University of Anbar
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فيزياء المواد

Physics of Materials

المرحلة الثالثة
الكورس الاول

اعداد
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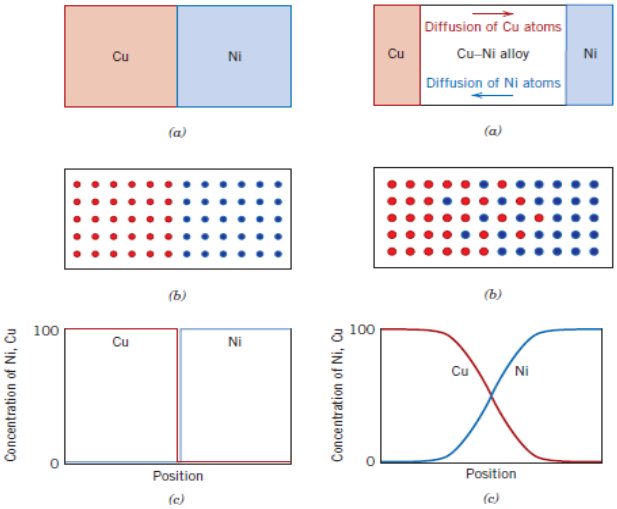
5.1 Diffusion انتشار

The diffusion is just the step by step خطوة بخطوة migration هجرة او نزوح of atoms from lattice site موقع شبيكي to lattice site. In fact في الحقيقة, the atoms in solid materials are in constant motion حركة ثابتة, rapidly سريعا changing positions تغير الموقع. For an atom to make such a move, two conditions شرطين must be met:

(1) there must يجب be an empty فارغ adjacent site موقع مجاور,

(2) the atom must have sufficient energy طاقة محددة to break bonds لكسر الاواصر with its neighbor atoms مع الذرة المجاورة and then cause وبعد ذلك تسبب some lattice distortion بعض التشويه للشبيكة during خلال the displacement الازاحة.



Several different models for this atomic motion have been proposed

1. **Vacancy Diffusion انتشار الفراغات**
   One mechanism الية involves تتضمن the interchange التغير الداخلي of an atom from a normal lattice position موقع الشبيكة الاعتيادي to an adjacent vacant فراغ مجاور lattice site لموقع الشبيكة or vacancy موقع شاغر , as represented كما ممثل in Figure 5.1

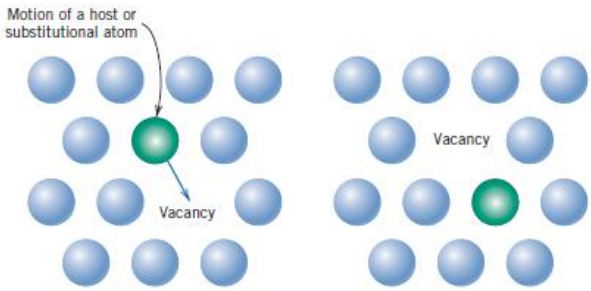


Figure 5.1 Vacancy Diffusion

2. Interstitial Diffusion الانتشار الخلالي

The second type النوع الثاني of diffusion من الانتشار involves يتضمن atoms that migrate تهاجر from an interstitial position موضع خلالي to a neighboring one الى موضع مجاور that is empty الذي يكون فارغ .

