Hardening Treatment

Lec-6

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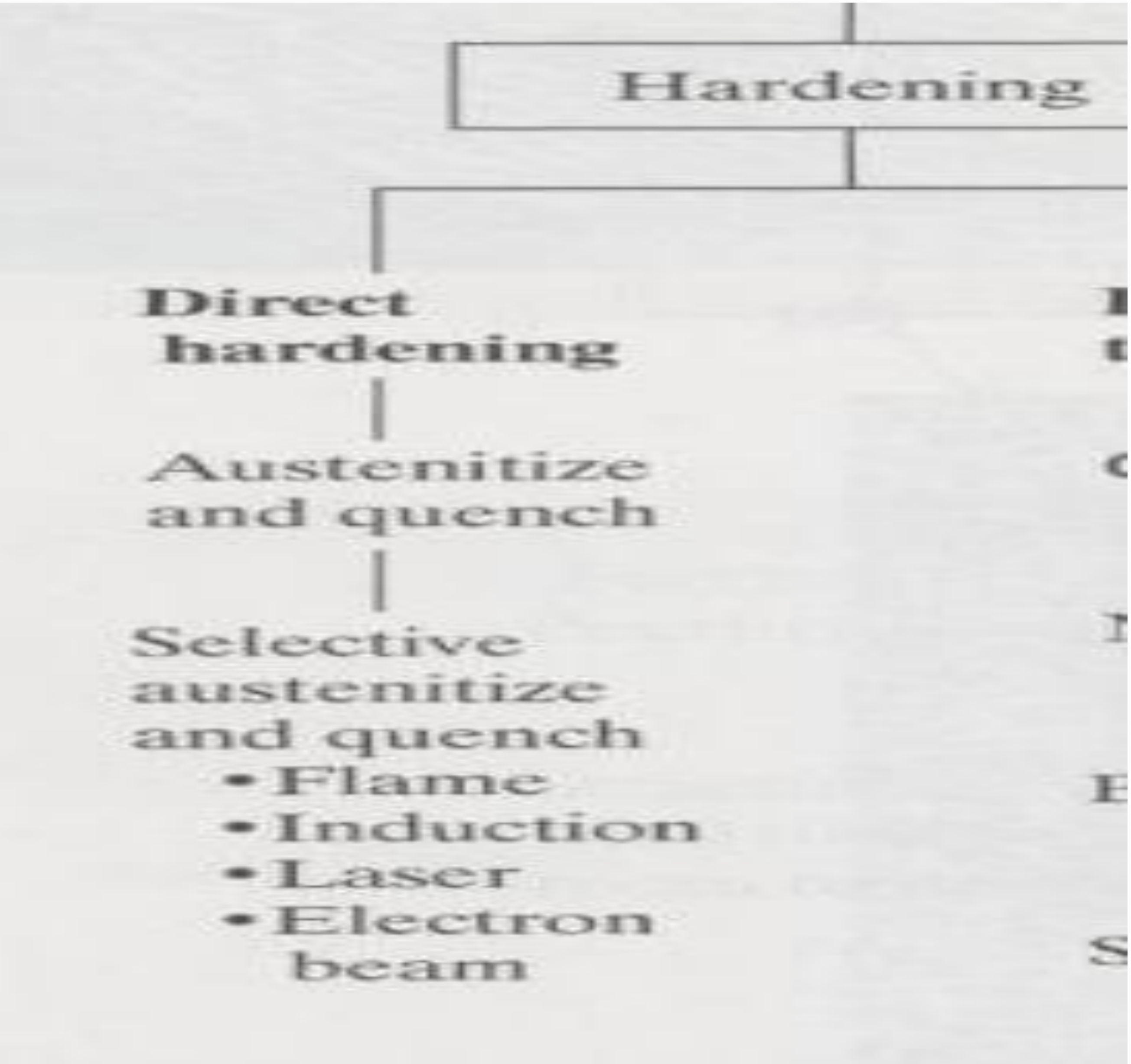


Hardening

Direct hardening

Austenitize and quench

Selective austenitize and quench

- Flame
- Induction
- Laser
- Electron beam

Direct Hardening – *Austenitizing and quench*:

- Austenitizing – again taking a steel with .6% carbon or greater and heating to the austenite region.
- Rapid quench to trap the carbon in the crystal structure – called martensite (BCT)
- Quench requirements determined from isothermal transformation diagram (IT diagram).
- Get “Through” Hardness!!!

