MSE200
Lecture 6 (CH. 5.1-5.4)
Diffusion
Instructor: Yuntian Zhu

•Objectives/outcomes: You will learn the following:

•Describe the rate processes in solids, the activation energy.

•Describe atomic diffusion and diffusion mechanisms.

•Describe substitutional and interstitial diffusion.

•Describe steady state diffusion and apply Fick's first law.

•Describe transient diffusion and apply Fick's second law.

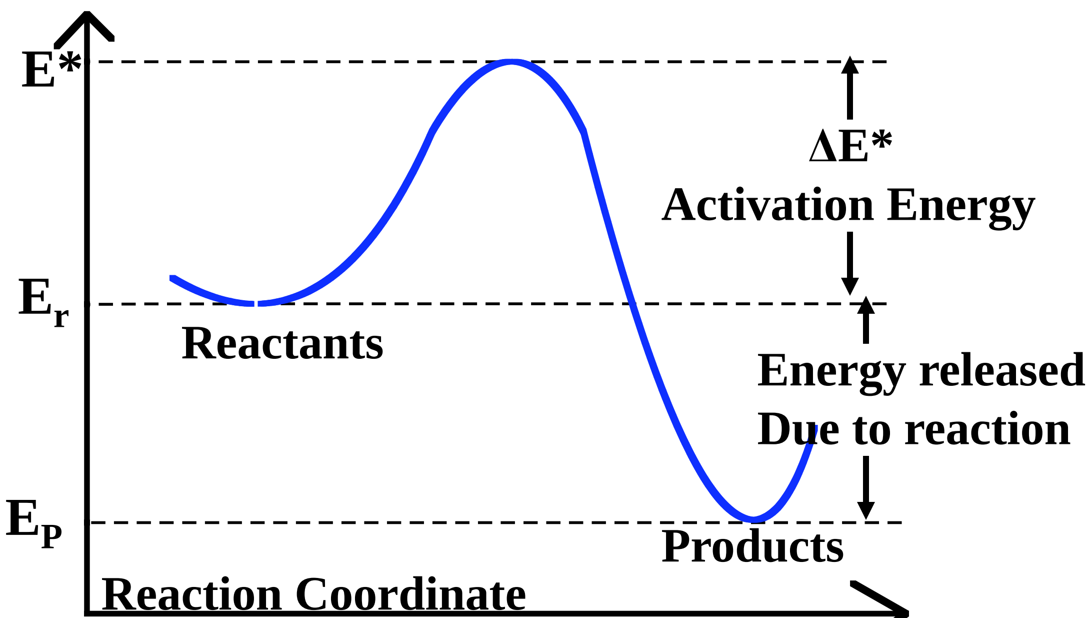
•Describe effect of temperature on diffusion rate.

•List a few industrial applications of diffusion.

Rate Process in Solids

- **At a given temperature, not all atoms have activation energy ΔE*. It should be supplied to them.**

$$rate = Ce^{\frac{-\Delta E_a}{kT}} = Ce^{\frac{-\Delta E}{RT}}$$



ΔE* = Activation Energy
k=Bottzmann's constant
=1.38x10^{-23} J/(atom K)

R= 8.314 J/(mol K)

Vacancy concentration

- **The number of vacancies at equilibrium at a particular temperature in a metallic crystal lattice is given by**

$$C_V = \frac{n_v}{N} = Ce^{\frac{-E_V}{kT}}$$

n_v = Number of vacancies per m^3 of metal
N = Number of atoms per m^3 of metal
E_v = Activation Energy to form a vacancy
T = Absolute Temperature.
K = Boltzmann's Constant =1.38 x 10^{-23} J/(atom K).
C = Constant

