الجامعة المستنصرية – كلية العلوم

قسم الفيزياء

Mustansiriyah Univ. – College of Science

Physics Department

Material Science 2

Third Class (B.SC.)

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Lecture (1 & 2)

Types of Materials, Bonds & Diffusion

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1- <u>Types of Materials</u>

Materials science and engineering plays a vital role in this modern age of science and technology. Various kinds of materials are used in industry, housing, agriculture, transportation, etc. to meet the plant and individual requirements.

Common engineering materials that fall within the scope of material science and engineering may be classified into one of the following **six groups**:

(i) Metals (ferrous and non-ferrous) and alloys
(ii) Ceramics
(iii) Organic Polymers
(iv) Composites
(v) Semiconductors
(vi) Biomaterials
(vii) Advanced Materials

2- <u>Types of Bonds</u>

Many solids are aggregates of atoms. <u>The arrangement of atoms in any solid material is determined by</u> **the character, strength and directionality of the chemical binding forces, cohesive forces or chemical bonds.** We call these binding forces as ***atomic interaction*** **forces**. The atoms, molecules or ions in a solid state are more closely packed than in the gaseous and liquid states and are held together by strong mutual **forces of attraction and repulsion.** <u>The type of bond that appears between atoms in crystal is determined by the electronic structure of interacting atoms.</u>

Seitz in 1940 classified solids into **five types according to the bonding of atoms**, which has become a generally adapted classification (Table (1)).

Table (1) Classification of solids according to the bonding of atoms

Solids	Type of Bond	Formation	Typical Examples
Covalent	Covalent, atomic or homopolar bonds	Electron shared between two atoms	Carbon (diamond), Ge, Si, SiC, etc
Ionic	Ionic or electrostatic bonds	Electron transfer and coulomb interaction between cation and anions	Alkali halides
Metal	Metallic	Freely moving electrons in array of positive ions	All metals and alloys
Molecular (vander waals)	Molecules between pairs	Weak attractive forces due to the dipole – dipole interaction	Noble gases
Hydrogen bond	Hydrogen atom attracted between two other atoms	Electrostatic bond of H- atom with an electronegative atom	Ice, organic compounds, biological materials

There are basically **two groups** of bonds:

(i) Primary Bonds: These are inter-atomic bonds in which electrostatic force holds the atoms together. Relatively large atomic forces develop in these bonds, making them more stable and imparting high strength. They have bond strength varying from 1-1.5 eV. these bonds are also known **as attractive bonds**. Following **three types of primary bonds** are found in different materials

(i) **Ionic or electrostatic bonds**

(ii) **Covalent, atomic or homopolar bonds**

(iii) **Metallic bonds**

The principal types of bonding is shown in Fig. (1).

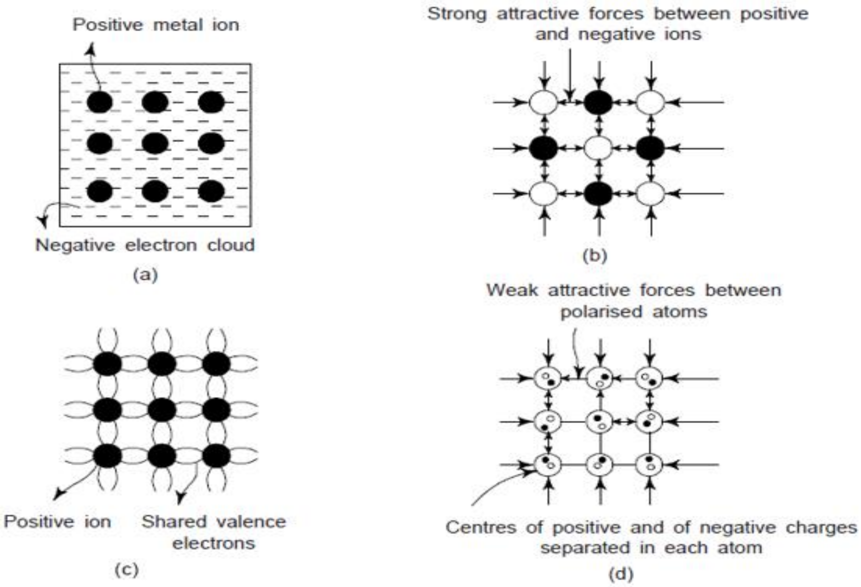


Fig. (1) The four principal types of chemical bonding in solids (a) Metallic bonding (b) Ionic bonding (c) Covalent bonding (d) Vander waals bonding

(ii) Secondary Bonds: A *secondary bond* is an intermolecular bond and weaker and less stable than primary bond. In this type of bonds, the forces hold the molecules together. These secondary bonds result from intermolecular or dipole attractions. Common examples of secondary bonds are **Vander Waals bonds and hydrogen bonds.**

3- Diffusion in Solids

Diffusion is the phenomenon of material transport by atomic motion, which enables the transfer of mass within a specific solid (on a microscopic level) or between a solid and a liquid, gas, or another solid phase.