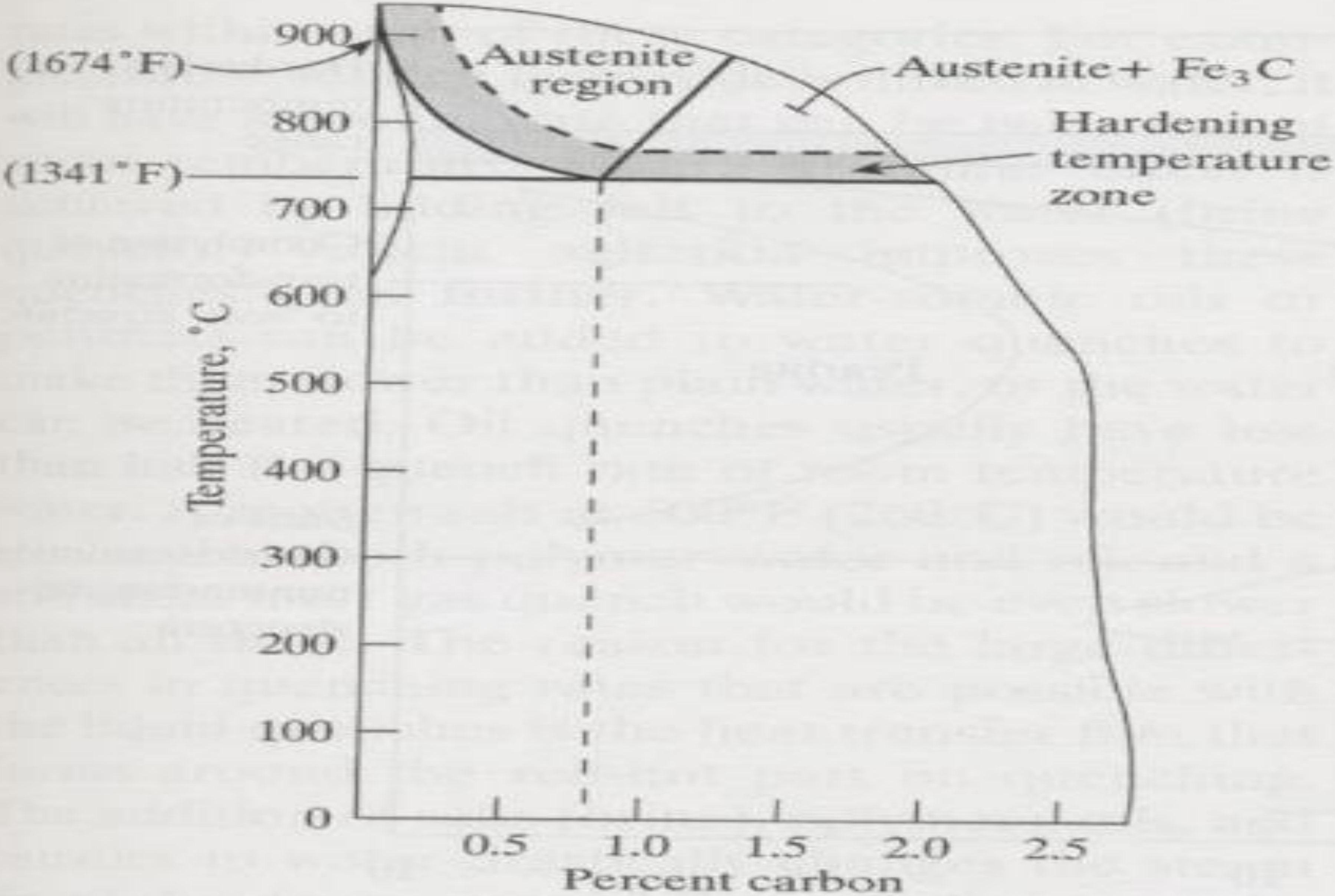


Figure 10–14
Hardening temperature range shown on the iron–carbon diagram

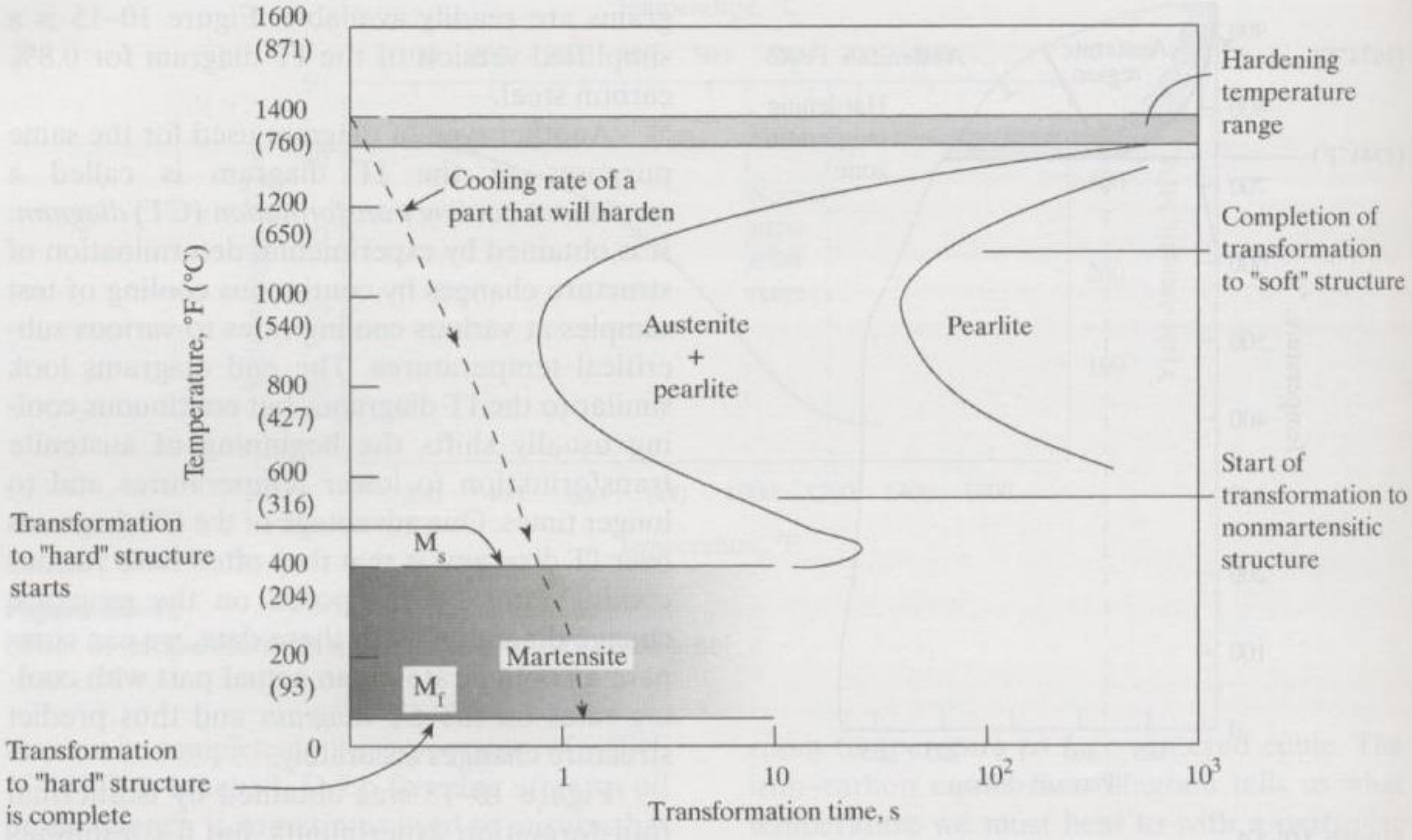


Figure 10–15
Typical time–temperature transformation diagram (IT)

For this particular steel want to cool from about 1400 F to <400 F in about 1 second!

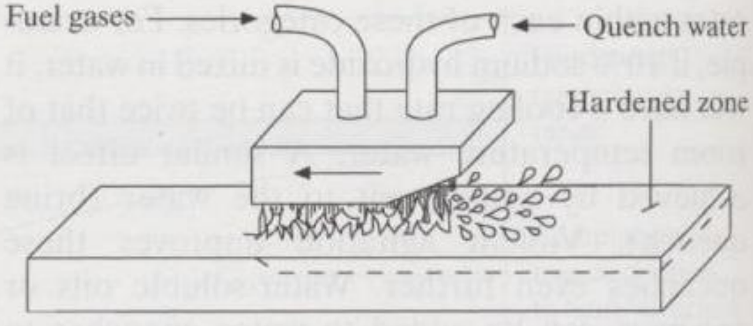
Quenching:

- Depending on how fast steel must be quenched (from IT diagram), the heat treater will determine type of quenching required:
  - Water (most severe)
  - Oil
  - Molten Salt
  - Gas/ Air (least severe)
