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ENR116 Engineering Materials

Module 2 Material Properties

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Welcome to ENR116 Engineering Materials

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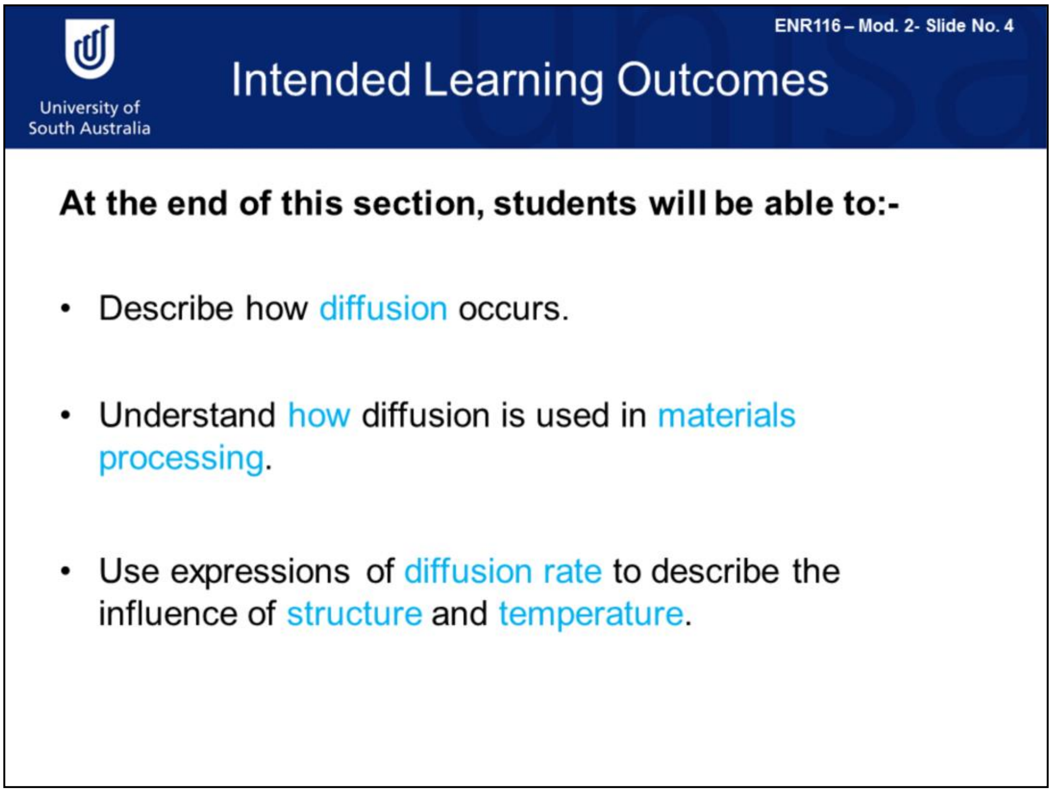
Diffusion (Chapter 5 in Callister)



The intended learning outcomes from this presentation are:

Describe how diffusion occurs

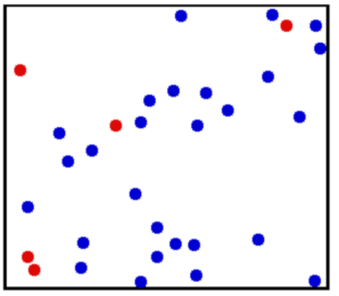
Understand how diffusion is used in materials processing

Use expressions of diffusion rate to describe the influence of structure and temperature