Diffusion can be demonstrated using a **diffusion couple**, created by joining bars of two different metals in intimate contact. When the couple is heated to a high temperature (below their melting points) for an extended period and then cooled, atoms from each metal diffuse across the interface, resulting in a gradual change in composition. As an example, Copper and Nickle in Fig. (2).

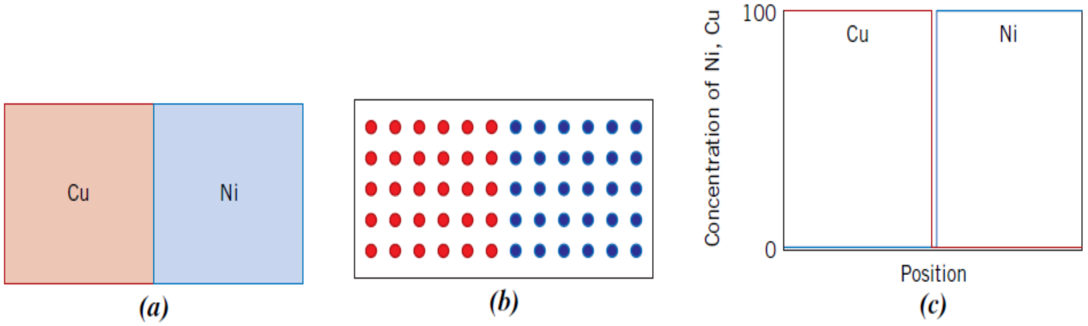
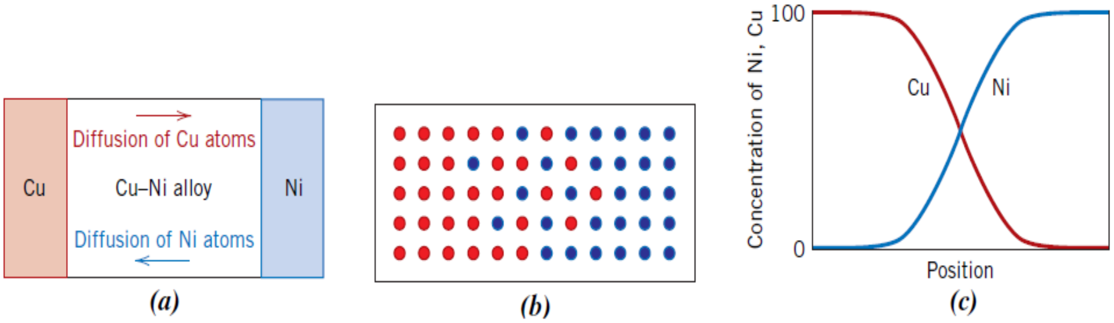


Fig. (2) (*a*) A copper–nickel diffusion couple before a high-temperature heat treatment. (*b*) Schematic representations of Cu (red circles) and Ni (blue circles) atom locations within the diffusion couple. (*c*) Concentrations of copper and nickel as a function of position across the couple.

Interdiffusion, or impurity diffusion, occurs when atoms of one metal migrate into another, creating a graded alloyed region with varying concentrations between the two metals, while pure metals remain at the extremities. As in Fig. (3)



(*a*) (*b*) (*c*)

Fig. (3) (*a*) A copper–nickel diffusion couple after a high-temperature heat treatment, showing the alloyed diffusion zone. (*b*) Schematic representations of Cu (red circles) and Ni (blue circles) atom locations within the couple. (*c*) Concentrations of copper and nickel as a function of position across the couple.

Interdiffusion involves the macroscopic movement of atoms from regions of high to low concentration, as seen in a Cu-Ni diffusion couple. In pure metals, diffusion also occurs, but since all atoms are of the same type, it is called **self-diffusion** and cannot be observed through compositional changes.

4- Diffusion Mechanisms

Diffusion at the atomic level involves atoms migrating between lattice sites, requiring **1- an adjacent empty site and 2- enough vibrational energy to break bonds and distort the lattice.** The number of atoms capable of diffusing increases with temperature, and two primary models explain this motion in metals.

Two dominant models are proposed for atomic motion in metallic diffusion.

4-1 Vacancy Diffusion

Vacancy diffusion is a mechanism where atoms move from a lattice position to an adjacent vacancy. This process requires the presence of vacancies, which increase at elevated temperatures. As atoms and vacancies exchange positions, their movements are opposite. Vacancy diffusion **facilitates both self-diffusion and**

interdiffusion, with impurity atoms substituting for host atoms in interdiffusion. As in Fig. (4-a).