  - Many phases in between!!! Ex: add water/polymer to water reduces quench time! Adding 10% sodium hydroxide or salt will have twice the cooling rate!

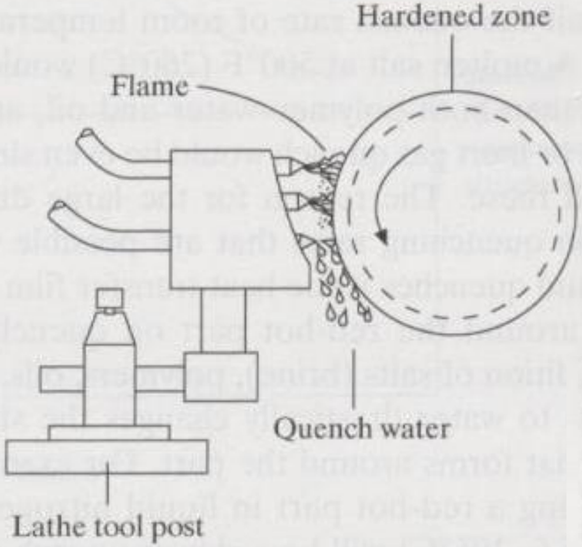
Selective Hardening :

- Same requirements as austenitizing:
  - Must have sufficient carbon levels (>0.4%)
  - Heat to austenite region and quench
- Why do?
  - When only desire a select region to be hardened: Knives, gears, etc.
  - Object to big to heat in furnace! Large casting w/ wear surface
- Types:
  - Flame hardening, induction hardening, laser beam hardening

