Diffusion

Chapter 5

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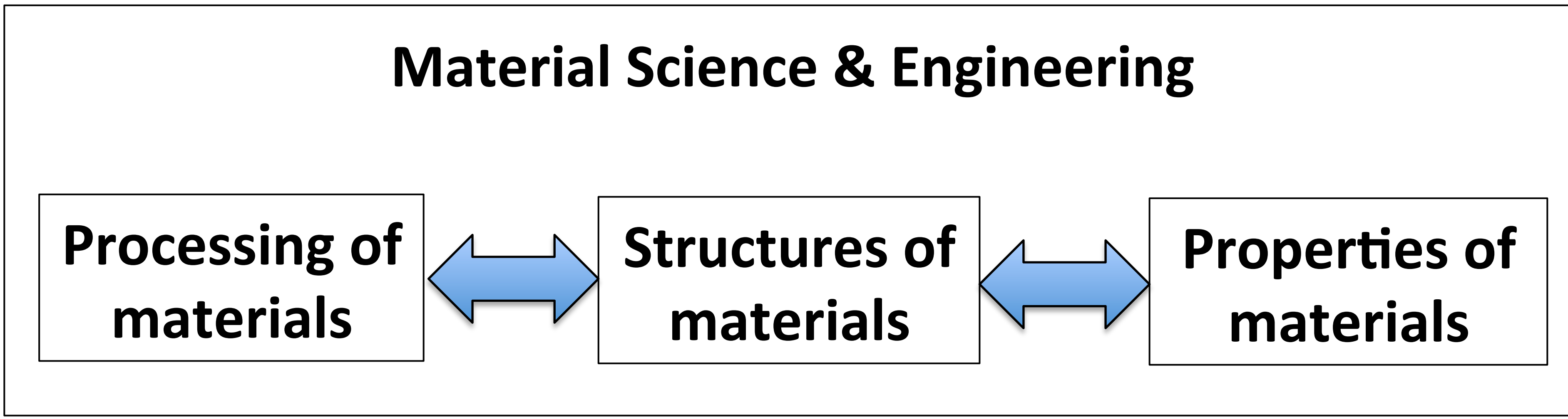
Second Semester 1434-1435

Outline

- Introduction
- Interdiffusion (or impurity diffusion) and self-diffusion
- Diffusion mechanisms
  - Required conditions
  - Models for metallic diffusion: vacancy diffusion and interstitial diffusion
- Steady state diffusion: Fick's first law

Why do we need to study diffusion?

From Chapter 1:

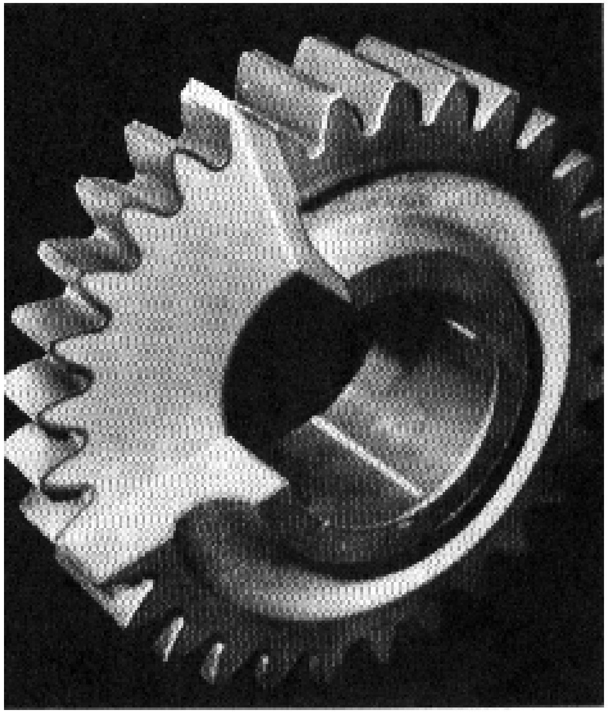


The properties of materials can be enhanced by heat treatment. The phenomena that occur during a heat treatment almost always involve atomic diffusion.