4-2 Interstitial Diffusion

Interstitial diffusion occurs when small atoms, such as hydrogen, carbon, nitrogen, and oxygen, migrate from one interstitial position to another in the lattice. This mechanism is **faster than** vacancy diffusion **because** interstitial atoms are smaller and more mobile, and there are more available interstitial sites than vacancies. Substitutional impurity atoms rarely form interstitials and do not diffuse via this mechanism. As in Fig. (4-b).

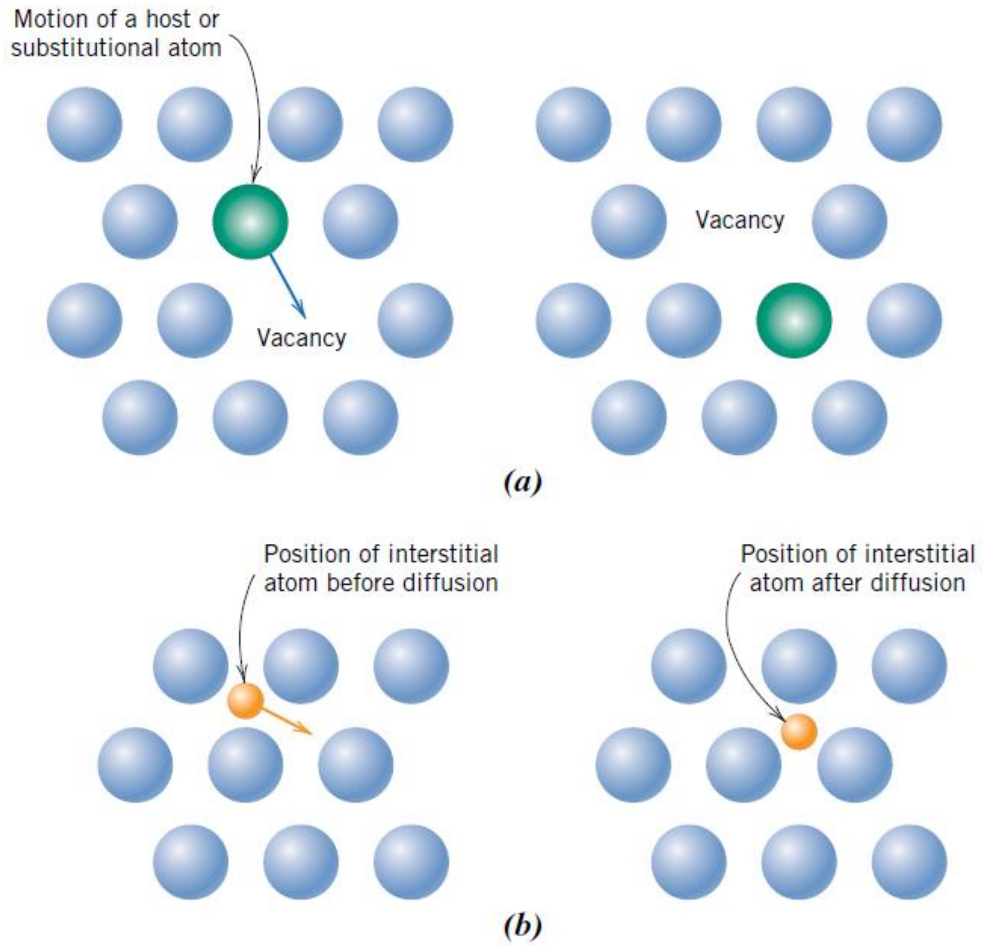


Fig. (4) Schematic representations of (*a*) vacancy diffusion and (*b*) interstitial diffusion.

5- Fick's First Law

Diffusion is **a time-dependent process** where the amount of an element transported within another depends on time. The rate of diffusion is expressed as the **diffusion flux (J)**, [(Kg/m^2. s) or (atoms/ m^2. s)], which is the mass or number of atoms (M) diffusing perpendicularly through a unit cross-sectional area of a solid per unit of time. In mathematical form:

$$J = \frac{M}{At} \qquad (1)$$

Where A : area which diffusion occur (m^2).

t: elapsed diffusion time (s).

The mathematics of steady – state diffusion in a single (x) direction expressed:

$$J = -D\frac{dC}{dx} \qquad (2)$$

This equation is sometimes called **Fick's first law.** Here, D is the diffusion coefficient, and dC/dx represents the concentration gradient. The flux is proportional to the concentration gradient, with the negative sign indicating that diffusion occurs from regions of higher to lower concentration.

Fick's first law describes steady-state diffusion, where the diffusion flux remains constant over time. This occurs when the mass of a diffusing species entering one side of a thin metal plate equals the mass exiting the other side, with no net accumulation, Fig. (5-a).