Diffusion

Diffusion: Mass transport by atomic motion

- Gases & Liquids – random (Brownian) motion


www.Wikipedia.com/Brownian_motion

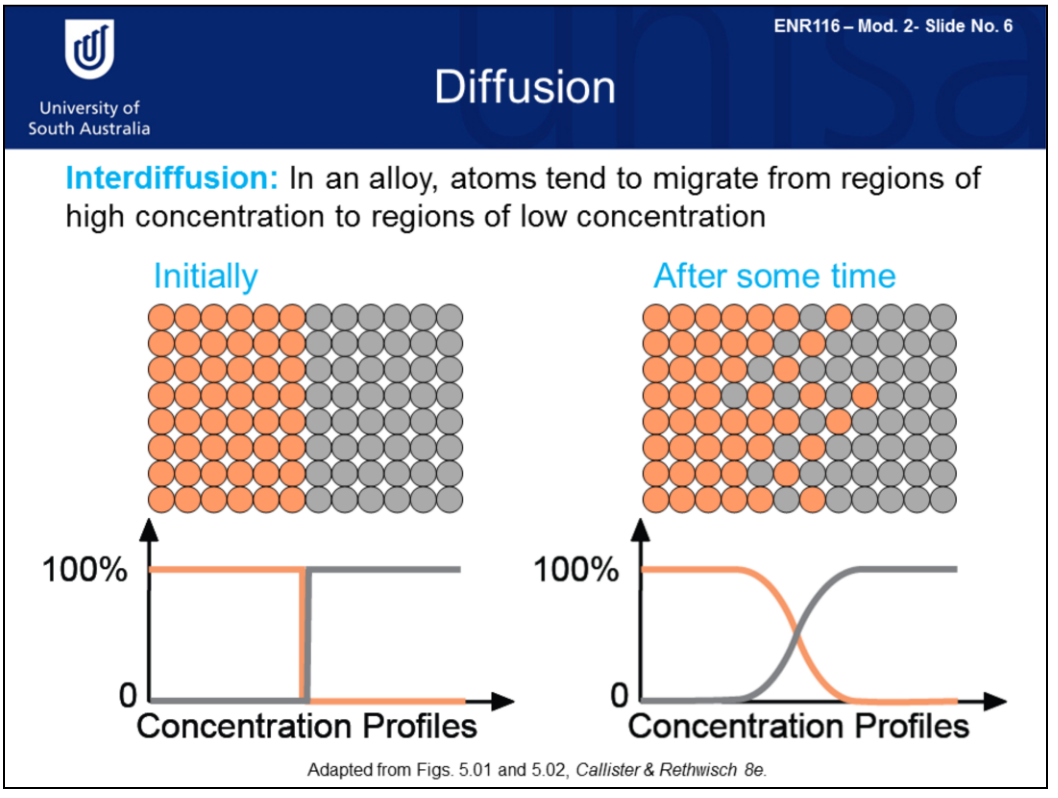
- Solids – Two mechanisms:

  Vacancy diffusion or Interstitial diffusion

Diffusion = mass transport by atomic motion

Diffusion mechanism depends on material type

Diffusion in solids is via vacancy or interstitial mechanisms



Two metal bars placed in intimate contact

Metals diffuse across the interface into each other over time

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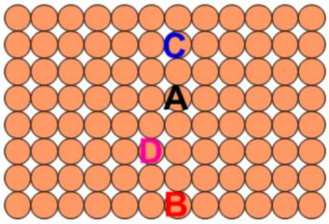
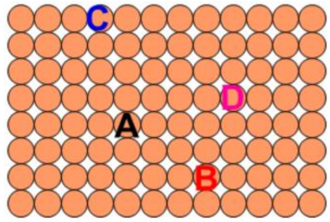
Diffusion

Self-diffusion: In an elemental solid, atoms also migrate.

Labelled atoms



After some time



Atoms also migrate within pure metals

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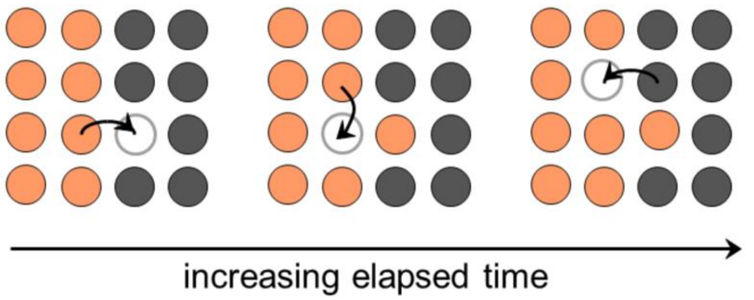
Diffusion mechanisms 1