Flame Hardening:

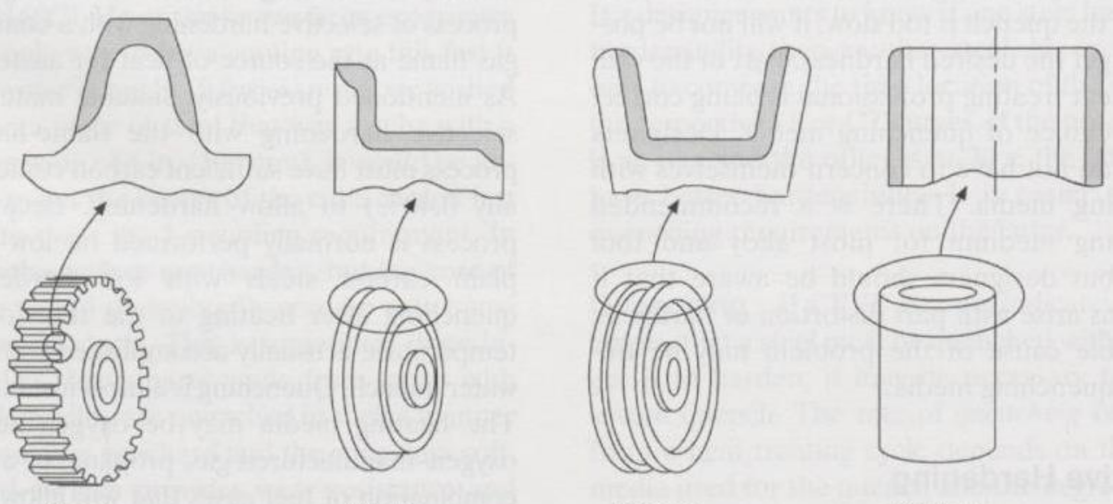


Flame hardening of flat plates



Flame hardening round bars in a lathe

Figure 10–16
Typical flame-hardening systems



Gears Wheels Sheaves Bushings

Figure 10–17
Flame-hardening profiles (white areas) for typical mechanical components

Induction Hardening

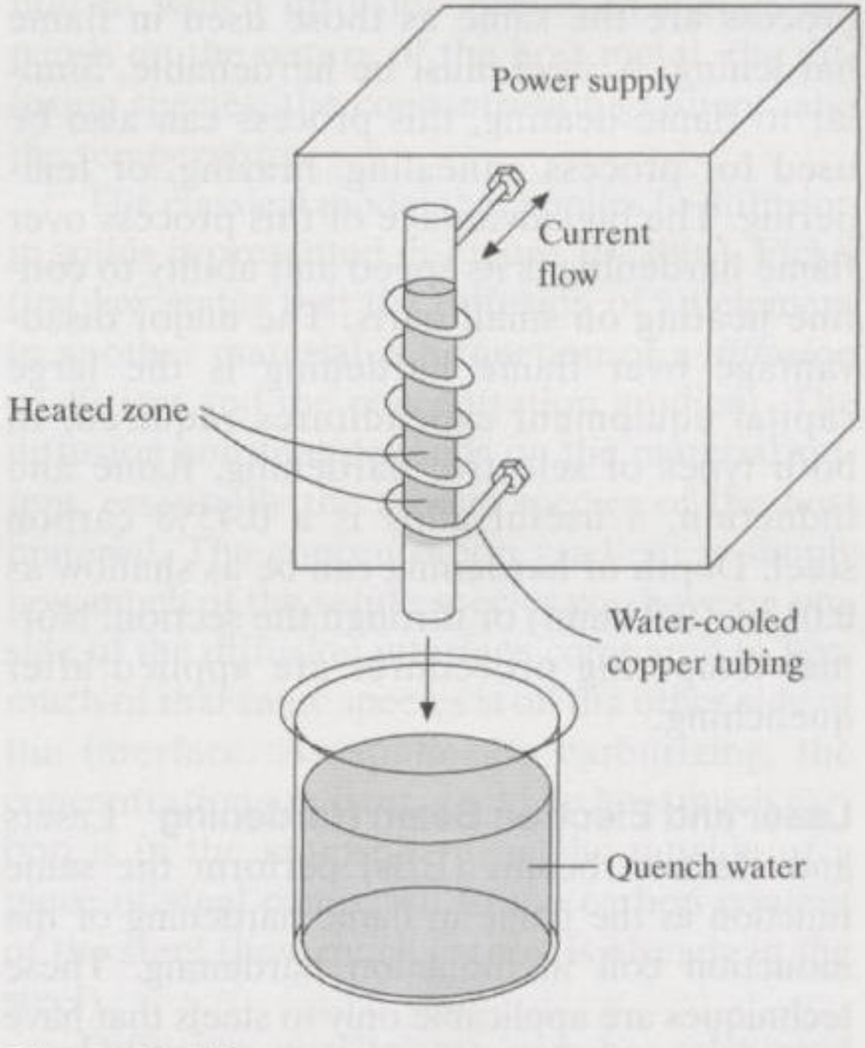


Figure 10–18
Induction hardening

Diffusion Hardening

- Why do?
  - Carbon content to low to through harden with previous processes.
  - Desire hardness only in select area
  - More controlled versus flame hardening and induction hardening.
  - Can get VERY hard local areas (i.e. HRC of 60 or greater)
  - Interstitial diffusion when tiny solute atoms diffuce into spaces of host atoms
  - Substitiutional diffusion when diffusion atoms to big to occupy interstitial sites – then must occupy vacancies