When concentration *C* is plotted versus position (or distance) within the solid *x*, the resulting curve is termed the **concentration profile;** furthermore, **concentration gradient** is the slope at a particular point on this curve. In the present treatment, the concentration profile is assumed to be linear, as depicted in Fig.(5-b), and

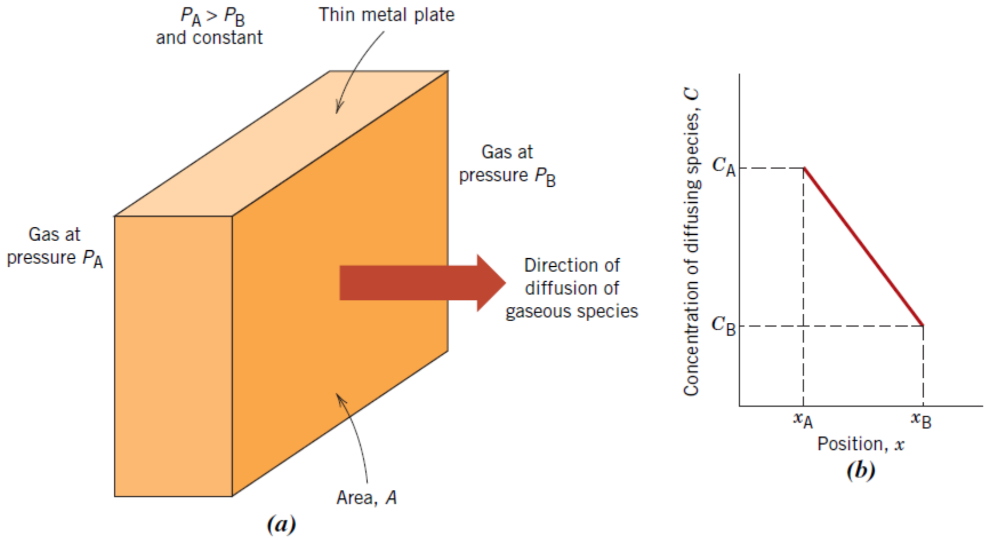


Fig. (5) (*a*) Steady-state diffusion across a thin plate. (*b*) A linear concentration profile for the diffusion situation in (*a*).

$$Concentration\ gradient = \frac{dC}{dx} = \frac{\Delta C}{\Delta x} = \frac{C_A - C_B}{x_A - x_B} \qquad (3)$$

$$\boldsymbol{Ficks\ first\ law} \Rightarrow \quad \boldsymbol{J = -D\frac{dC}{dx} = -D\frac{C_A - C_B}{x_A - x_B}} \qquad (4)$$

For diffusion problems, it is sometimes convenient to express concentration in terms of mass of diffusing species per unit volume of solid (**kg/m^3 or g/cm^3**).

EXAMPLE (1)

A plate of iron is exposed to a carburizing (carbon-rich) atmosphere on one side and a decarburizing (carbon-deficient) atmosphere on the other side at 700 ℃ (1300 ℉). If a condition of steady state is achieved, calculate the diffusion flux of carbon through the plate if the concentrations of carbon at positions of 5 and 10 mm (5×10^{-3} and 10^{-2} m) beneath the carburizing surface are 1.2 and 0.8 kg/m^3, respectively. Assume a diffusion coefficient of 3×10^{-11} m^2/s at this temperature.

Solution

Fick’s first law, Equation (4), is used to determine the diffusion flux. Substitution of the values just given into this expression yields

$$\boldsymbol{J = -D\frac{C_A - C_B}{x_A - x_B}} = -(3 \times 10^{-11})\frac{(1.2 - 0.8)}{(5 \times 10^{-3} - 10^{-2})} = 2.4 \times 10^{-9}\, kg/m^2.s$$

6- Fick's Second Law—Nonsteady-State Diffusion

Nonsteady-state diffusion involves time-dependent changes in diffusion flux and concentration gradient, causing accumulation or depletion of the diffusing species. This is described by Equation (5).

$$\frac{\partial C}{\partial t} = \frac{\partial}{x}\left(D\frac{\partial C}{\partial x}\right) \qquad (5)$$

known as **Fick's second law,** is used. If the diffusion coefficient is independent of composition (which should be verified for each particular diffusion situation), Equation (5) simplifies to

$$\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial x^2} \qquad (6)$$

Furthermore, the following assumptions are made:

1. Before diffusion, any of the diffusing solute atoms in the solid are uniformly distributed with concentration of C_0.

2. The value of x at the surface is zero and increases with distance into the solid.

3. The time is taken to be zero the instant before the diffusion process begins.

These conditions are simply stated as follows:

Initial condition For $t = 0$, $C = C_0$ at $0 \le x \le \infty$

Boundary conditions

For $t > 0$, $C = C_s$ (the constant surface concentration) at $x = 0$

For $t > 0$, $C = C_0$ at $x = \infty$

Application of these conditions to Equation (6) yields the solution

$$\frac{C_x - C_0}{C_s - C_0} = 1 - erf\left(\frac{x}{2\sqrt{Dt}}\right) = constant \qquad (7)$$

$$erf z = \frac{2}{\sqrt{\pi}}\int_0^z e^{-t^2}dt$$

Where C_x represents the concentration at depth x after time t. The expression $erf\left(x/2\sqrt{Dt}\right)$ is the Gaussian error function, values of which are given in mathematical tables for various $x/2\sqrt{Dt}$ values; a partial listing is given in Table (2).