Vacancy Diffusion: atoms exchange with vacancies



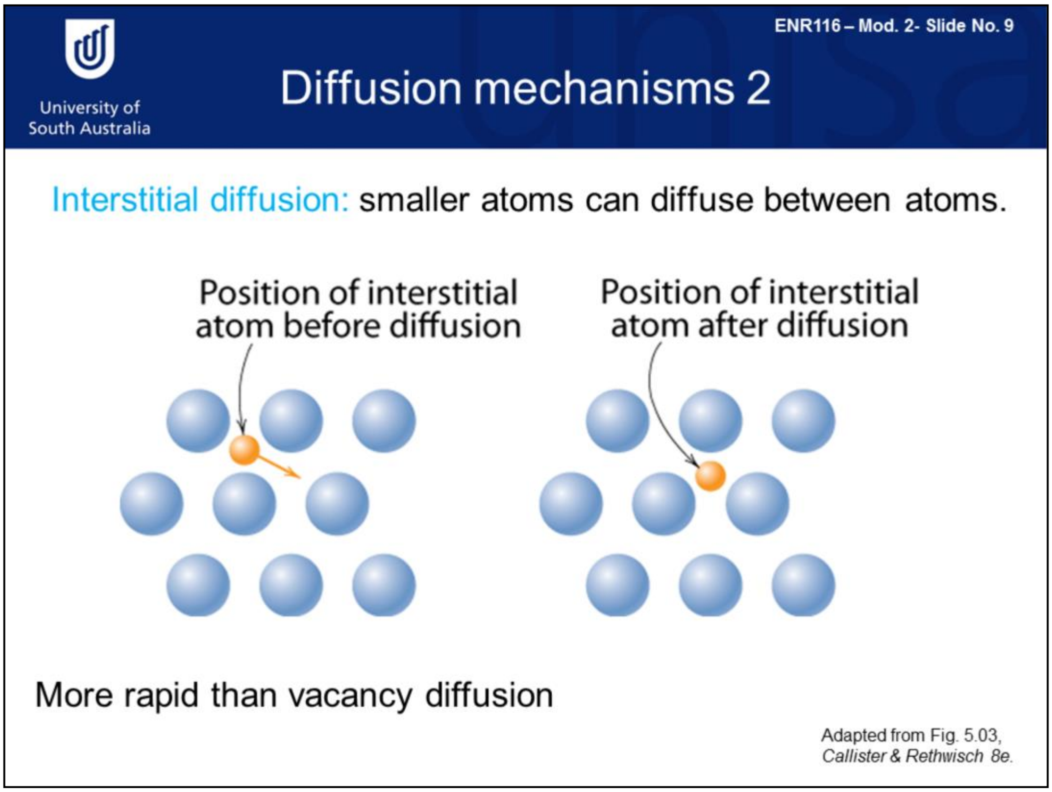
Applies to substitution (impurity) atoms

Rate of vacancy diffusion depends on:

- number of vacancies
- activation energy to exchange

Vacancy diffusion = atoms exchange with vacancies

Rate depends on no. of vacancies, and activation energy



Interstitial diffusion = smaller atoms diffusing between atoms

For example Carbon into Iron

More rapid than vacancy diffusion due to the size of the diffusing atoms

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Processing using diffusion

Case Hardening:

An example of interstitial diffusion is a case hardened gear.

Carbon atoms diffuse into the host iron atoms at the surface.

Result: The presence of C atoms makes iron (steel) harder

Fig. 05, pg 122a, *Callister & Rethwisch 8e.* (Courtesy of Surface Division, Midland-Ross.)

Carbon atoms in the surface of an iron gear can be used to make the surface harder and more resistant to wear.

Quantifying Diffusion

How do we quantify the amount or rate of diffusion?

Diffusion Flux, J

$$J \equiv \text{Flux} \equiv \frac{\text{moles (or mass) diffusing}}{(\text{surface area})(\text{time})} = \frac{\text{mol}}{\text{cm}^2\text{s}} \text{ or } \frac{\text{kg}}{\text{m}^2\text{s}}$$

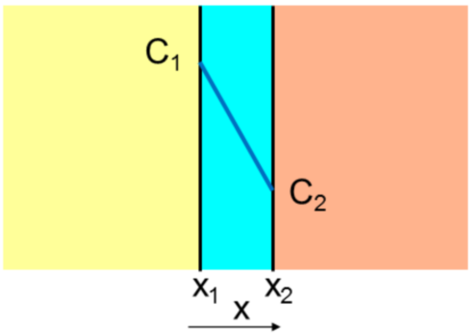
Units of Diffusion:

Diffusion Flux, J, is given in mol/cm^2 s, or kg/m^2 s.

Steady-state diffusion

Rate of diffusion independent of time

Flux proportional to concentration gradient = $\dfrac{dC}{dx}$



Fick's first law of diffusion:

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

if linear $\dfrac{dC}{dx} \cong \dfrac{\Delta C}{\Delta x} = \dfrac{C_2 - C_1}{x_2 - x_1}$

$D \equiv$ diffusion coefficient

Steady state diffusion described by Fick's First Law of Diffusion

J = -D (dC/dx)

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Example: Chemical protective clothing (CPC)

Methylene chloride is a common ingredient of paint removers. Besides being an irritant, it also may be absorbed through skin. When using this paint remover, protective gloves should be worn.