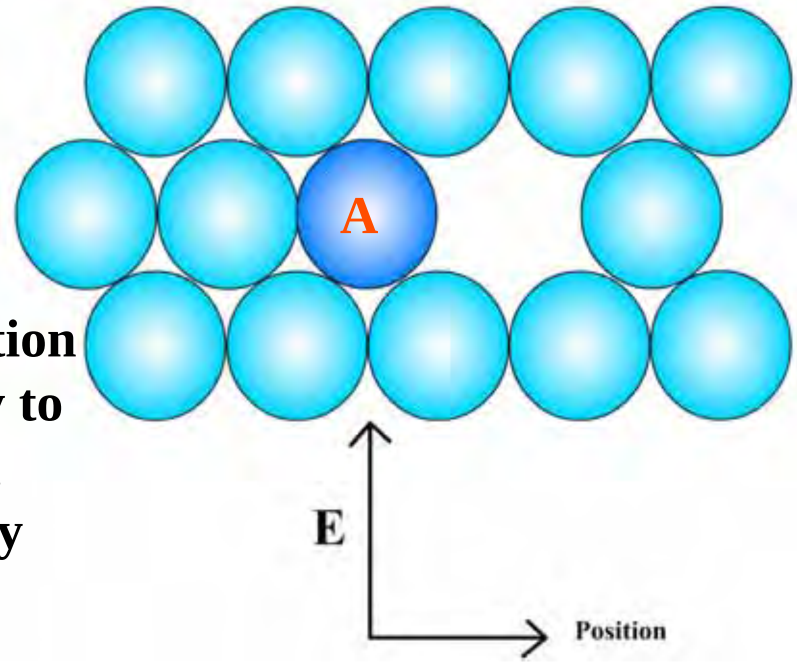
Atomic Diffusion in Solids

- **Diffusion is a process by which a matter is transported through another matter or itself (self diffusion).**

- **Examples:**

http://www.youtube.com/watch?v=y0WoJ3SGRck

Vacancy or Substitutional Diffusion

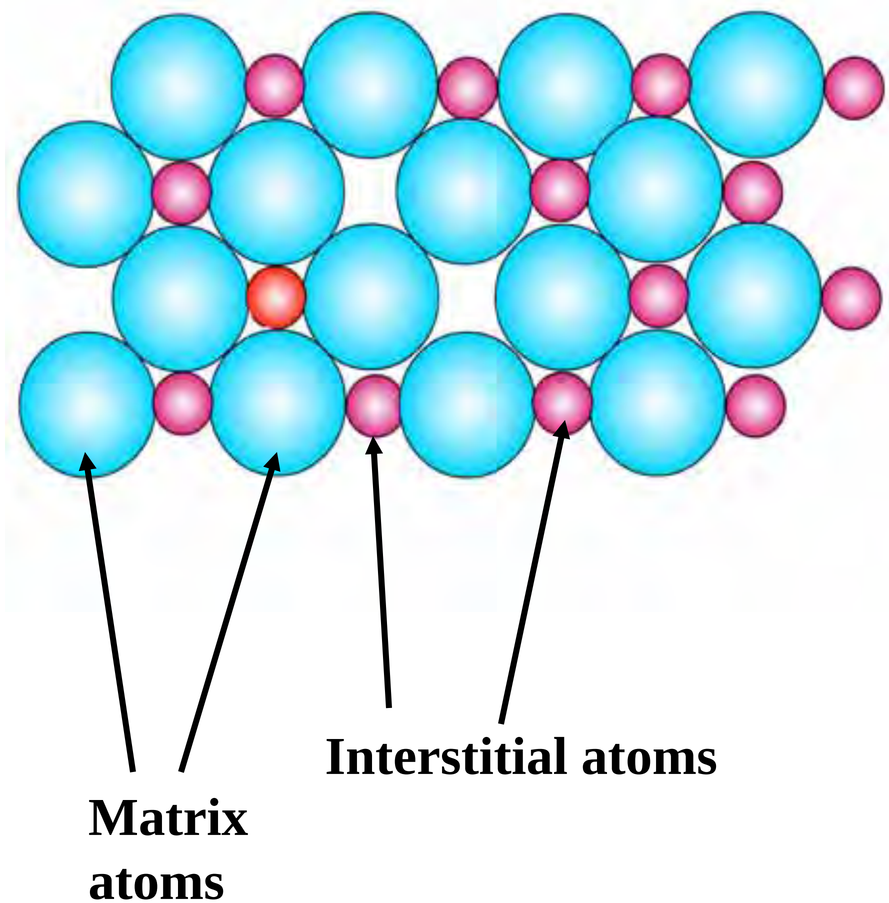


Activation Energy of Self diffusion = **Activation Energy to form a Vacancy** + **Activation Energy to move a vacancy**