Figure 10–20
Basic concepts for diffusion processes

Diffusion concepts

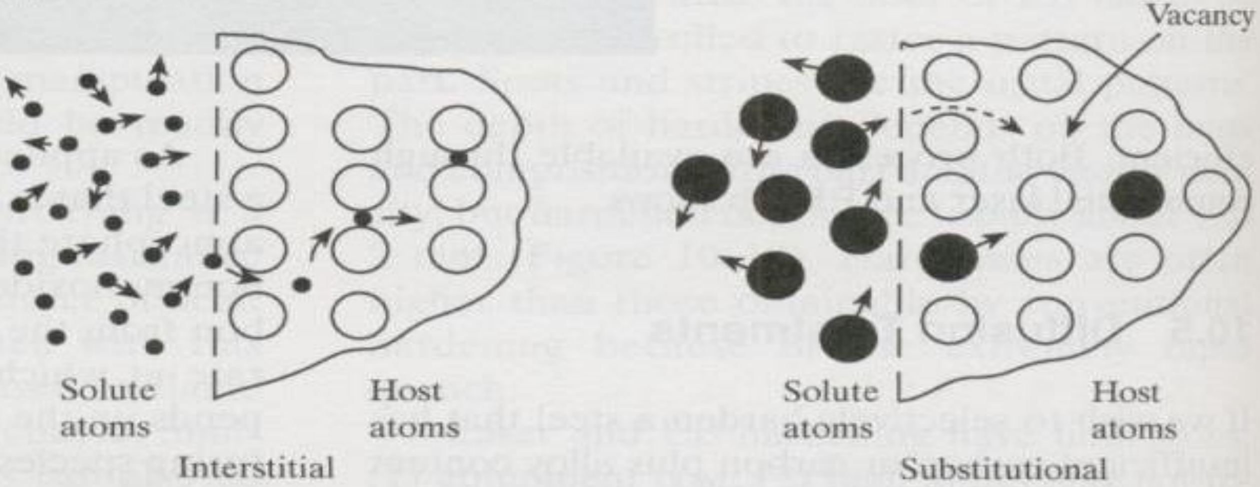
(a) Model

Fick's law: $J = D \frac{dc}{dx}$

where J = flux of atoms (atoms/time/area)
D = diffusion coefficient (area/time)
$\frac{dc}{dx}$ = concentration gradient (c = atoms/volume; x = distance)

Diffusion coefficient: $D = D_0 e^{\Delta H/RT}$
D_0 = a diffusion constant for a material
$\Delta H/RT$ = activation energy for process to occur; ΔH depends on the material system, R is a constant, and T is absolute temperature

(b) How it occurs



(c) Where it applies

	Solute	Host
Carburizing	C	Low-carbon steels
Nitriding	N	Nitriding steels
Carbonitriding	C + N	Low-carbon steels
Boronizing	B	Low-carbon steels
Chromizing	Cr	Low- and high-carbon steels

Diffusion Hardening:

- Requirements:
  - High temp (> 900 F)
  - Host metal must have low concentration of the diffusing species
  - Must be atomic suitability between diffusing species and host metal

Diffusion Hardening:

- Most Common Types:
  - Carburizing
  - Nitriding
  - Carbonitriding
  - Cyaniding

Diffusion Hardening - *Carburizing*:

- Pack carburizing most common:
  - Part surrounded by charcoal treated with activating chemical – then heated to austenite temperature.
  - Charcoal forms CO2 gas which reacts with excess carbon in charcoal to form CO.
  - CO reacts with low-carbon steel surface to form atomic carbon
  - The atomic carbon diffuses into the surface
  - Must then be quenched to get hardness!

