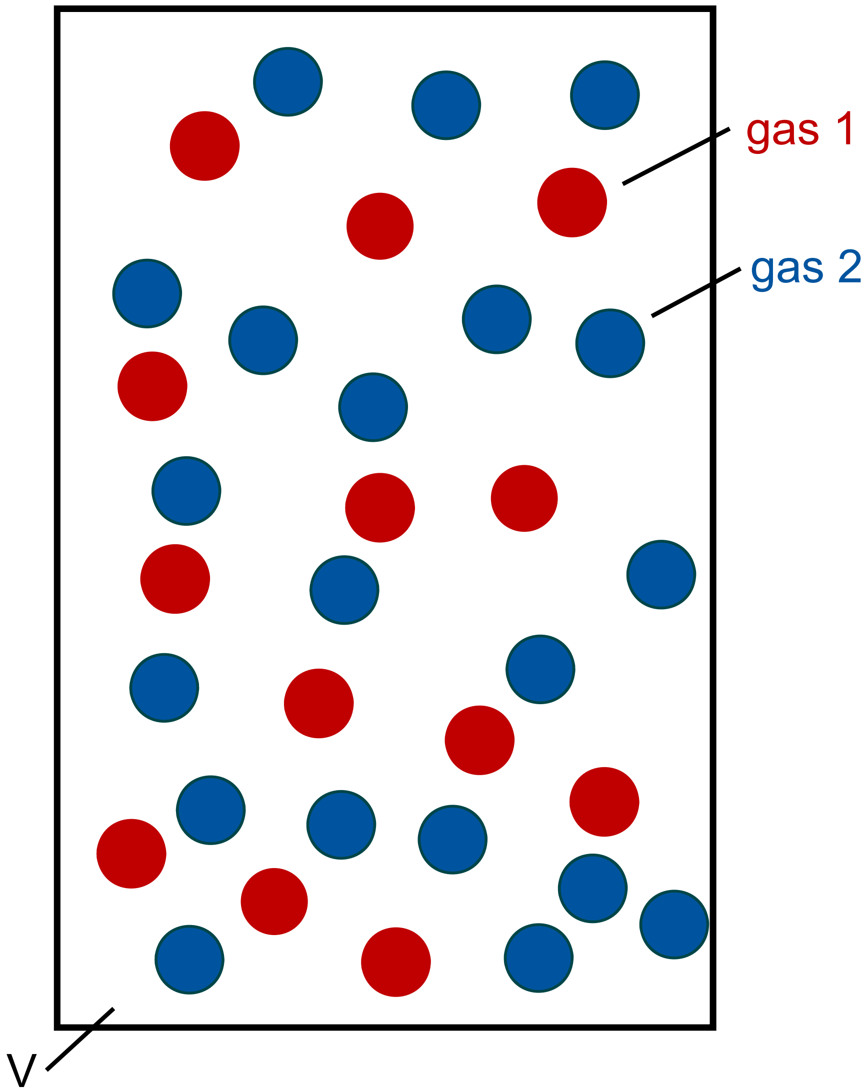
# Diffusion – Example: semi-permeable membrane in dialysis machines