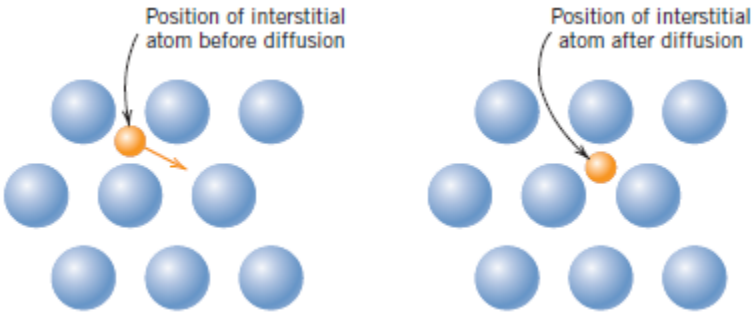


Figure 5.2 Interstitial Diffusion

5.2 Steady-State Diffusion انتشار ثابت الحالة

Diffusion is a time-dependent process الانتشار عملية معتمد على الزمن, the quantity كمية of an element that is transported منتقلة within another بداخل الاخر is a function دالة of time. Often غالبا it is necessary ضروري to know لمعرفة how fast كم سريع diffusion occurs يحدث الانتشار, or the rate اومعدل of mass transfer انتقال الكتلة. This rate هذا المعدل is frequently expressed يعبر عن as a diffusion flux تدفق الانتشار (J), defined ويعرف as the mass (or, equivalently, the number of atoms) M diffusing تنتشر through خلال and perpendicular وعمودي to a unit cross-sectional area مساحة وحدة المقطع of solid per unit of time. In mathematical form الصيغة الرياضية, is represented as

$$J = \frac{M}{At} \qquad (5.1)$$

where A denotes تشير الى the area across which diffusion is occurring يحدث and t is the diffusion time. In differential form, this expression becomes

$$J = \frac{1}{A}\frac{dM}{dt} \qquad (5.2)$$

The units for J are kilograms or atoms per meter squared per second (kg/m^2. s or $atoms/m^2$. s).

When concentration C is plotted versus position (or distance) within the solid x, as in figure 5.3

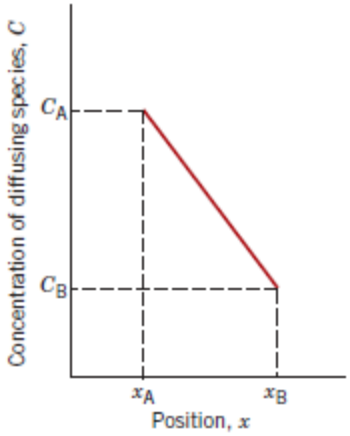


Figure 5.3

Therefore, the concentration gradient تدرج التركيز is equal to

$$\text{concentration gradient} = \frac{dC}{dx}$$

Then the concentration gradient can be written as

$$\text{concentration gradient} = \frac{\Delta C}{\Delta x} = \frac{C_A - C_B}{x_A - x_B}$$

The flux is proportional to the concentration gradient (Which is sometimes called Fick's first law)

$$J = -D\frac{dC}{dx} \qquad (5.3)$$

The constant of proportionality D is called the diffusion coefficient معامل الانتشار, which is expressed in square meters per second.

EXAMPLE PROBLEM 5.1

Diffusion Flux Computation

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°C (1300°F). 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 5.3, is utilized to determine the diffusion flux. Substitution of the values above into this expression yields

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

5.3 Temperature Influence Diffusion تاثير الحرارة على الانتشار

Temperature has a most influence تاثير كبير on the coefficients المعاملات and diffusion rates معدلات الانتشار. The temperature dependence اعتماد of the diffusion coefficients is

$$D = D_0 \exp\left(-\frac{Q_d}{RT}\right) \qquad (5.4)$$

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)

Table 5.1 A Tabulation of Diffusion Data

Diffusing Species	Host Metal	$D_0(m^2/s)$	Activation Energy Q_d kJ/mol	Activation Energy Q_d eV/atom	Calculated Value T(°C)	Calculated Value $D(m^2/s)$
Fe	α-Fe (BCC)	2.8×10^{-4}	251	2.60	500	3.0×10^{-21}
					900	1.8×10^{-15}
Fe	γ-Fe (FCC)	5.0×10^{-5}	284	2.94	900	1.1×10^{-17}
					1100	7.8×10^{-16}
C	α-Fe	6.2×10^{-7}	80	0.83	500	2.4×10^{-12}
					900	1.7×10^{-10}
C	γ-Fe	2.3×10^{-5}	148	1.53	900	5.9×10^{-12}
					1100	5.3×10^{-11}
Cu	Cu	7.8×10^{-5}	211	2.19	500	4.2×10^{-19}
Zn	Cu	2.4×10^{-5}	189	1.96	500	4.0×10^{-18}
Al	Al	2.3×10^{-4}	144	1.49	500	4.2×10^{-14}
Cu	Al	6.5×10^{-5}	136	1.41	500	4.1×10^{-14}
Mg	Al	1.2×10^{-4}	131	1.35	500	1.9×10^{-13}
Cu	Ni	2.7×10^{-5}	256	2.65	500	1.3×10^{-22}

Diffusion Coefficient Determination

Using the data in Table 5.1, compute the diffusion coefficient for magnesium in aluminum at 550°C.