Table (2) Tabulation of Error Function Values.

z	*erf*(*z*)	*z*	*erf*(*z*)	*z*	*erf*(*z*)
0	0	0.55	0.5633	1.3	0.9340
0.025	0.0282	0.60	0.6039	1.4	0.9523
0.05	0.0564	0.65	0.6420	1.5	0.9661
0.10	0.1125	0.70	0.6778	1.6	0.9763
0.15	0.1680	0.75	0.7112	1.7	0.9838
0.20	0.2227	0.80	0.7421	1.8	0.9891
0.25	0.2763	0.85	0.7707	1.9	0.9928
0.30	0.3286	0.90	0.7970	2.0	0.9953
0.35	0.3794	0.95	0.8209	2.2	0.9981
0.40	0.4284	1.0	0.8427	2.4	0.9993
0.45	0.4755	1.1	0.8802	2.6	0.9998
0.50	0.5205	1.2	0.9103	2.8	0.9999

The concentration parameters that appear in Eq. (7) are noted in Figure (6), a concentration profile taken at a specific time.

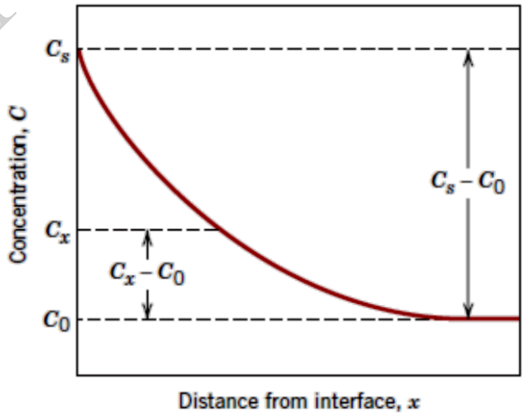


Fig. (6) Concentration profile for nonsteady-state diffusion; concentration parameters relate to Eq. (6).

Example (2)

Consider one such alloy that initially has a uniform carbon concentration of 0.25 wt% and is to be treated at 950°C. If the concentration of carbon at the surface is suddenly brought to and maintained at 1.20 wt%, how long will it take to achieve a carbon content of 0.80 wt% at a position 0.5 mm below the surface? The diffusion coefficient for carbon in iron at this temperature is 1.6×10^{-11} m^2/s; assume that the steel piece is semi-infinite.

Solution:

Because this is a nonsteady-state diffusion problem in which the surface composition is held constant, Eq. (7) is used. Values for all the parameters in this expression except time t are specified in the problem as follows:

$C_0 = 0.25$ wt% C

$C_s = 1.20$ wt% C

$C_x = 0.80$ wt% C

$x = 0.50$ mm $= 5 \times 10^{-4}$ m

$D = 1.6 \times 10^{-11}$ m^2/s

Thus,

$$\frac{\boldsymbol{C_x - C_0}}{\boldsymbol{C_s - C_0}} = \mathbf{1} - \boldsymbol{erf}\left(\frac{\boldsymbol{x}}{\mathbf{2}\sqrt{\boldsymbol{Dt}}}\right) \Rightarrow \frac{0.8-0.25}{1.2-0.25}$$

$$= 1 - erf\left(\frac{5\times10^{-4}}{2\sqrt{(1.6\times10^{-11})t}}\right)$$

$$0.421 = erf\left(\frac{62.5}{\sqrt{t}}\right)$$

$$\Rightarrow \quad t = 25400\, s = 7.1\, h$$

Example (3)

The diffusion coefficients for copper in aluminum at 500 and 600°C are 4.8×10^{-14} and 5.3×10^{-13} m^2/s, respectively. Determine the approximate time at 500°C that will produce the same diffusion result (in terms of concentration of Cu at some specific point in Al) as a 10 h heat treatment at 600°C.

Solution:

The composition in both diffusion situations will be equal at the same position (i.e., x is also a constant), thus:

$$\boldsymbol{Dt = constant}$$

at both temperatures. That is,

$$D_{500}\, t_{500} = D_{600}\, t_{600} \;\; \Rightarrow \;\; t_{500} = \frac{D_{600}\, t_{600}}{D_{500}} = \frac{5.3\times10^{-13}\times10}{4.8\times10^{-14}} = 110.4\, h$$

7- Factors That Influence Diffusion

1- Diffusing Species

The magnitude of the diffusion coefficient D is indicative of the rate at which atoms diffuse. Self-diffusion occurs by a vacancy mechanism, whereas carbon diffusion in iron is interstitial.