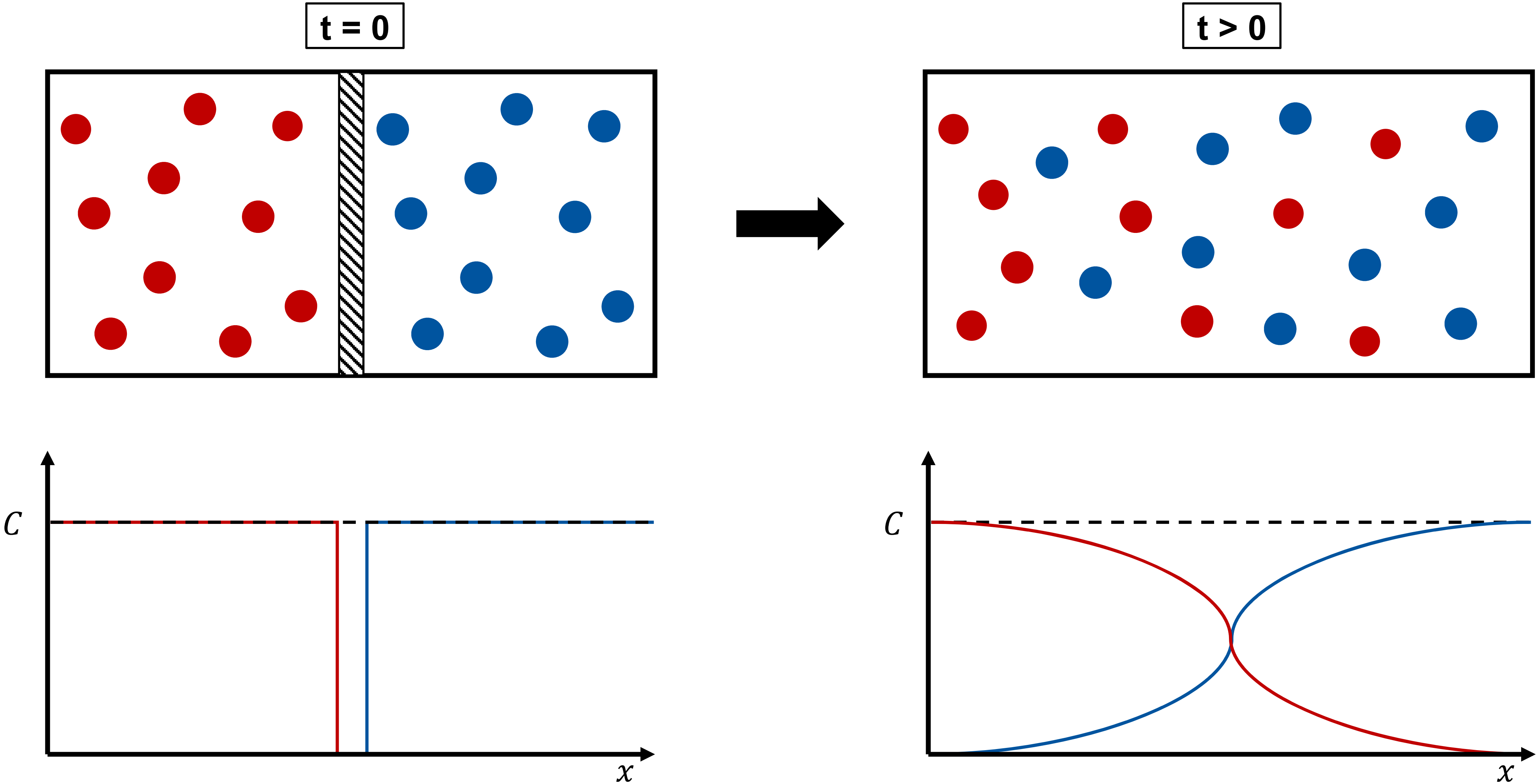
# Mass transfer – fundamentals of binary mixtures




**Introduction:**

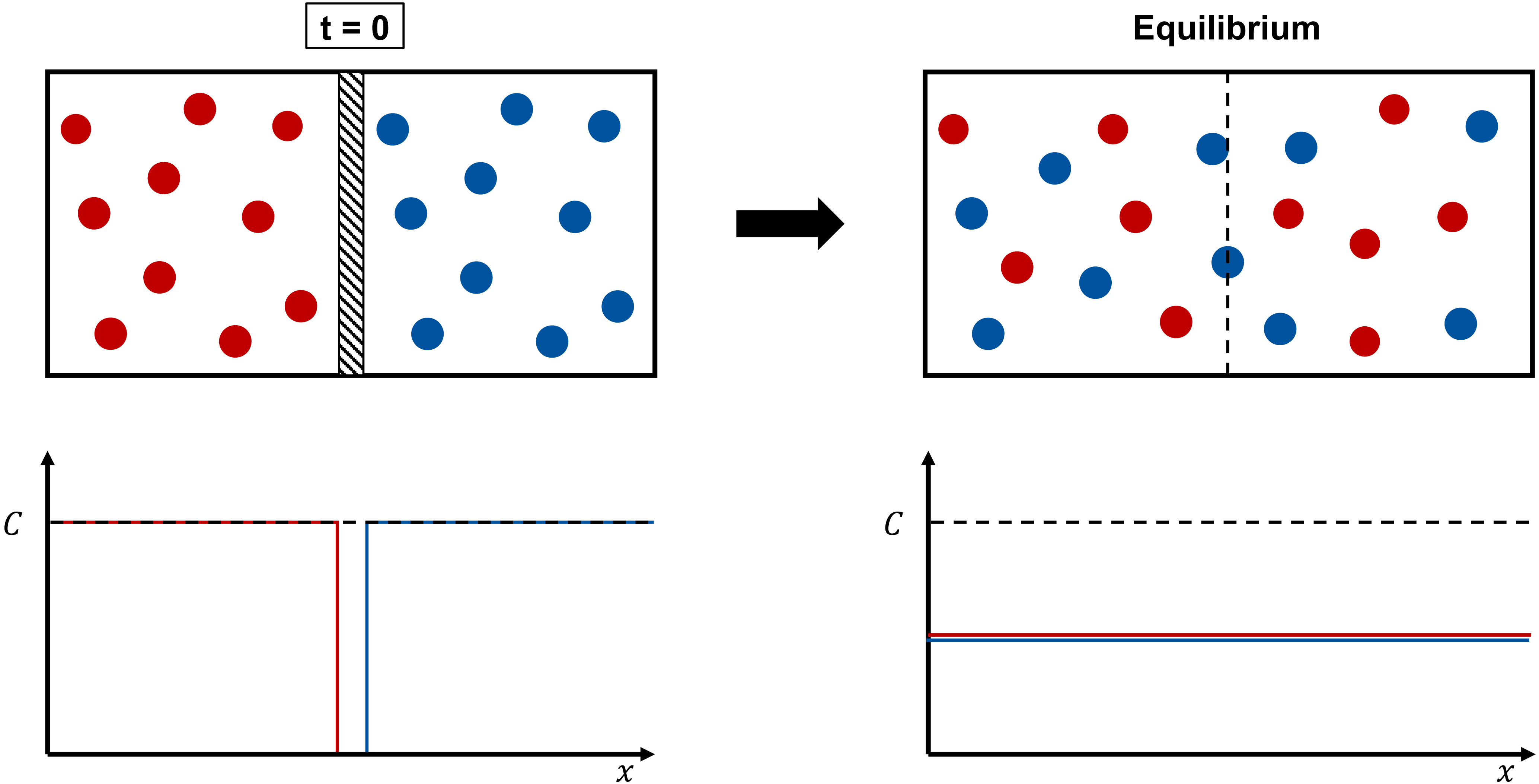
- Enclosed volume
- Two different gases
- Constant pressure at temperature