Example: PROCESSING USING DIFFUSION

Case Hardening:

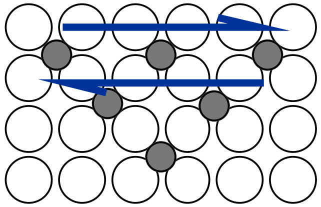
--Diffuse carbon atoms into the host iron atoms at the surface.



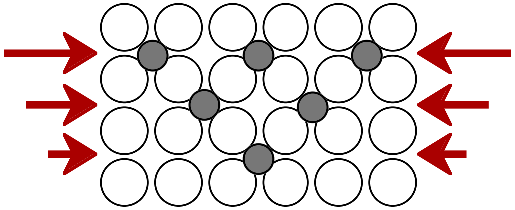
a case hardened gear

• Result: The "Case" is

--hard to deform: C atoms "lock" planes from shearing.



--hard to crack: C atoms put the surface in compression.

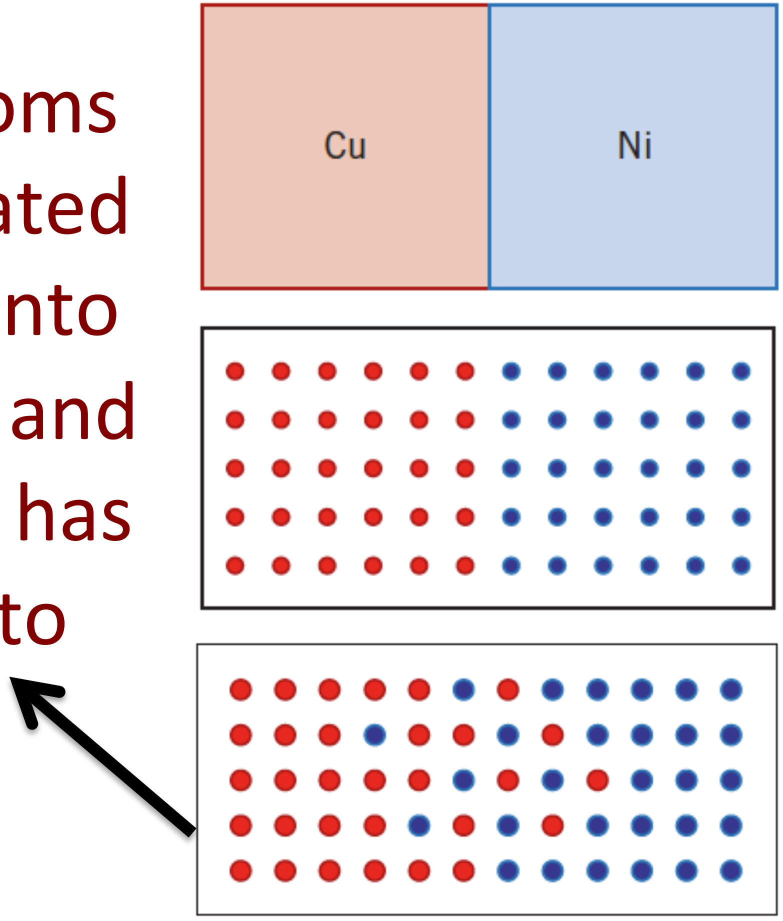


Introduction

Diffusion: Mass transport by atomic motion.

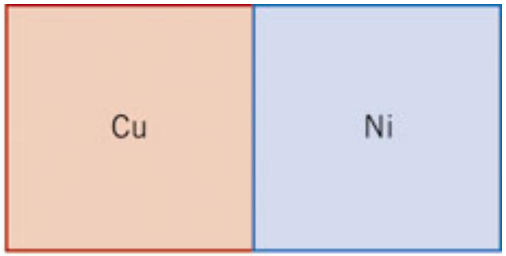
= Migration of atoms from lattice site to lattice site.

