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MSE-S308

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1855

Diffusion in Solids

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Change in Structure

Properties of materials

phase

homogenization

Spheroidization

Continuum material

Basic Differential eqn

its solution

D, experimental Determination

Diffusion

Mass flow process by which atoms (molecules) change their positions relative to their neighbours in a given phase under the influence of thermal energy & a gradient.

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- Concentration gradient
- electric field gradient
- magnetic field gra—
- stress gradient

we shall consider mass flow under concentration gradients only.

Fick's Macroscopic Laws of Diffusion

Consider

Unidirectional flow of matter in a binary system of A & B atoms

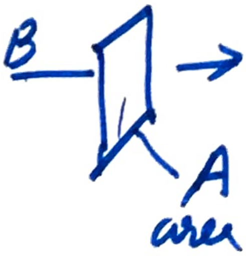
these atoms move in opposite direction under the influence of a concⁿ gradient

Assume that

B atoms is the only moving species

Fick's first Law, states that

$$\frac{dn}{dt} = -DA\frac{dc}{dx}$$



$\frac{dn}{dt}$ → no. of moles of B atoms crossing per unit time, a cross sectional plane of area A, perpendicular to the diffusion direction x

flux $J = \frac{1}{A}\frac{dn}{dt} = -D\frac{dc}{dx}$

$$\boxed{J = -D\frac{dc}{dx}}$$

Fick's I^{st} law of Diffusion

Steady State Diffusion

Diffusion flux does not change with time

Diffusion is a time dependent process

the quantity of an element that is transported within another is a function of time

It is necessary to know How fast diffusion occurs ?

or

the rate of mass transfer.

Rate of mass transfer

⇓ expressed as

Diffusion flux (J)

↓ Defined as

the mass (or no. of atoms) M diffusing through & perpendicular to a unit cross-sectional area of solid per unit time

$$J = \frac{M}{At}$$

A – area across which diffusion occurs

t – diffusion time

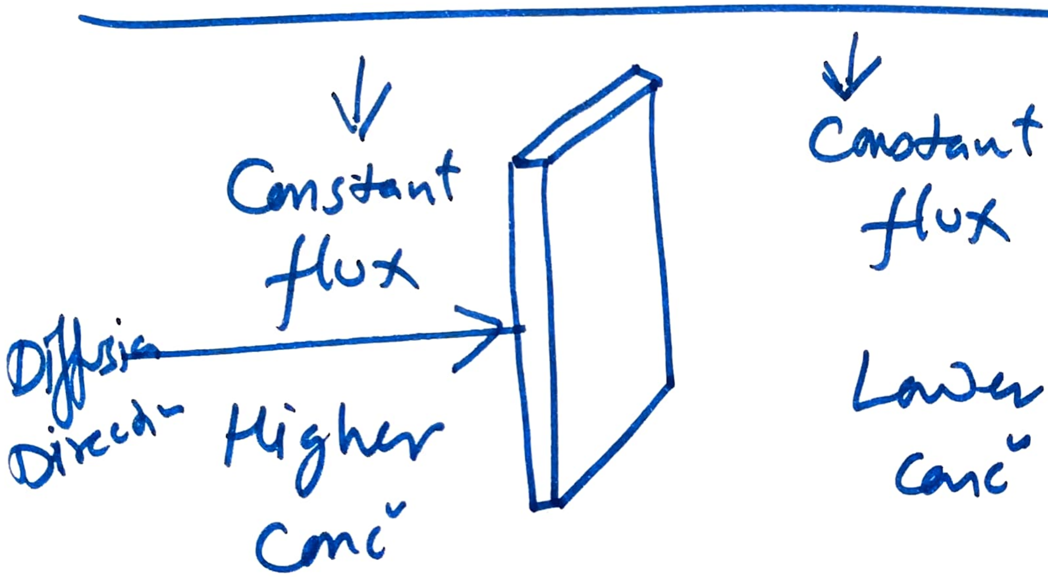
In differential form

$$J = \frac{1}{A}\frac{dM}{dt}$$

unit of J ⇒ $kg/m^2\text{-}s$ or $\frac{atoms}{m^2\text{-}s}$

if J does not change with time a steady state condition exist.