If butyl rubber gloves (0.04 cm thick) are used, what is the diffusive flux of methylene chloride through the glove?

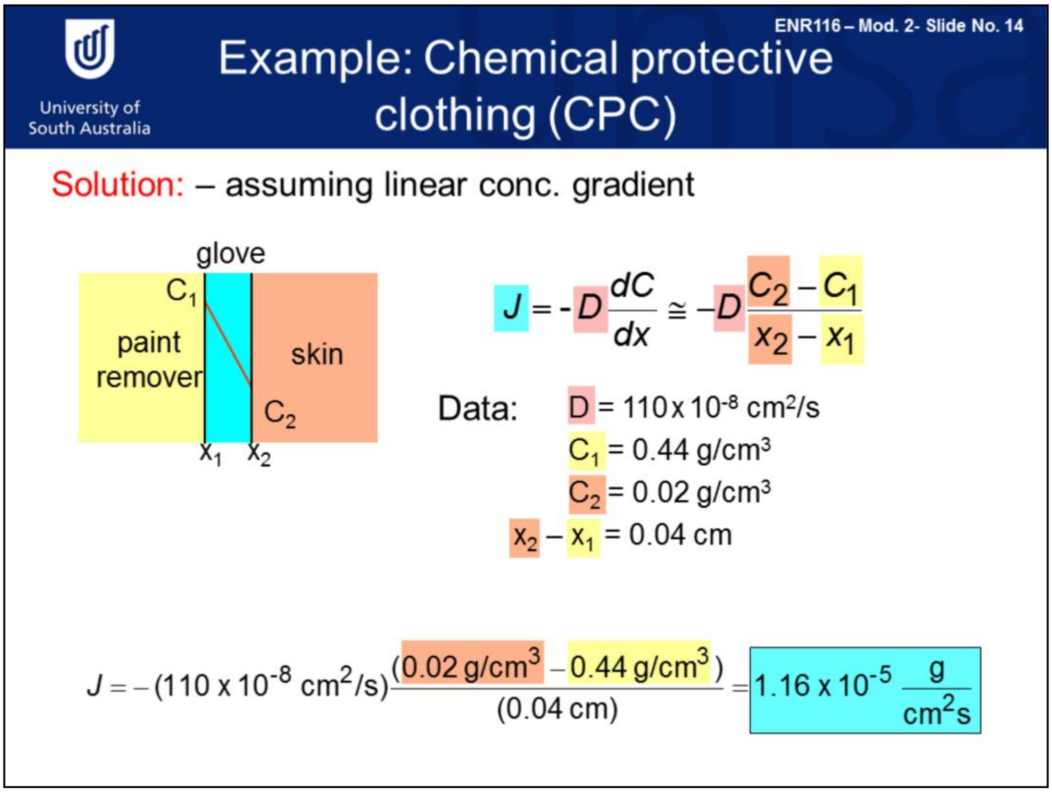
Data:

Diffusion coefficient in butyl rubber: $D = 110 \times 10^{-8}\ cm^2/s$

surface concentrations: $C_1 = 0.44\ g/cm^3$

$C_2 = 0.02\ g/cm^3$

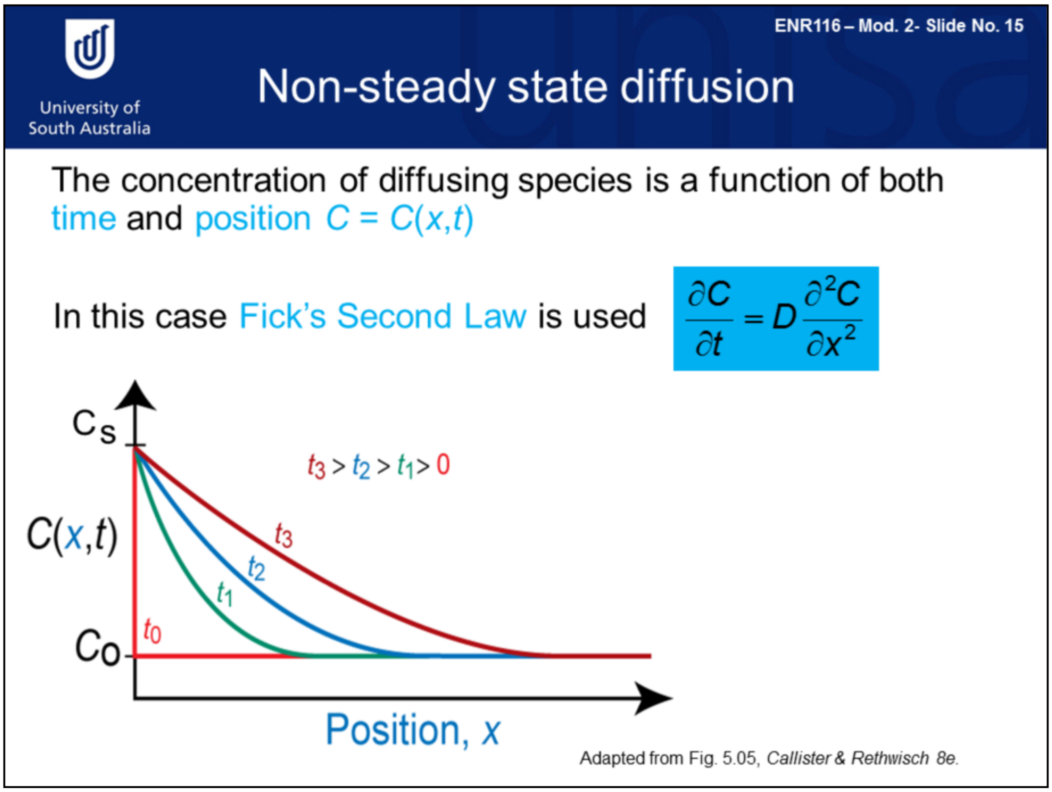
Common example of steady state diffusion



Assume steady state diffusion

Concentration gradient is linear

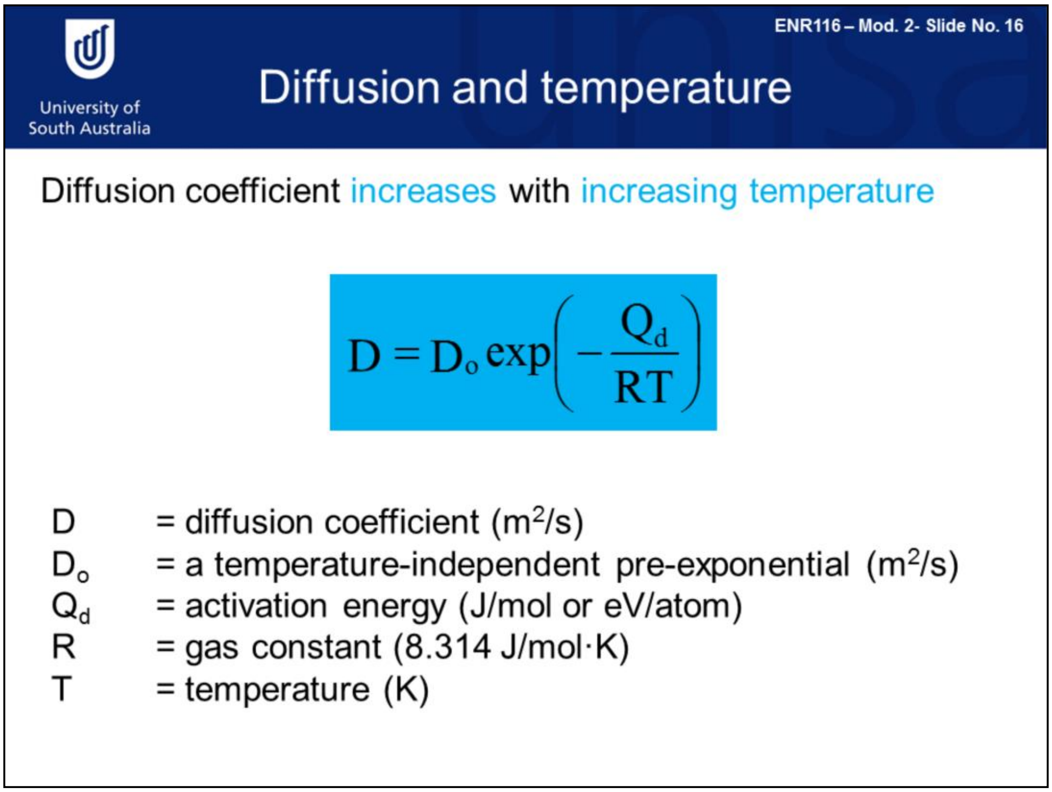
Fick's First Law can be applied



In the non-steady state the concentration profile develops with time.