# Mass transfer – concentration curve



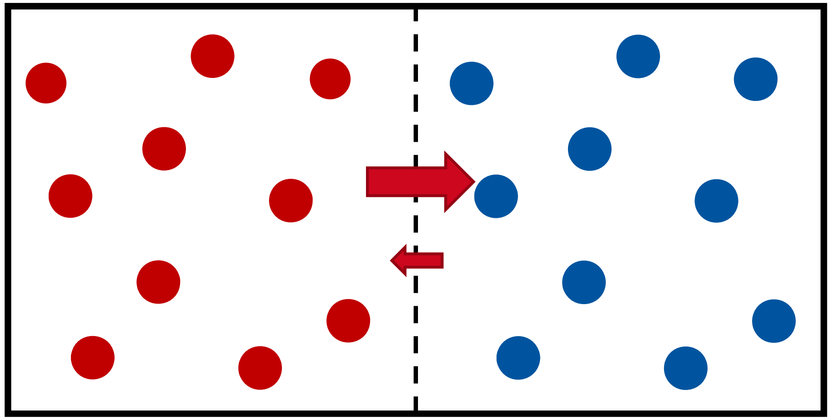

Concentration: $C_\mathrm{i} = \frac{n_\mathrm{i}}{V}$ (number of molecules per volume, $\left[\frac{\mathrm{mol}}{\mathrm{m}^3}\right]$)

# Mass transfer – concentration curve



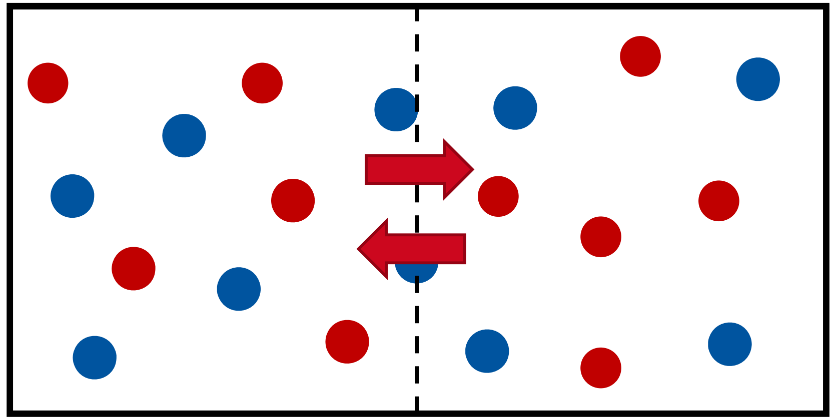

Concentration: $C_\mathrm{i} = \frac{n_\mathrm{i}}{V}$ (number of molecules per volume, $\left[\frac{\mathrm{mol}}{\mathrm{m}^3}\right]$)