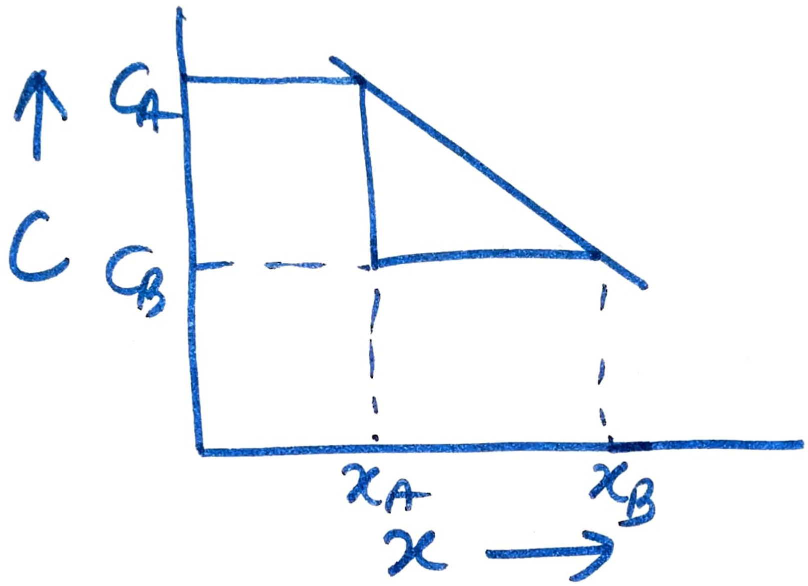
Example of Steady state diffusion



Diffusion of atoms of a gas through a plate of metal for which the concentration of the diffusing species on both surfaces of the plate are held constant.

when Concentration C is Plotted with position (or distance) with in the solid x the curve is termed as

Concentration profile



the slope
at a particular point
on the curve is called

Concentration gradient

$$= \frac{dc}{dx} = \frac{\Delta c}{\Delta x}$$

$$= \frac{C_A - C_B}{x_A - x_B}$$

unit of conc^n $\frac{kg}{m^3}$ or $\frac{g}{cm^3}$

Mathematically

Steady state Diffusion

(in single x Direction)

$$J = -D \frac{\partial c}{\partial x}$$

Fick's First Law

$J \rightarrow$ flux

flow per unit cross-sectional area per unit time

(kg/m^2-s , atoms/m^2-s)

D - Diffusion coeff (or Diffusivity)

- It is a constant characteristic of the system
- It depends on the
  - Nature of the diffusing species
  - The matrix in which it is diffusing
  - The temperature at which diffusion occurs

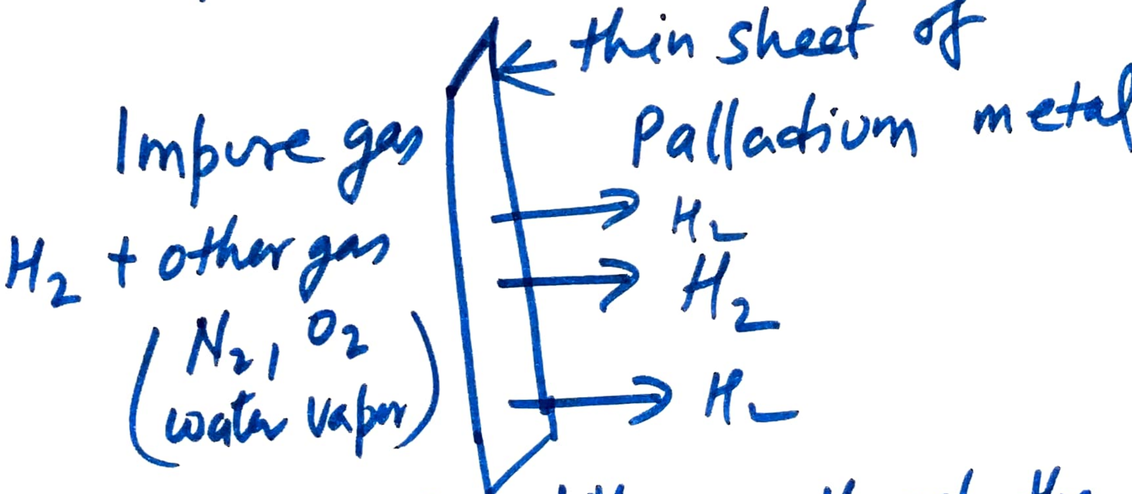
(cm^2/sec , m^2/sec)