- **requirement: Vacancy**
- **As the melting point increases, activation energy also increases (why?)**

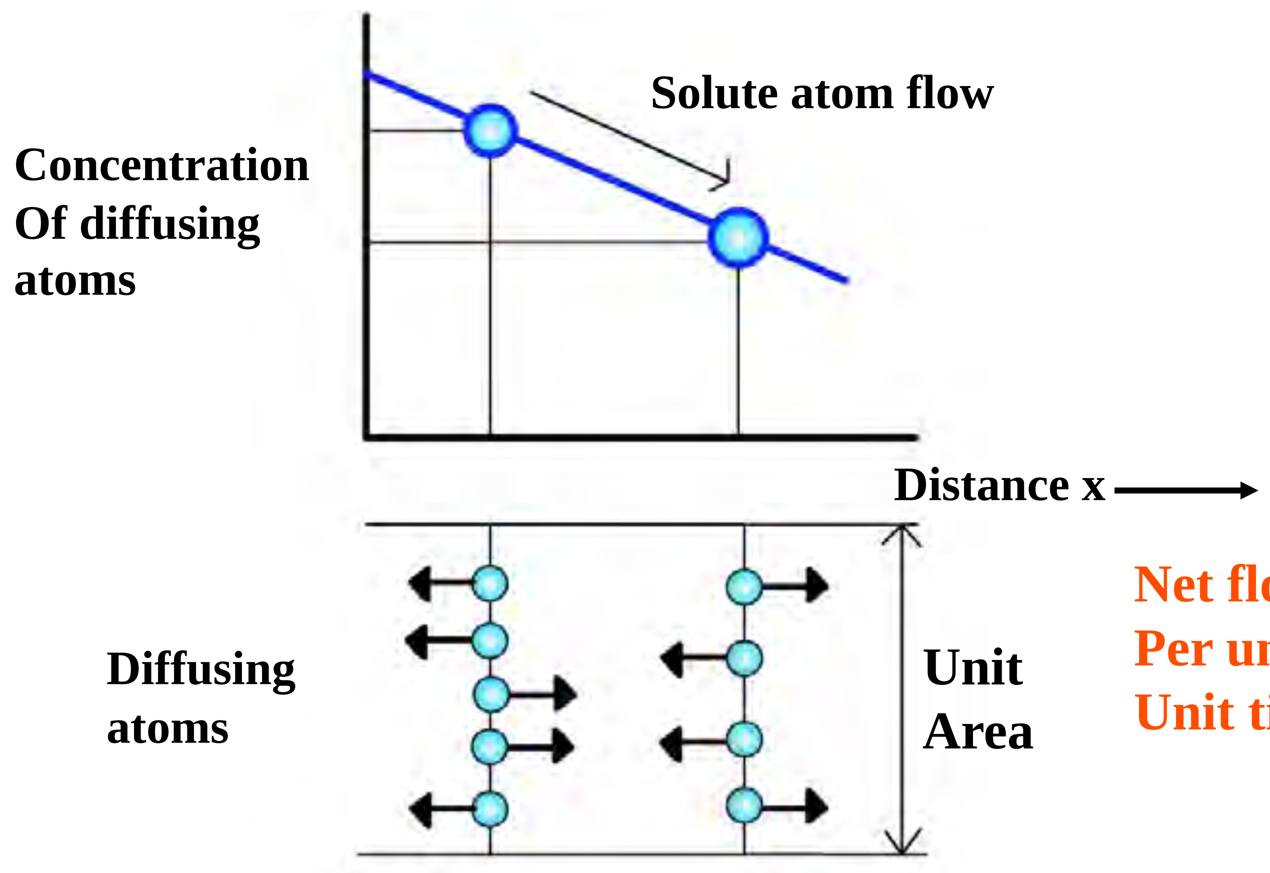
Interstitial Diffusion mechanism

- **Atoms move from one interstitial site to another.**



Steady State Diffusion

- **No change in concentration with time**
- **No chemical reaction occurs. Only net flow of atoms.**