Copper atoms have migrated (diffused) into the nickel, and that nickel has diffused into copper.



The Cu-Ni couple is heated for an extended period at an elevated temperature and cooled to room temp.

1. Interdiffusion (or impurity diffusion): diffusion of atoms of one metal into another metal



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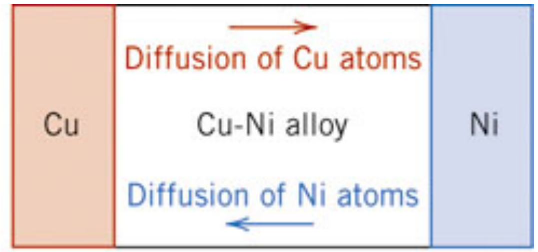
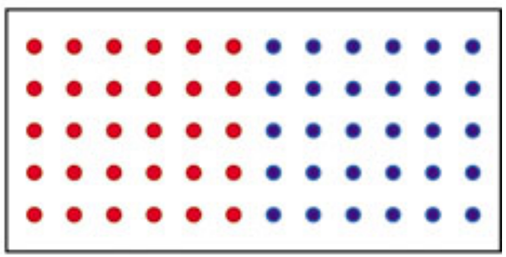
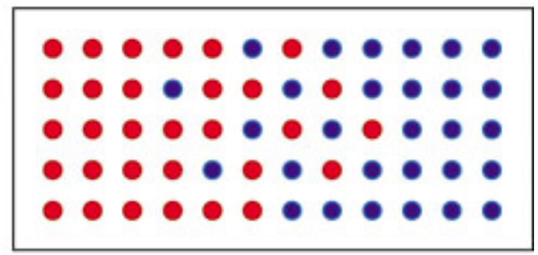


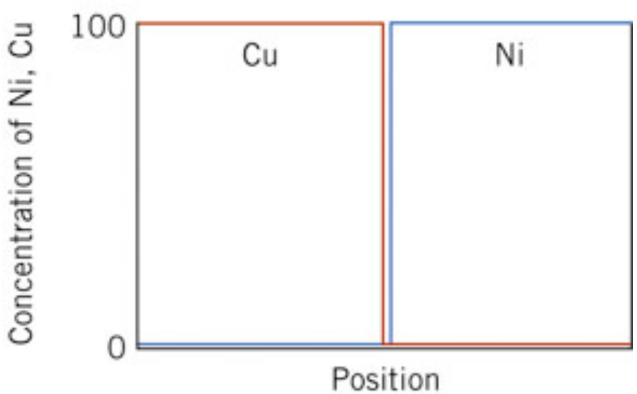
(a)

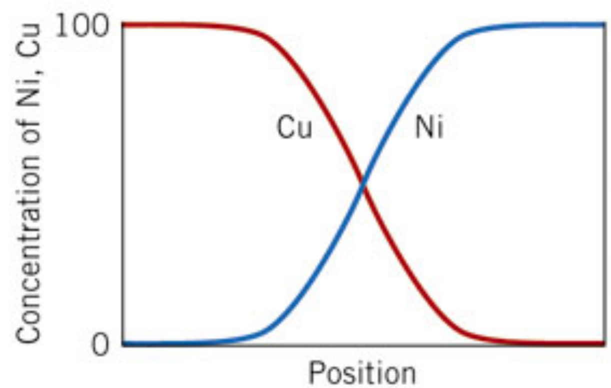


(b)



(b)