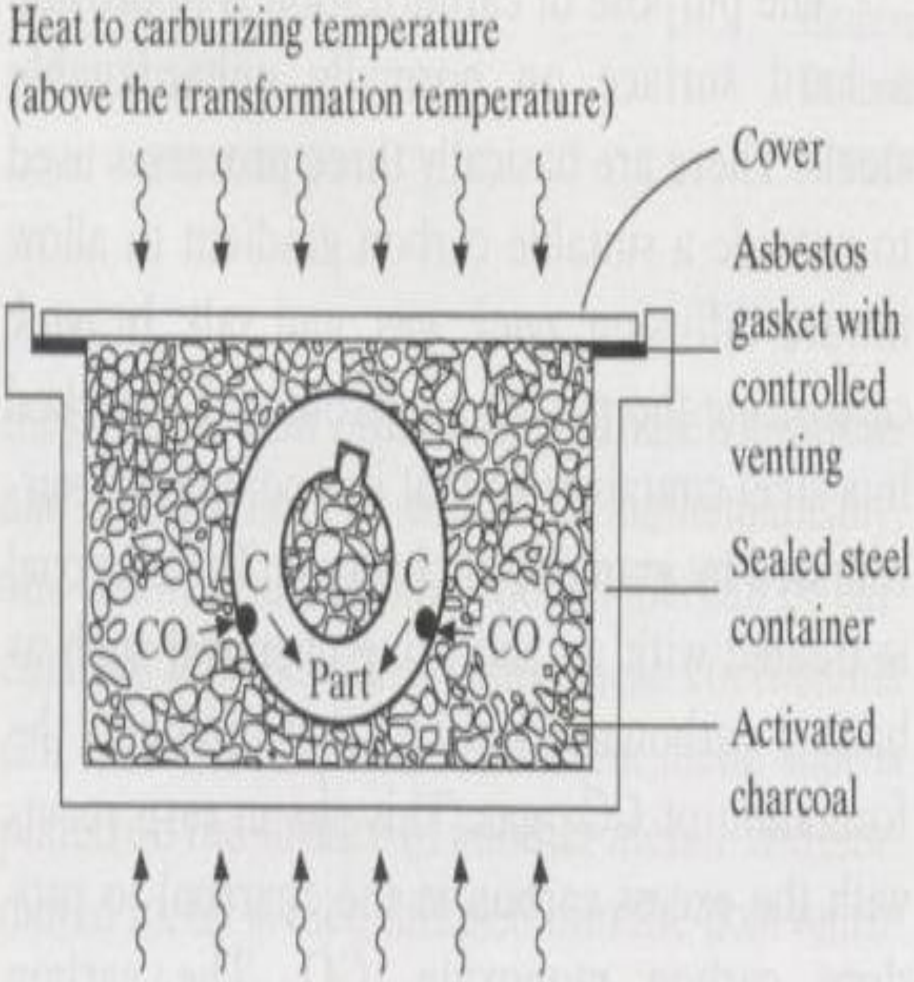


Figure 10–21
Pack carburizing

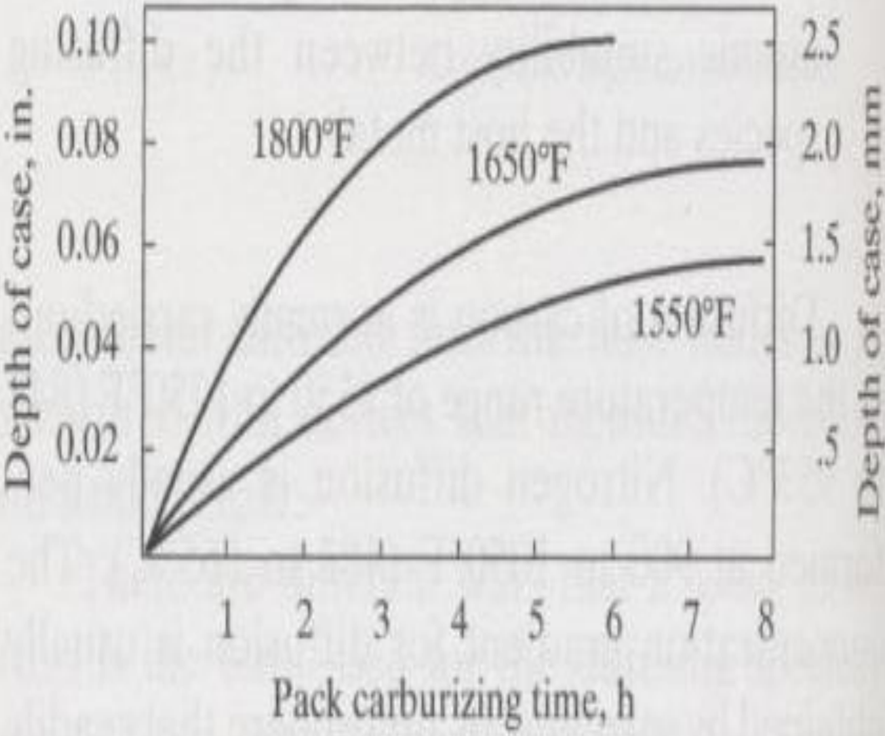
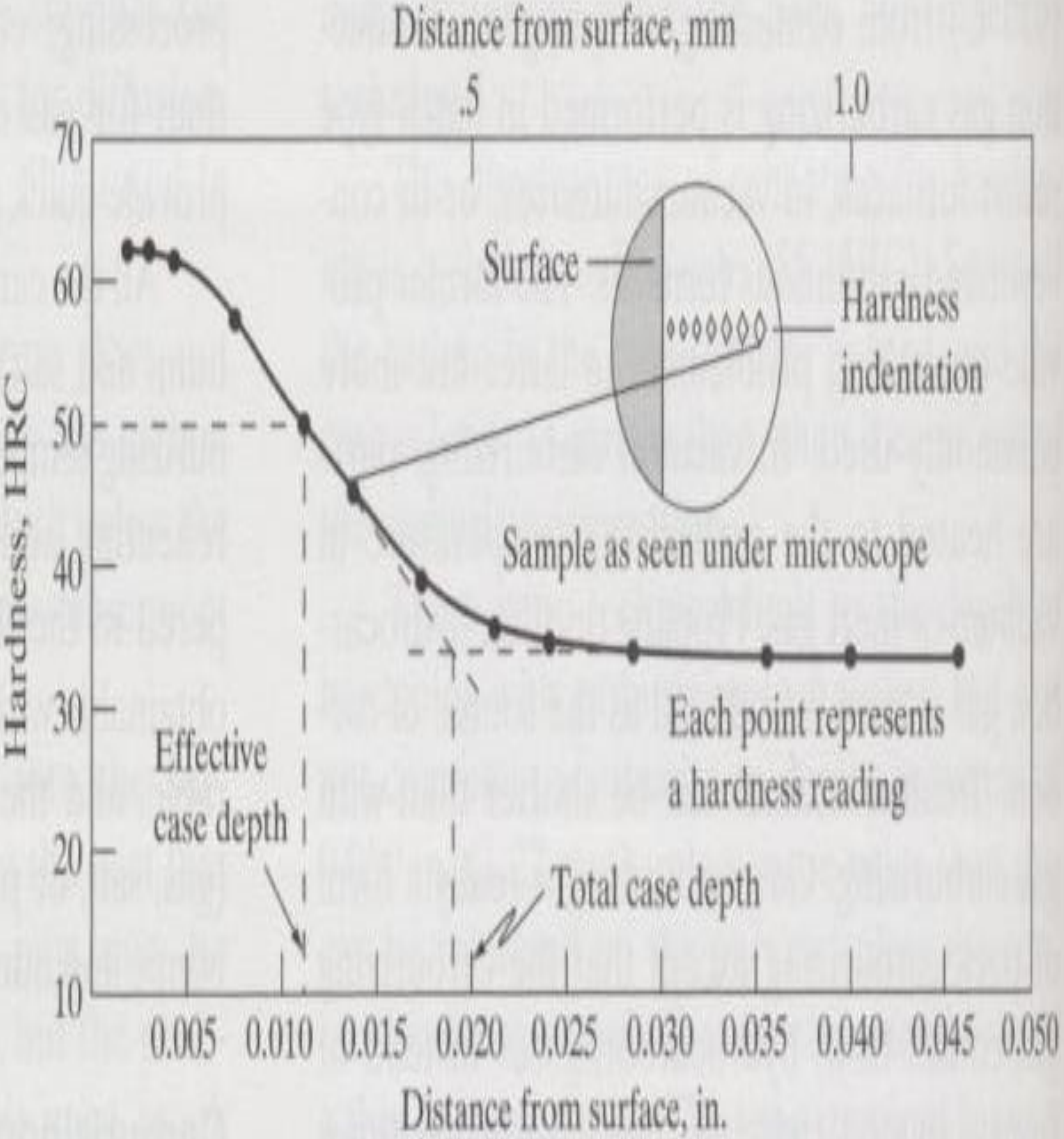


Figure 10–22
Effect of carburizing temperature on case depth

Source: G. M. Enos and W. E. Fontaine. *Elements of Heat Treatment*. New York: John Wiley & Sons, Inc., 1963.

Figure 10–23
Determination of carburized or carbonitrided case depth by microhardness survey



Diffusion Hardening - *Nitriding*:

- Nitrogen diffused into surface being treated. Nitrogen reacts with steel to form very hard iron and alloy nitrogen compounds.
- Process does not require quenching – big advantage.
- The case can include a white layer which can be brittle – disadvantage
- More expensive than carburizing

Tutorial

Example 1 *Steel gear, having carbon content of 0.2% is to be gas carburized to achieve carbon content of 0.96% at the surface and 0.4% at 0.5 mm depth from the surface. If the process is to be carried out at 927°C, find the time required for carburization. Given, diffusion coefficient of carbon in given steel =* $1.28 \times 10^{-11} m^2/s$. [B.E., M.Sc (M.S.)]