Net flow of atoms Per unit area per Unit time = J

Fick's First Law (for steady state diffusion)

- **The flux or flow of atoms is given by**

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

J = Flux or net flow of atoms.
D = Diffusion coefficient/diffusivity
$\frac{dc}{dx}$ **= Concentration Gradient.**

- **Temperature effect:**

$$D = D_0 \exp\left(-\frac{Q}{RT}\right)$$

Non-Steady State Diffusion

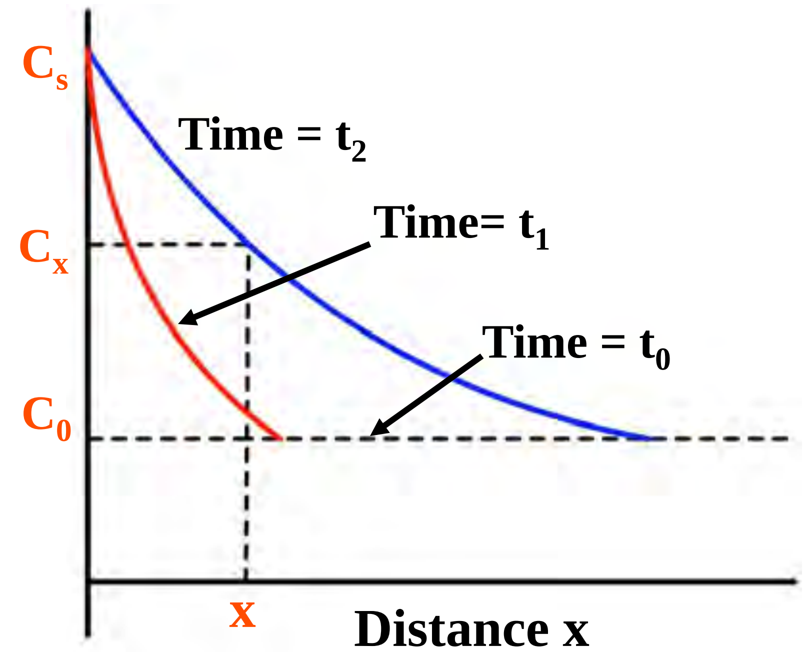
- **Concentration of solute atoms at any point in metal changes with time in this case.**
- **Ficks second law:**