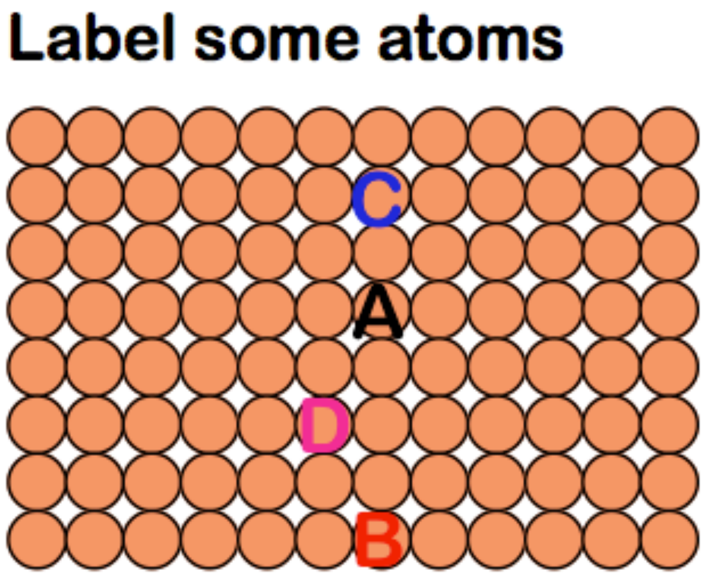


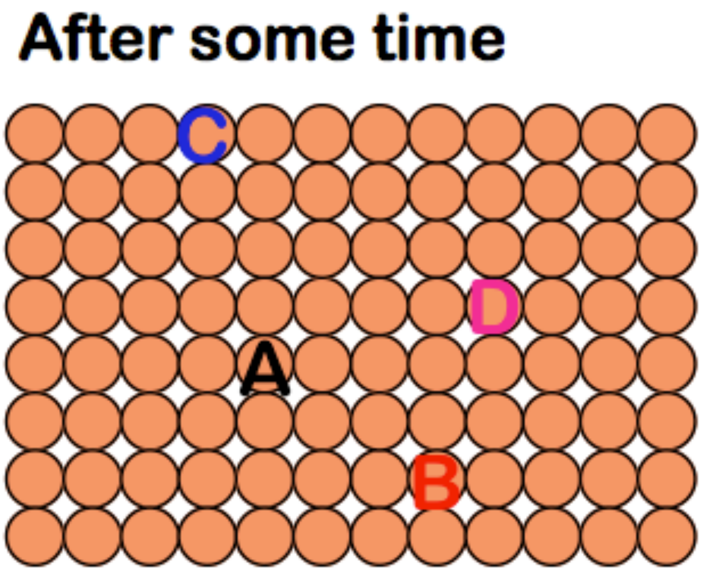


2. Self-diffusion:

Atomic migration in pure metals

all atoms exchanging positions are of the same type





DIFFUSION MECHANISMS

Diffusion: Migration of atoms from lattice site to lattice site

Two conditions must be met:

1. There must be an empty adjacent site.

2. Atoms must have sufficient energy to break bonds with its neighbor atoms.

   This energy is vibrational in nature!

Note about vibrational energy:

❑ Atomic vibrations:

Atoms in solid materials are constantly vibrating at very high frequencies and with relatively small amplitudes.

❑ With rising temperature, the average vibrational energy of atoms increases.

Temperature ⇧ ➔➔➔ **Vibrational energy** ⇧

❑ Increase in temperature ➔ Increase in vibrational atomic motion➔ Rupture large no. of atomic bonds➔ Melting

DIFFUSION MECHANISMS

Two conditions must be met:

1. There must be an empty adjacent site.

2. Atoms must have sufficient energy to break bonds with its neighbor atoms.

"At a specific temperature some small fraction of the total number of atoms is capable of diffusive motion, by virtue of the magnitudes of their vibrational energies. This fraction increases with rising temperature."

DIFFUSION MECHANISMS

Two main models for metallic diffusion *(i.e. models for diffusion or atomic motion in metals)***:**