Solution

This diffusion coefficient may be determined by applying Equation 5.4; the values of D_0 and Q_d from Table 5.1 are 1.2×10^{-4} m²/s and 131 kJ/mol, respectively. Thus,

$$D = (1.2 \times 10^{-4}\ \text{m}^2/\text{s}) \exp\left[-\frac{(131{,}000\ \text{J/mol})}{(8.31\ \text{J/mol}\cdot\text{K})(550 + 273\ \text{K})}\right]$$
$$= 5.8 \times 10^{-13}\ \text{m}^2/\text{s}$$

5.4 Phase diagram مخطط الطور

Is a diagram مخطط which plots يرسم to describe لوصف a system نظام consist of متكون من many phases عدد من الاطوار of structures.

- The understanding لفهم of phase diagrams for alloy systems نظام سبيكة is extremely important مهم جدا because there is a strong correlation علاقة قوية between microstructure التركيب الماكروي and mechanical properties
- Phase diagrams provide يجهز valuable information معلومات قيمة about melting الذوبان , casting الصب, crystallization التبلور.

5.4.1 Phase الطور

A **phase** may be defined as a homogeneous portion جزء of a system that has uniform متماثل physical and chemical characteristics خواص. Every pure نقي material is considered تعتبر to be a phase. (every solid, liquid, and gaseous الغازي solution محلول).A single-phase system نظام الطور الاحادي is termed **homogeneous** متجانس. Systems composed المتكونة of two or more phases او طورين اكثر are termed تسمى **mixtures** خلائط or **heterogeneous** غير متجانس systems. Most metallic alloys السبائك الفلزية and, for that matter المعدن, ceramic, polymeric, and composite المتراكبة systems are heterogeneous.

5.4.2 Equilibrium حالة التوازن

Equilibrium is another essential concept مفهوم اساسي اخر that is best described يوصف جيدا in terms بمصطلحات of a thermodynamic quantity كمية called تسمى the **free energy** الطاقة الحرة. In brief باختصار, free energy is a function دالة

of the internal energy للطاقة الداخلية of a system, and also the randomness العشوائية or disorder عدم ترتيب of the atoms or molecules (or entropy). A system is at equilibrium if its free energy is at a minimum under تحت some specified محدد combination تراكب of temperature, pressure, and composition.

A simple type نوع is used to explain شرح and demonstrate وتوضيح the phase diagram, as an example, the one for H_2O, which is shown in Figure 5.4, it may be noted that regions مناطق for three different phases—solid, liquid, and vapor—are delineated رسم خطوط on the plot الرسم . Each of the phases كل الاطوار will exist under موجودة تحت equilibrium conditions شروط التوازن over حول the temperature–pressure ranges مديات of its corresponding area المنطقة المقابلة.