$$\frac{dC_x}{dt} = \frac{d}{dx}\left(D \frac{dc_x}{dx} \right)$$

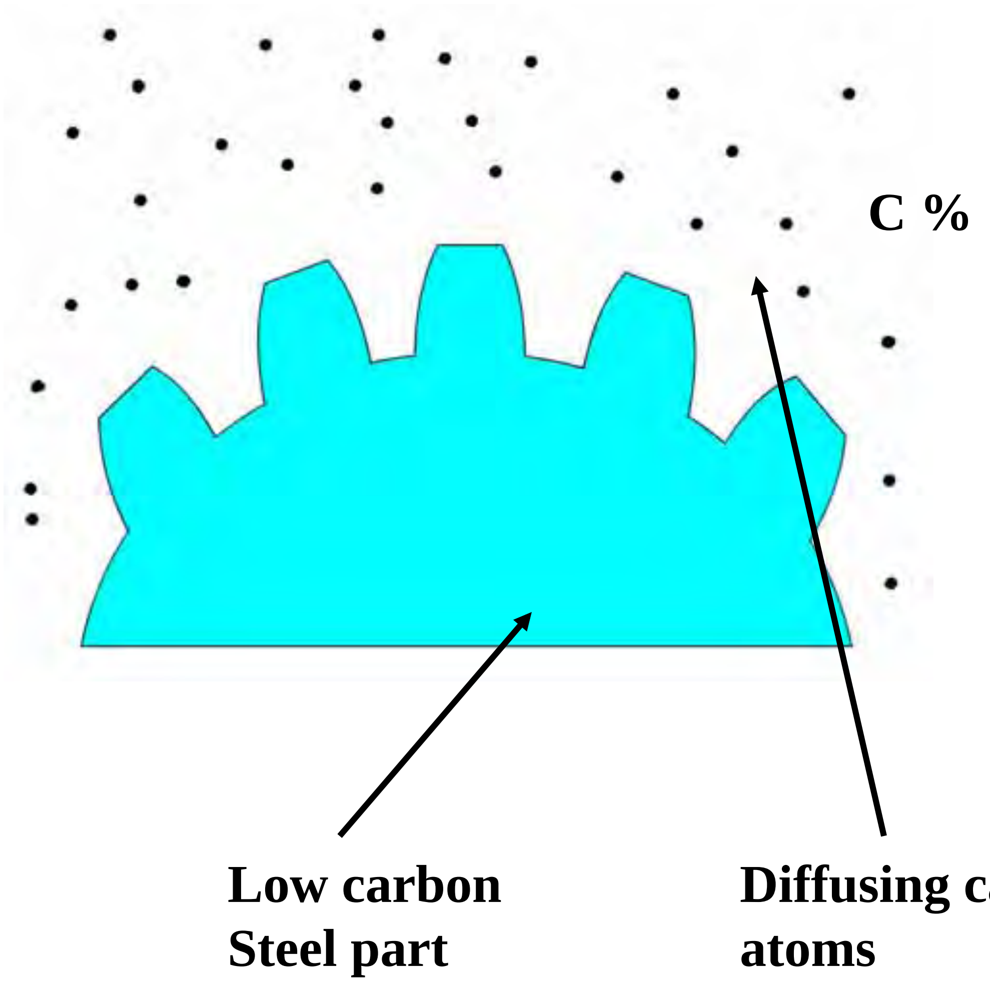
Fick's Second Law – Solution

$$\frac{C_s - C_x}{C_s - C_0} = erf\left(\frac{x}{2\sqrt{Dt}}\right)$$

- C_s = Surface concentration of element in gas diffusing into the surface.
- C_0 = Initial uniform concentration of element in solid.
- C_x = Concentration of element at distance x from surface at time t1.
- x = distance from surface
- D = diffusivity of solute
- t = time.



Carburizing



(After "Metals Handbook," vol.2: "Heat Treating," 8th ed., American Society of Metals, 1964, p.100)

Effect of Temperature on Diffusion

- **Dependence of rate of diffusion on temperature is given by**

$$D = D_0 e^{\frac{-Q}{RT}}$$

or

$$\ln D = \ln D_0 - \frac{Q}{RT}$$

D = Diffusivity m2/S
D_0 = Proportionality constant m^2/S
Q = Activation energy of diffusing species J/mol
R = Molar gas constant = 8.314 J/mol.K
T = Temperature (K)

Effect of Temperature on Diffusion-Example

- **If diffusivity at two temperatures are determined, two equations can be solved for Q and D_0**
- **Example:-**

The diffusivity of silver atoms in silver is 1 x 10^{-17} at 500^0C and 7 x 10^{-13} at 1000^0C.

Therefore,

$$\frac{D_{1000}}{D_{500}} = \frac{\exp(-Q/RT_2)}{\exp(-Q/RT_1)} = \exp\left(\frac{-Q}{R}\left(\frac{1}{T_2}-\frac{1}{T_1}\right)\right)$$

$$\frac{7\times10^{-13}}{1\times10^{-17}} = \exp\left(-\frac{Q}{R}\left(\frac{1}{1273}-\frac{1}{773}\right)\right)$$

Solving for *activation energy* Q

$$Q = 183KJ/mol$$

Home work

Example Problems: 5.1, 5.2, 5.3, 5.4, 5.5, 5.6,
Regular Problems, Chapter 5:3, 13, 16, 21, 25,
Reading assignment for the next class after test 1: 5.1-5.4

Test 1 review and policy

- Understand the underlined concept in the VG
- Example problems
- Homework problems

- 35 multiple choices at 3 points each
- Bring your student ID
- Have you ID # for the score sheet!