2- Temperature

Temperature has a most profound influence on the coefficients and diffusion rates. The temperature dependence of the diffusion coefficients is

$$\boldsymbol{D = D_0\, exp\left(\frac{-Q_d}{RT}\right)} \qquad (8)$$

where

D_0 = a temperature-independent preexponential (m^2/s)

Q_d = the activation energy for diffusion (J/mol or eV/atom)

R = the gas constant, 8.31 J/mol.K or 8.62×10^{-5} eV/atom.K

T = absolute temperature (K)

The activation energy may be thought of as that energy required to produce the diffusive motion of one mole of atoms. A large activation energy results in a relatively small diffusion coefficient. Taking natural logarithms of Eq. (8) yields:

$$\boldsymbol{\ln D = \ln D_0 - \frac{Q_d}{R}\left(\frac{1}{T}\right)} \qquad (9)$$

or, in terms of logarithms to the base 10,

$$\boldsymbol{\log D = \log D_0 - \frac{Q_d}{2.3R}\left(\frac{1}{T}\right)} \qquad (10)$$

Because D_0, Q_d, and R are all constants.

Example (4)

Compute the diffusion coefficient for magnesium in aluminum at 550 ℃. Knowing that the values of D_0 and Q_d are 1.2×10^{-4} m^2/s and 130 kJ/mol, respectively.

Solution

This diffusion coefficient may be determined by applying Equation (8); Thus,

$$\boldsymbol{D = D_0\, exp\left(\frac{-Q_d}{RT}\right)}$$

$$D = \left(1.2 \times \frac{10^{-4} m^2}{s}\right) \exp\left[\frac{130 \times \frac{10^3 J}{mol}}{\left(8.31 \frac{J}{mol.K}\right)(550 + 273)K}\right]$$

D= 6.7×10^{-13} m^2/s

Example (5)

Figure (7) shows a plot of the logarithm (to the base 10) of the diffusion coefficient versus reciprocal of absolute temperature for the diffusion of copper in gold. Determine values for the activation energy and the preexponential.

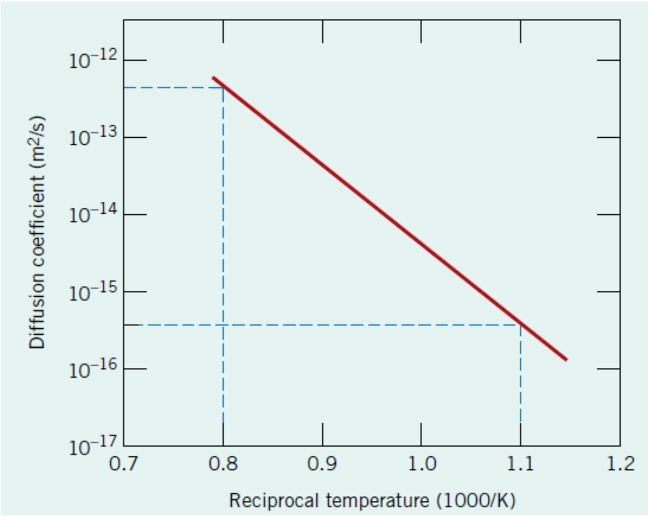


Fig. (7) Plot of the logarithm of the diffusion coefficient versus the reciprocal of absolute temperature for the diffusion of copper in gold.

Solution

From Equation (10) the slope of the line segment in Figure (7) is equal to $=Q_d/2.3R$, and the intercept at $1/T = 0$ gives the value of $\log D_0$. Thus, the activation energy may be determined as

$$\boldsymbol{\log D = \log D_0 - \frac{Q_d}{2.3R}\left(\frac{1}{T}\right)}$$

$slope = \frac{Q_d}{2.3\,R}$ $\Rightarrow$ $Q_d = -2.3\,R\,(slope) = -2.3\,R\left[\frac{\Delta(\log D)}{\Delta\left(\frac{1}{T}\right)}\right] = -2.3\,R[\frac{\log D_1 - \log D_2}{\frac{1}{T_1}-\frac{1}{T_2}}]$

where D_1 and D_2 are the diffusion coefficient values at $1/T_1$ and $1/T_2$, respectively. Let us arbitrarily take

$1/T_1 = 0.8 \times 10^{-3}\ (K)^{-1}$ and $1/T_2 = 1.1 \times 10^{-3}\ (K)^{-1}$.

We may now read the corresponding $\log D_1$ and $\log D_2$ values from the line segment in Figure (7).