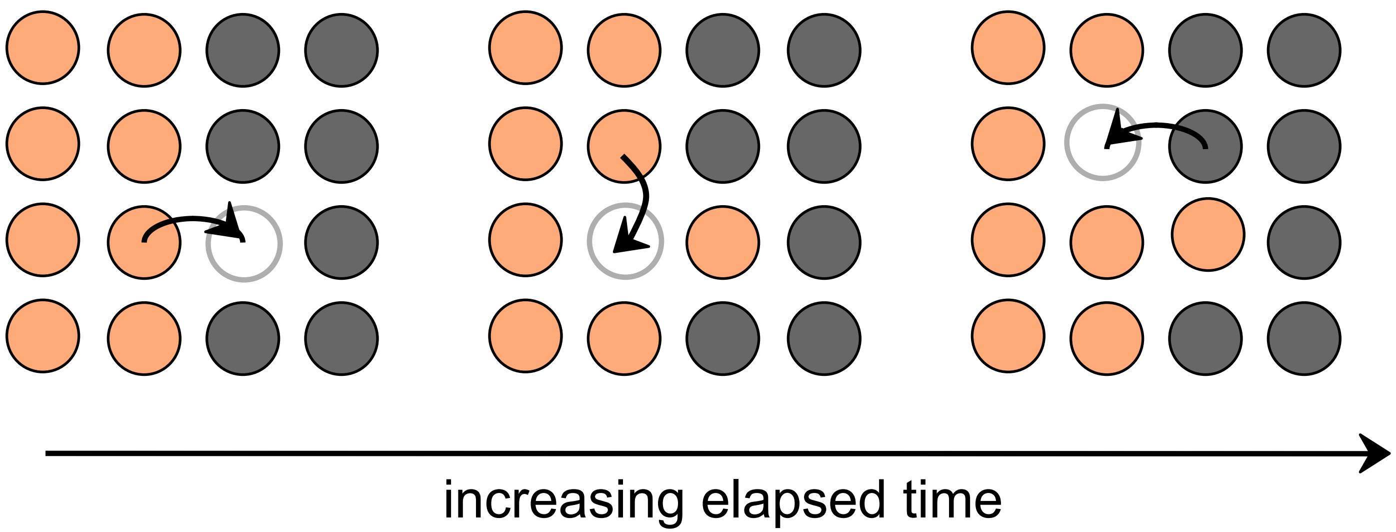
A. Vacancy Diffusion

B. Interstitial Diffusion

Diffusion Mechanisms

A. Vacancy Diffusion-atomic motion is from lattice site to an adjacent vacancy

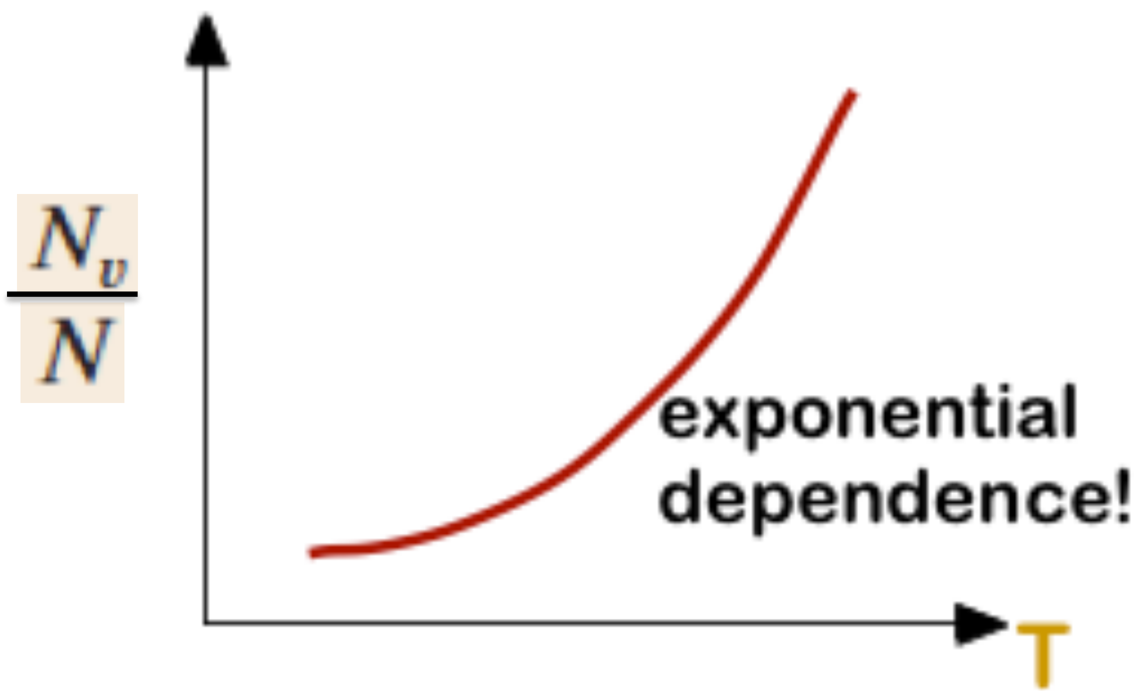
- atoms exchange with vacancies
- rate depends on:
  --number of vacancies
  --activation energy to exchange.