# Molecular/Statistical concept of diffusion



- Probability of a red molecule crossing the control plane from left to right
  - ≫ Probability that a red molecule crosses the control plane from right to left
  - → Effective flow of red molecules from left to right

**Equilibrium**



- Probability of a red molecule crossing the control plane from left to right
  - = Probability that a red molecule crosses the control plane from right to left
  - → No more effective flow of red molecules from left to right

# One-dimensional equimolar diffusion in resting binary mixtures

## Diffusive molar flux (quantity of molecules moving):

$$\text{Molar flux} = \text{Diffusion coefficient} \cdot \text{negative gradient of molar concentration}$$

## Diffusive molar flux:

1. Fick's law:

$$\boxed{\begin{aligned} \dot{n}_1'' &= D_{12}\left(-\frac{dC_1}{dx}\right) \\ \dot{n}_2'' &= D_{21}\left(-\frac{dC_2}{dx}\right) \end{aligned}}$$

$$\left[\frac{\text{mol}}{\text{s m}^2}\right] = \left[\frac{\text{m}^2}{\text{s}}\right]\left[\frac{\text{mol}}{\text{m}^3\ \text{m}}\right]$$

Equivalent to Fourier‘s Law

## Diffusive molar flux:

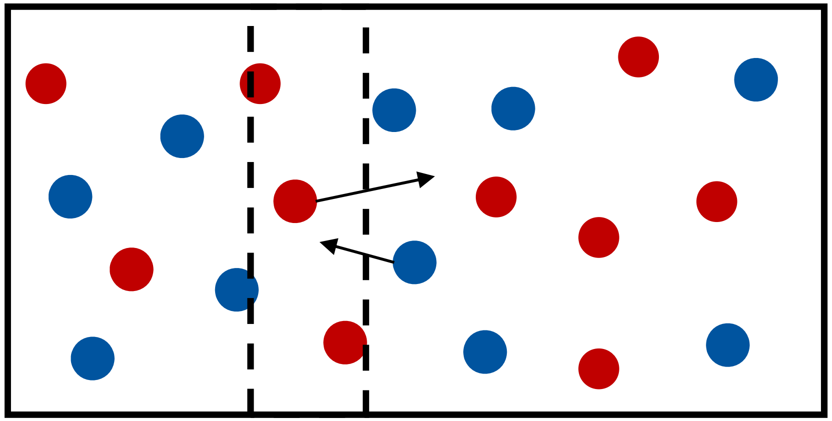
1. $C_1 + C_2 = \mathrm{C} = \text{const.}$ $\qquad \dfrac{dC_1}{dx} + \dfrac{dC_2}{dx} = 0$

2. $n_1 + n_2 = \mathrm{n} = \text{const.}$ $\qquad \dot{n}_1'' + \dot{n}_2'' = 0$

   $\rightarrow\ \dot{n}_1'' = -\dot{n}_2''$

3. $\dfrac{\dot{n}_1''}{D_{12}} + \dfrac{\dot{n}_2''}{D_{21}} = -\left(\dfrac{dC_1}{dx} + \dfrac{dC_2}{dx}\right)$ $\qquad \boxed{D_{12} = D_{21} = \boldsymbol{D}}$

# Molecular/Statistical concept of diffusion



- Mechanical equilibrium: pressure is constant everywhere
  → Substance concentration is identical everywhere

- Molecular movement over boundaries of the control volume: Molecule A leaves the control volume
  → is replaced by molecule A (macroscopically no visible change)
  → is replaced by molecule B (visible diffusion process)

- To maintain mechanical equilibrium, for every "visible/active" molecule A that goes outside, a molecule B must enter the control volume

# Relationship between substance flow and mass flow

## Diffusive mass flow:

- Description of substance flow by Fick‘s Law: $$\dot{n}_i'' = -D_i \cdot \frac{dC_i}{dx}$$
- Multiplication with the molar mass $M_i$: $$M_i \cdot \dot{n}_i'' = -M_i \cdot D_i \cdot \frac{dC_i}{dx}$$
- Results in diffusive mass flow $j_i''$ : $$j_i'' = \dot{m}_i'' = -D \cdot \frac{d\rho_i}{dx} = -\rho \cdot D \cdot \frac{d\xi_i}{dx}$$

## Comprehension questions

**What is the meaning of Fick's Law?**

**What does equimolar diffusion mean?**

**What is the relationship between molar flux and diffusive mass flux?**