Note [Before this is done, however, a note of caution is offered: The vertical axis in Figure (7) is scaled logarithmically (to the base 10); however, the actual diffusion coefficient values are noted on this axis. For example, for D = 10^{-14} m^2/s, the logarithm of D is -14.0, not 10^{-14}. Furthermore, this logarithmic scaling affects the readings between decade values; for example, at a location midway between 10^{-14} and 10^{-15}, the value is not 5×10^{-15} but, rather, $10^{-14.5} = 3.2 \times 10^{-15}$.]

Thus from Fig. (7) $1/T_1 = 0.8 \times 10^{-3}\ (K)^{-1} \rightarrow \log D_1 = -12.4$,

$1/T_2 = 1.1 \times 10^{-3}\ (K)^{-1} \rightarrow \log D_2 = -15.45$

and the activation energy, as determined from the slope of the line segment in Figure (7) , is

$$Q_d = -2.3\ R\left[\frac{\log D_1 - \log D_2}{\frac{1}{T_1} - \frac{1}{T_2}}\right]$$

$$= -2.3 \times 8.31 \frac{J}{mol.K}\left[\frac{-12.4 - (-15.45)}{0.8 \times 10^{-3} K^{-1} - 1.1 \times 10^{-3} K^{-1}}\right]$$

$$= 194000 \frac{J}{mol} = 194\ KJ/mol$$

Now, rather than try to make a graphical extrapolation to determine D_0, we can obtain a more accurate value analytically using Equation (10), and we obtain a specific value of *D* (or log *D*) and its corresponding *T* (or 1/*T*) from Figure (7). Because we know that log $D = -15.45$ at $1/T = 1.1 \times 10^{-3}\ (K)^{-1}$, then

$$\boldsymbol{\log D = \log D_0 - \frac{Q_d}{2.3R}\left(\frac{1}{T}\right)}$$

$$\boldsymbol{\log D_0 = \log D + \frac{Q_d}{2.3R}\left(\frac{1}{T}\right)} = -15.45 + \frac{194000 \frac{J}{mol} \times 1.1 \times 10^{-3} K^{-1}}{2.3 \times 8.31 \frac{J}{mol.k}}$$

$$= -4.28$$

Thus $D_0 = 10^{-4.28}\ m^2/s = 5.2 \times 10^{-5}\ m^2/s$

Example (6)

The wear resistance of a steel gear is to be improved by hardening its surface. This is to be accomplished by increasing the carbon content within an outer surface layer as a result of carbon diffusion into the steel; the carbon is to be supplied from an external carbon-rich gaseous atmosphere at an elevated and constant temperature. The initial carbon content of the steel is 0.20 wt%, whereas the surface concentration is to be maintained at 1.00 wt%. For this treatment to be effective, a carbon content of 0.60 wt% must be established at a position 0.75 mm below the surface. Specify an appropriate heat treatment in terms of temperature and time for temperatures between 900 and 1050˚C. Use data in Table 5.2 for the diffusion of carbon in g-iron. for the diffusion of carbon in g-iron, $D_0 = 2.3 \times 10^{-5}$ m^2/s and $Q_d = 148{,}000$ J/mol.

Knowing $\frac{x}{2\sqrt{Dt}} = 0.4747 \quad when \quad erf\left(\frac{x}{2\sqrt{Dt}}\right) = 0.5$

Solution

Because this is a nonsteady-state diffusion situation, let us first employ Equation (7), using the following values for the concentration parameters:

$C_0 = 0.20$ wt% C

$C_s = 1.00$ wt% C

$C_x = 0.60$ wt% C

Therefore,

$$\frac{C_x - C_0}{C_s - C_0} = 1 - erf\left(\frac{x}{2\sqrt{Dt}}\right)$$

$$\frac{C_x - C_0}{C_s - C_0} = \frac{0.6 - 0.2}{1 - 0.2} = 1 - erf\left(\frac{x}{2\sqrt{Dt}}\right)$$

$$\frac{0.4}{0.8} = 1 - erf\left(\frac{x}{2\sqrt{Dt}}\right)$$

$$\mathbf{0.5 = 1 - erf\left(\frac{x}{2\sqrt{Dt}}\right)}$$

$$\mathbf{0.5 = erf\left(\frac{x}{2\sqrt{Dt}}\right)}$$

Thus, $\mathbf{\frac{x}{2\sqrt{Dt}} = 0.4747}$

The problem stipulates that *x* = 0.75 mm = 7.5 ×10^{-4} m. Therefore,

$$\mathbf{\frac{(7.5\ \times 10^{-4}\ m)}{(2\sqrt{Dt})} = 0.4747}$$

This leads to Dt= 6.24×10^{-7}m^2

Furthermore, the diffusion coefficient depends on temperature according to Equation (8)