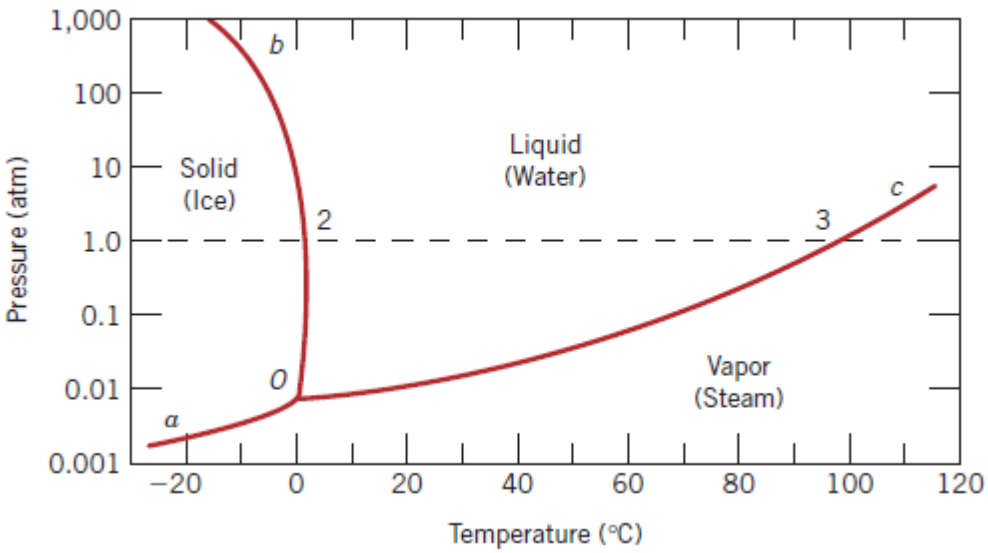


Figure 5.4 Pressure–temperature phase diagram for H2O

The three curves shown on the plot (labeled aO, bO, and cO) are phase boundaries حدود الطور; at any point في كل نقطة on one of these curves, the two phases on either side of the curve are in equilibrium with one another.

Binary Phase Diagrams مخطط ثنائي الطور

Another type of phase diagram is one in which temperature and composition are variable parameters معاملات متغيرة.

Binary phase diagrams are maps خرائط that represent تمثل the relationships العلاقات between temperature and the compositions التركيب and quantities وكميات of phases at equilibrium حالة التوازن,

For example, a type of binary phase that is characterized by the copper–nickel system (Figure 5.5). The temperature is plotted along the ordinate, and the abscissa الاحداثي السيني represents the composition of the alloy, in weight percent (bottom) and atom percent (top) of nickel. The composition ranges from 0 wt% Ni (100 wt% Cu) on the left horizontal extremity to 100 wt% Ni (0 wt% Cu) on the right.

Three different phase regions, or fields, appear on the diagram, an alpha (α) field, a liquid (L) field, and a two-phase α + L field. Each region is defined by the phase or phases that exist over the range of temperatures and compositions delineated by the phase boundary lines.

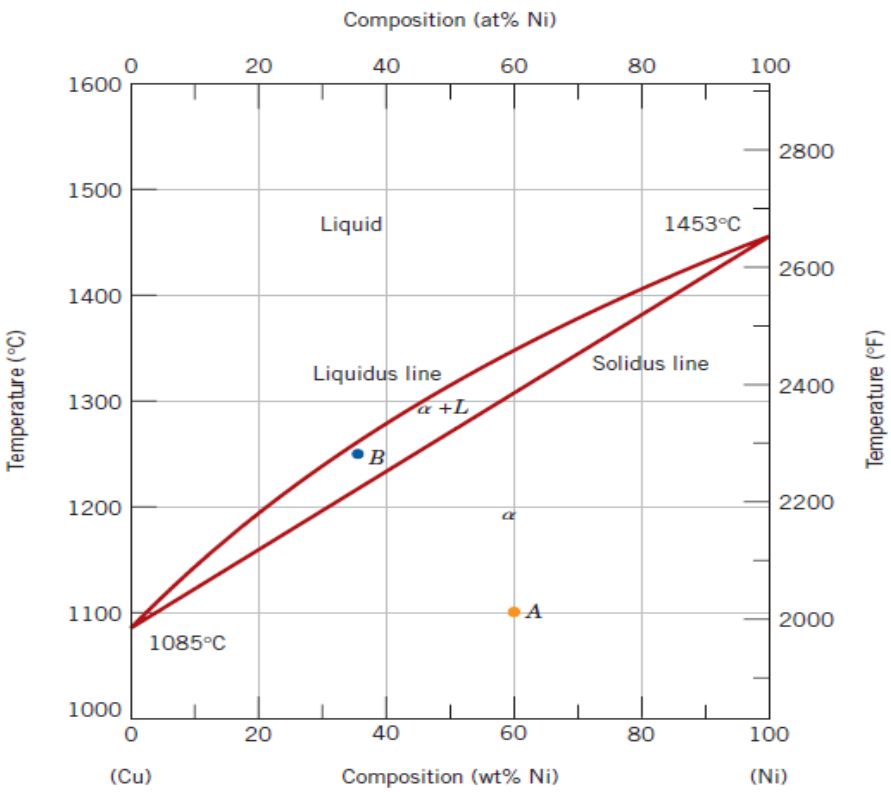


Figure 5.5 Binary phase diagram of Ni and Cu.

References

1- Fundamentals of Materials Science and Engineering, William D. Callister, Jr. David G. Rethwisch
2- Materials _Science_ and _Engineering_9th . William D. Callister, Jr. David G. Rethwisch