Do you remember the relationship between vacancy and temperature (Ch. 4)?

Review from Chapter 4: Equilibrium concentration of vacancies

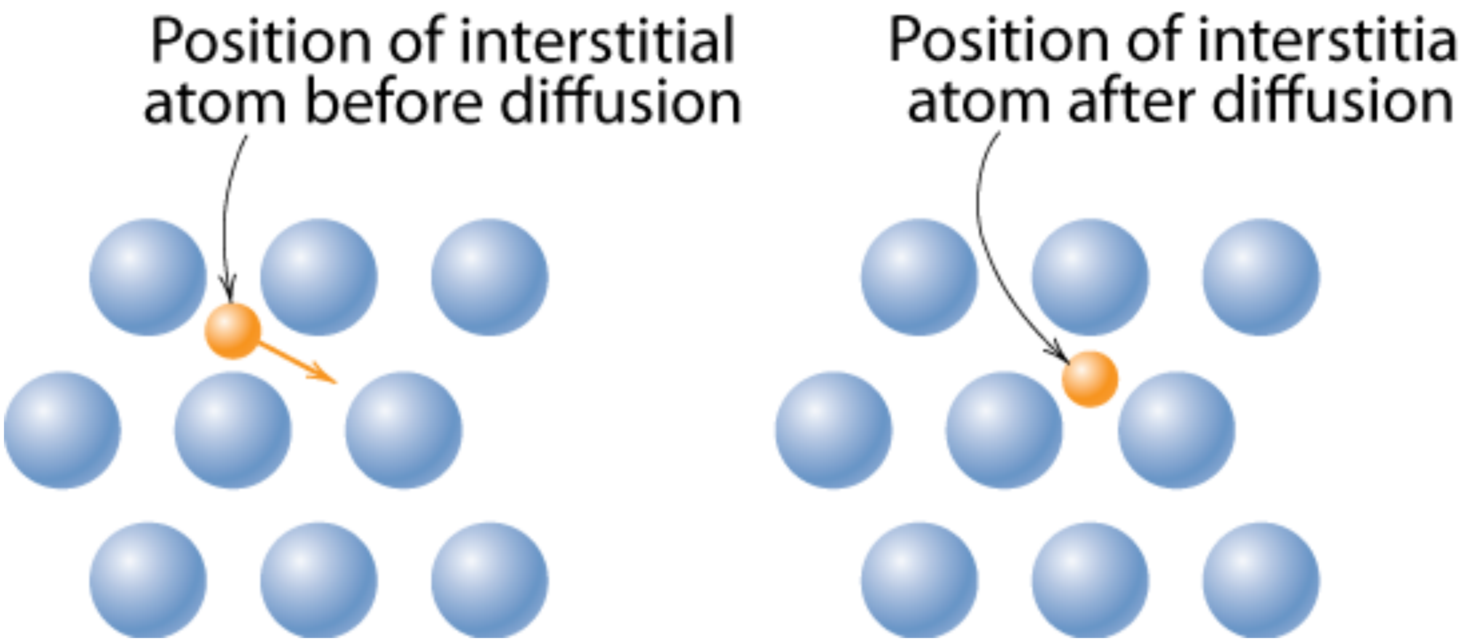
$$N_v = N \exp\left(-\frac{Q_v}{kT}\right)$$



- As the temperature increase the number of vacancies also increase.