$$\mathbf{D = D_0\, exp\left(\frac{-Q_d}{RT}\right)}$$

Hence,

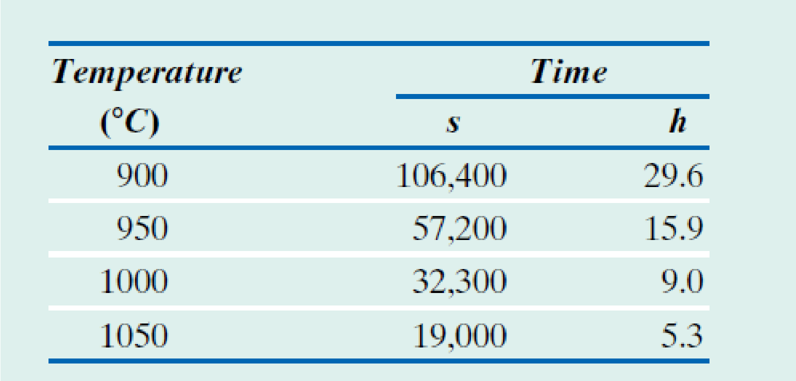
$$\mathbf{Dt = D_0\, exp\left(\frac{-Q_d}{RT}\right)(t) = 6.24\times10^{-7} m^2}$$

$$\mathbf{\left(2.3 \times 10^{-5}\frac{m^2}{s}\right) exp\left(\frac{-\frac{148000J}{mol}}{8.31\frac{J}{mol\,.K}T}\right)(t) = 6.24 \times 10^{-7} m^2}$$

And solving for time t, we obtain

$$t(in\ s) = \frac{0.0271}{\exp\left(-\frac{17810}{T}\right)}$$

Thus, the required diffusion time may be computed for some specified temperature (in K). The following table gives *t* values for four different temperatures that lie within the range stipulated in the problem.



Temperature (°C)	Time	
	s	h
900	106,400	29.6
950	57,200	15.9
1000	32,300	9.0
1050	19,000	5.3

Homework

Questions

1- Briefly explain the difference between *self diffusion* and *interdiffusion*.

2- Compare interstitial and vacancy atomic mechanisms for diffusion.

3- Cite two reasons why interstitial diffusion is normally more rapid than vacancy diffusion.

4- Briefly explain the concept of steady state as it applies to diffusion.

5- State and explain Fick's laws of diffusion. How diffusion coefficient depends upon temperature?

6- The unit of diffusion coefficient is

(1) $m^2 s$ *(2)* $m^2 s^{-1}$ *(3)* $m^2 s^{-2}$ *(4)* $m^2 s^2$

7- Substitutional diffusion becomes possible if

(1) the temperature of solid solution is sufficiently high.

(2) the activation energy for vacancy formation is low.

(3) atoms are significantly different in size.

(4) vacancies are present in a substitutional solid solution.

8- *The unit of flux J is*

(1) moles $m^{-2}s^{-1}$ or atoms m^{-2} s^{-1} *(2) atoms m^{2} s^{-1}*

(3) moles m^{-3} s^{-1} *(4) moles $m^{-1}s^{-1}$*

9- *For metal atoms, the most probable mechanism of diffusion is*

(1) Vacancy mechanism *(2) Interstitial mechanism*

(3) Direct interchange mechanism (4) None of the above (1)

10- *The dependence of diffusion coefficient on temperature in a certain temperature range is described by*

(1) $D = D_0 \exp (Q/T)$ *(2) $D = D_0 \exp (-Q/RT)$*

(3) $D = D_0 \exp (-Q^2/RT)$ *(4) $D = D_0 \exp (Q^4/RT)$*

11- *Fick's first law of diffusion is applicable under*

(1) steady state conditions of mass flow *(2) non-steady state conditions*

(3) steady as well as non-steady state conditions (4) none of the above

12- *In the presence of impurities and deviations from stoichiometry, the diffusion rate of ions in ionic crystals*

(1) enhances (2) decreases

(3) remains unaffected (4) first decreases and then enhances

13- In comparison to lattice diffusion, the activation energy for diffusion along surfaces and grain boundaries is

(1) higher (2) lower (3) almost negligible (4) infinite

14- Interstitial diffusion is much ------------than substitutional diffusion.

15- Substitutional solutes-------- by interchanging positions with vacancies.

16- Solutions to Fick’s second law are available for given set of initial and ------ conditions.

17- Diffusion is the transfer-------- of atoms which is accompanied with a change of concentration of the components in certain zones of an ---------- .

Short Answer Questions

1. What do you understand by solid state diffusion?

2. What is self diffusion?

3. What is steady state diffusion?

4. How the mathematics for nonsteady state are described?

5. What can be inferred from the magnitude of the diffusion coefficient?

6. What is the effect of the presence of impurities and deviations from stoichiometry on the diffusion rate of ions in ionic crystals?

7. What is activation energy for diffusion?