PHYSICS OF MATERIALS

Physics School Autumn 2025

Series 5 **10 October 2025**

Exercise 1: Steel carburizing

We want to carburize steel with 0.5wt% C at 1mm from the surface. We use a carburizing gas (for example, methane) at 1000°C to achieve an equivalent 1% concentration at the surface. Knowing that the initial carbon content of steel is 0.02wt% (saturated ferrite), what is the duration of the heat treatment? Diffusivity data are given in Table 5.1

Exercise 2: Conduction in an ionic crystal (Nerst law)

An ionic crystal undergoes an electric field, E. Electrical conduction is essentially determined by ion transport. Calculate the electrical conductivity σ and determine the effect of the temperature. What if there is a gradient of the ion concentration?

Exercise 3: Conduction in a two-component ionic crystal

Consider an ionic crystal with two constituents, A and B. The diffusion coefficients D_A^* and D_B^* are known. Suppose only A and B diffuse without chemical interaction, and the lattice remains steady.

Give the expression of the electric field opposed to diffusion at equilibrium and that of the electrical ionic conductivity. Hint: Use the equation derived in above exercise 2.

Table 5.1 Diffusion coefficient

DIFFUSIVITY DATA FOR A NUMBER OF METALLIC SYSTEMS[a]

Solute	Solvent	$D_0(m^2/s)$	Q (kJ/mol)	Q (kcal/mol)
Carbon	Fcc iron	20×10^{-6}	142	34.0
Carbon	Bcc iron	220×10^{-6}	122	29.3
Iron	Fcc iron	22×10^{-6}	268	64.0
Iron	Bcc iron	200×10^{-6}	240	57.5
Nickel	Fcc iron	77×10^{-6}	280	67.0
Manganese	Fcc iron	35×10^{-6}	282	67.5
Zinc	Copper	34×10^{-6}	191	45.6
Copper	Aluminum	15×10^{-6}	126	30.2
Copper	Copper	20×10^{-6}	197	47.1
Silver	Silver	40×10^{-6}	184	44.1
Carbon	Hcp titanium	511×10^{-6}	182	43.5

SOURCE: Data from L. H. Van Vlack, *Elements of Materials Science and Engineering*, 4th ed., Addison-Wesley Publishing Co., Inc., Reading, Mass., 1980.

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Table 5.2 Error function

THE ERROR FUNCTION

z	erf (z)	z	erf (z)
0.00	0.0000	0.70	0.6778
0.01	0.0113	0.75	0.7112
0.02	0.0226	0.80	0.7421
0.03	0.0338	0.85	0.7707
0.04	0.0451	0.90	0.7969
0.05	0.0564	0.95	0.8209
0.10	0.1125	1.00	0.8427
0.15	0.1680	1.10	0.8802
0.20	0.2227	1.20	0.9103
0.25	0.2763	1.30	0.9340
0.30	0.3286	1.40	0.9523
0.35	0.3794	1.50	0.9661
0.40	0.4284	1.60	0.9763
0.45	0.4755	1.70	0.9838
0.50	0.5205	1.80	0.9891
0.55	0.5633	1.90	0.9928
0.60	0.6039	2.00	0.9953
0.65	0.6420		

SOURCE: *Handbook of Mathematical Functions*, M. Abramowitz and I. A. Stegun, eds., National Bureau of Standards, Applied Mathematics Series 55, Washington, D.C., 1972.