Cont'd: Diffusion Mechanisms

B. Interstitial diffusion –atomic motion is from interstitial site to interstitial site.



- ✓ Interstitial diffusion occurs more rapidly than vacancy diffusion *(since the interstitial atoms are smaller and thus more mobile)*
- ✓ Probability of interstitial diffusion is higher than vacancy diffusion (since there are more empty interstitial positions than vacancies)

STEADY STATE DIFFUSION

Steady state diffusion

1) **Diffusion flux:**

The flux is the rate of flow per unit area (rate generally means quantity per unit time).

e.g. amount of water flows through a cross sectional area each second.

➔ **Diffusion flux**: The quantity of mass diffusing through a unit cross-sectional area of material per unit time.

Mathematically, we can write:

$$J = \frac{M}{A\,t}$$

where

J=diffusion flux (Kg/m^2-s)

M= mass (Kg)

A= area (m^2)

t=time (s)

In a differential form,

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

2) Steady state diffusion:

If the system is in a steady state, then the properties are independent of time.

Steady state diffusion: The flux (J) is independent of time

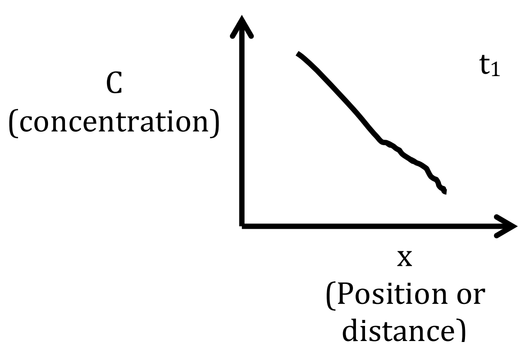
➔ This means that the rate of diffusion into a given system is equal to the rete of diffusion out

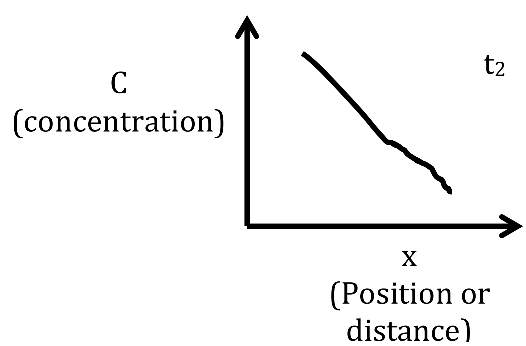
➔ No net accumulation of depletion of diffusing species).

➔ In this case, the concentrations of the diffusing species at certain position are independent of time.

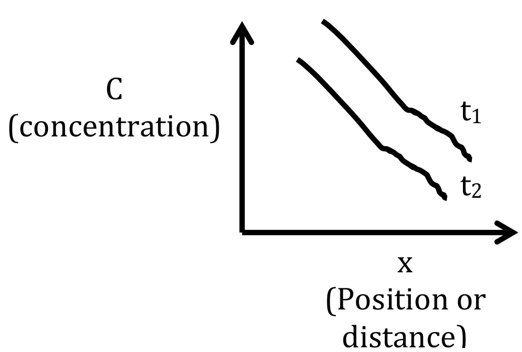
➔ The concentration profile is independent of time.

The two concentration profile plots (at time t_1 and t_2) below are similar





However, for non-steady state diffusion:



3) Fick's first law:

For steady state diffusion,

$$J = -D\frac{dC}{dx}$$

where

J=diffusion flux (Kg/m2-s)

D=diffusion proportionality (m2/s)

C= concentration (Kg/m3)

t=time (s)

The above relation reads that the diffusion flux is proportional to the negative of the concentration gradient.

i.e.

The flow of diffusion goes from regions of higher concentration to regions of lower concentration.

NOTE:

The gradient of any scalar function (df/dx) points in the direction of the greatest rate of increase of the function. The magnitude tells you how fast the function increase.