Solution We have

$$\frac{dc}{dt} = D\frac{d^2c}{dx^2} \tag{1}$$

The solution of Eq. (1) can be written as

$$\frac{c_s - c_x}{c_s - c_0} = \text{erf}\left(\frac{x}{2\sqrt{Dt}}\right) \tag{2}$$

Substituting the proper values in Eq. (2), we hve

$$\frac{0.9-0.4}{0.9-0.2} = \text{erf}\left(\frac{0.5\times10^{-3}}{2\sqrt{12.8\times10^{-12}\ t}}\right)$$

or

$$0.7143 = \text{erf}\left(\frac{69.88}{\sqrt{t}}\right)$$

Let

$$z = \frac{69.88}{\sqrt{t}}$$

$\therefore$

$$\text{erf}\ z = 0.7143 \tag{3}$$

$x = 0.5\ \text{mm} = 0.5 \times 10^{-3}$ m

$D = 1.28 \times 10^{-11}\ \text{m}^2/\text{s}$

$t = ?$

$c_s \rightarrow$ Surface concentration of diffusion element in the surface = 0.9%

$c_o \rightarrow$ Initial uniform concentration of the element in the solid = 0.2%

$c_x \rightarrow$ Concentration of the diffusing element at a distance x from the surface = 0.4%

From table, we find the erf z lies between 0.7112 and 0.7421 for which z lies between 0.75 and 0.80. One can find the number z by interpolation.

$$\frac{0.7143-0.7112}{0.7421-0.7112} = \frac{z-0.75}{0.80-0.75}$$

or

$$z = 0.755$$

From (3),

$$\frac{(69.88)^2}{(0.755)^2} = t$$

$\therefore$

$$t = 8566.35 = 142.8\ \text{min.}$$

XAMPLE PROBLEM 5.2

Nonsteady-State Diffusion Time Computation I

For some applications, it is necessary to harden the surface of a steel (or iron-carbon alloy) above that of its interior. One way this may be accomplished is by increasing the surface concentration of carbon in a process termed **carburizing;** the steel piece is exposed, at an elevated temperature, to an atmosphere rich in a hydrocarbon gas, such as methane (CH_4).

Consider one such alloy that initially has a uniform carbon concentration of 0.25 wt% and is to be treated at 950°C (1750°F). 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} m²/s; assume that the steel piece is semi-infinite.

Solution

Since this is a nonsteady-state diffusion problem in which the surface composition is held constant, Equation 5.5 is used. Values for all the parameters in this expression except time *t* are specified in the problem as follows:

$$\begin{aligned} C_0 &= 0.25 \text{ wt\% C} \\ C_s &= 1.20 \text{ wt\% C} \\ C_x &= 0.80 \text{ wt\% C} \\ x &= 0.50 \text{ mm} = 5 \times 10^{-4} \text{ m} \\ D &= 1.6 \times 10^{-11} \text{ m}^2/\text{s} \end{aligned}$$

Thus,

$$\frac{C_x - C_0}{C_s - C_0} = \frac{0.80 - 0.25}{1.20 - 0.25} = 1 - \operatorname{erf}\left[\frac{(5 \times 10^{-4} \text{ m})}{2\sqrt{(1.6 \times 10^{-11} \text{ m}^2/\text{s})(t)}}\right]$$

$$0.4210 = \operatorname{erf}\left(\frac{62.5 \text{ s}^{1/2}}{\sqrt{t}}\right)$$

We must now determine from Table 5.1 the value of *z* for which the error function is 0.4210. An interpolation is necessary, as

z	**erf(*z*)**
0.35	0.3794
z	0.4210
0.40	0.4284

$$\frac{z - 0.35}{0.40 - 0.35} = \frac{0.4210 - 0.3794}{0.4284 - 0.3794}$$

or

$$z = 0.392$$

Therefore,

$$\frac{62.5\ \mathrm{s}^{1/2}}{\sqrt{t}} = 0.392$$

and solving for t,

$$t = \left(\frac{62.5\ \mathrm{s}^{1/2}}{0.392}\right)^2 = 25{,}400\ \mathrm{s} = 7.1\ \mathrm{h}$$

Table 7.1 Error function

z	erf z	z	erf z
0.000	0.0000	0.85	0.7707
0.025	0.0282	0.90	0.7970
0.05	0.0564	0.95	0.8209
0.10	0.1125	1.0	0.8427
0.15	0.1680	1.1	0.8802
0.20	0.2227	1.2	0.9103
0.25	0.2763	1.3	0.9340
0.30	0.3268	1.4	0.9523
0.35	0.3794	1.5	0.9661
0.40	0.4284	1.6	0.9763
0.45	0.4755	1.7	0.9838
0.50	0.5205	1.8	0.9891
0.55	0.5633	1.9	0.9928
0.60	0.6039	2.0	0.9953
0.65	0.6420	2.2	0.9981
0.70	0.6778	2.4	0.9993
0.75	0.7112	2.6	0.9998
0.80	0.7421	2.8	0.9999

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

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

Example 3 *The diffusion coefficients of carbon in α-Ti were determined at following temperatures.*

Temperature (°C)	*D (m²/s)*
736	2×10^{-13}
782	5×10^{-13}
835	1.3×10^{-12}

(a) Assuming that Arhenius type rate process equation is valid, find the constant of the equation and activation energy, and (b) determine the diffusion coefficient at 500°C. [B.E., M.Sc., (M.S.)]

Solution We have

$$D = D_0 \exp(-\Delta E/kT) \tag{1}$$