$\frac{\partial c}{\partial x}$ → Concentration gradient in the x-direction

−ve sign → Indicates that the flow of matter occurs down the concentration gradient, from a high to low concentration

One practical example of <u>Steady state diffusion</u>

Purification of Hydrogen Gas



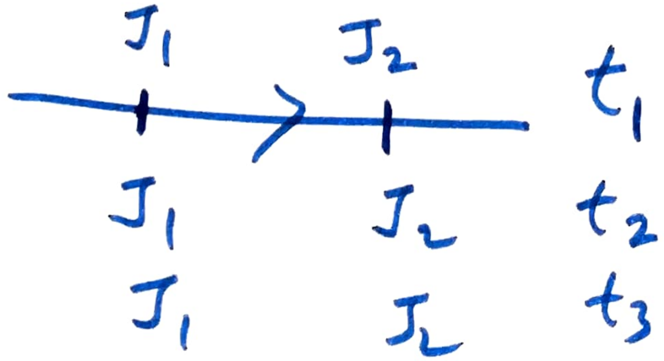
the H_2 Selectively diffuses through the sheet to the opposite side, which is maintained at a constant and lower H_2 pressure.

Fick's first law

can be used to describe flow under Steady state conditions.

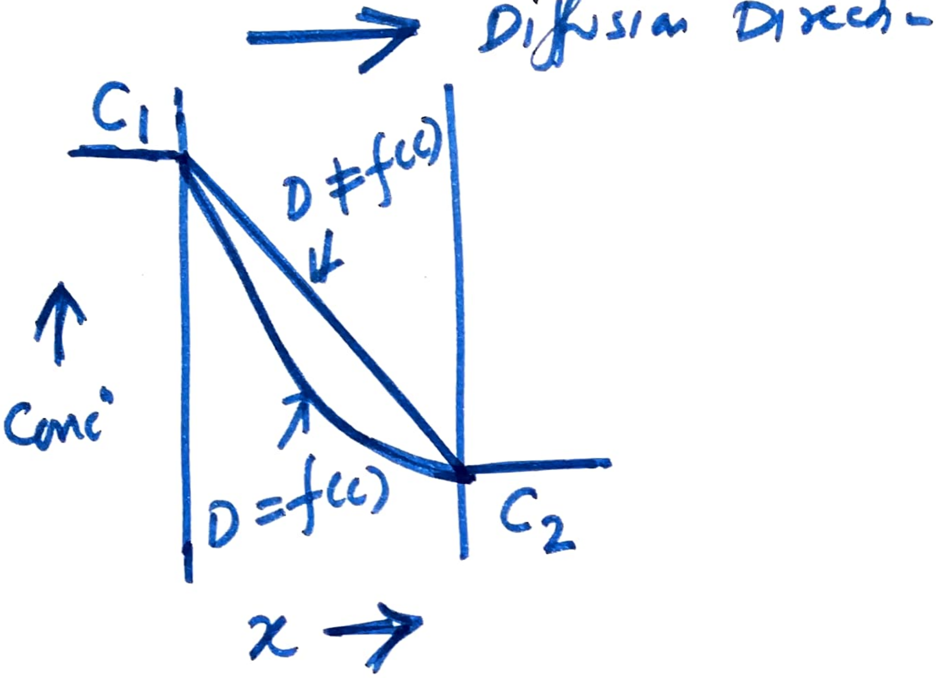
↓ under this condition

the flux is independent of time & remains the same at any cross sectional plane along the diffusion direction.



$$J \neq f(x, t)$$

Concentration - Distance profile under steady state condition



(i) if D is independent of conc^n

$$D \neq f(c)$$

Profile is straight line

(ii) if D depends on conc^n

& $$D = f(c)$$

the profile will be such that the product $D\left(\frac{\partial c}{\partial x}\right)$ is a constant

In neither case, the profile changes with time, under conditions of steady state flow.