Fick's Second Law of Diffusion is used

Non-steady state diffusion must be understood to optimise the properties of materials



Diffusion coefficient depends on D_0, Q_d and T

D_0 and Q_d are fixed for a given system

T has a major effect on D

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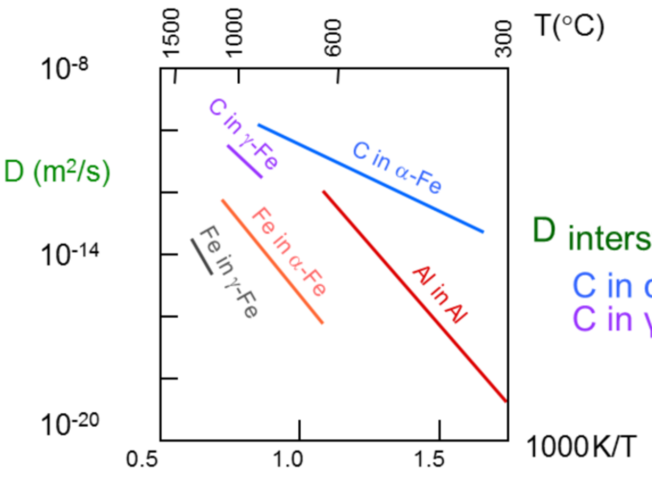
Diffusion in different systems



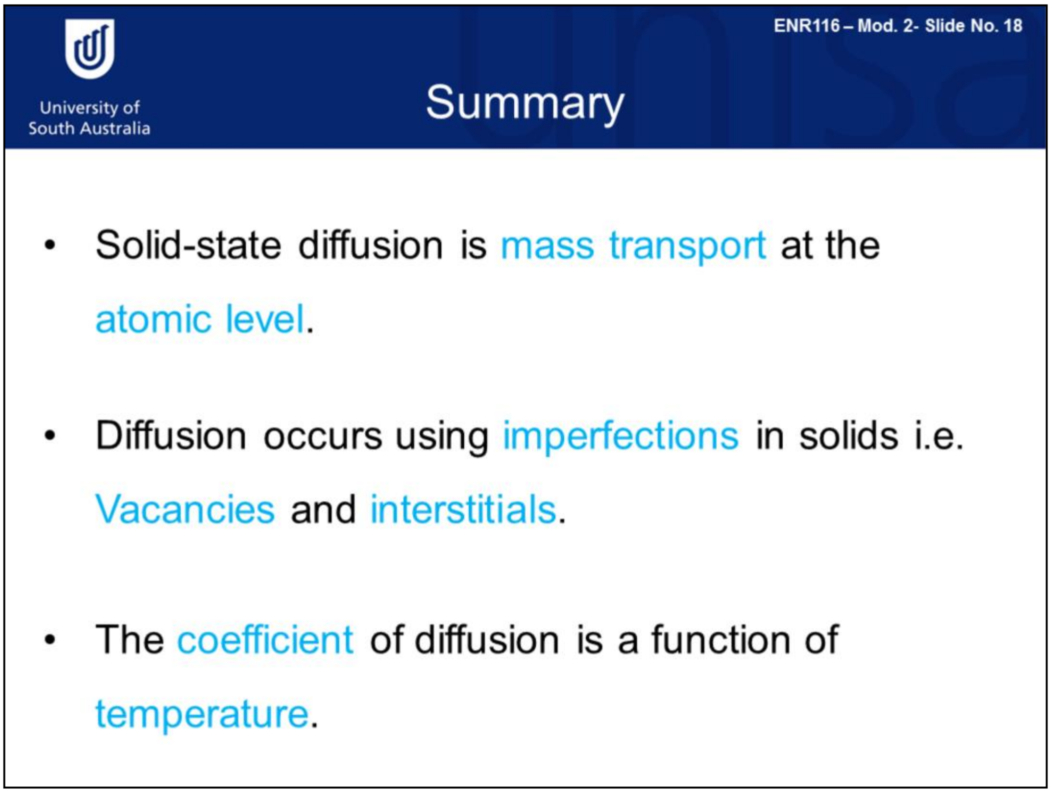
$D_{interstitial} >> D_{substitutional}$

D interstitial	D substitutional
C in α-Fe	Al in Al
C in γ-Fe	Fe in α-Fe
	Fe in γ-Fe

Adapted from Fig. 5.07, *Callister & Rethwisch 8e.*

D increases with T

D is also affected by crystal structure, and diffusion mechanism



Solid-state diffusion is mass transport at the atomic level.
Diffusion occurs in solids due to imperfections
Diffusion coefficient is a function of T

Thank you