BOSTON UNIVERSITY

COLLEGE OF ENGINEERING

MATERIALS SCIENCE LABORATORY

ME306

LAB #3

Diffusion

Introduction

The purpose of this lab is to introduce you to the mechanisms of diffusion and how diffusion constants can be derived.

Diffusion

Diffusion is the movement of atoms within a solution. The net movement is usually in the direction from regions of high concentration toward regions of low concentration in order to achieve homogeneity of the solution, which may be a liquid, solid, or a gas.

In solids, the only mechanism for atomic transport is through diffusion, however, convection or mechanical mixing are effective alternatives in gases and liquids. Diffusion is a thermodynamic process, which implies that some activation energy is required for diffusion to occur.

Fick's first law helps us in calculating the rate at which atoms diffuse in a material. It states that the net flux of atoms 'J' is equal to the product of the diffusion coefficient 'D' and the concentration gradient.

$$J = -D\frac{\partial c}{\partial x}$$

Fick's second law is for non-steady state diffusion and helps us in understanding the concentration of one diffusing species near the surface of the material as a function of time and distance.

$$\frac{\partial c}{\partial t} = D\frac{\partial^2 c}{\partial x^2}$$

Where the diffusion coefficient is dependent upon the concentration and is therefore a function of position and varies with time, as the material diffuses further.

$$D = x_{Solute} D_{Solvent} + x_{Solvent} D_{Solute}$$

As mentioned earlier, diffusion is a thermodynamic process. For diffusion to occur, atoms must overcome an energy barrier that prevents it from diffusing. This is the activation energy of a material diffusing in another 'Q' and is aided by the temperature factor 'RT'.

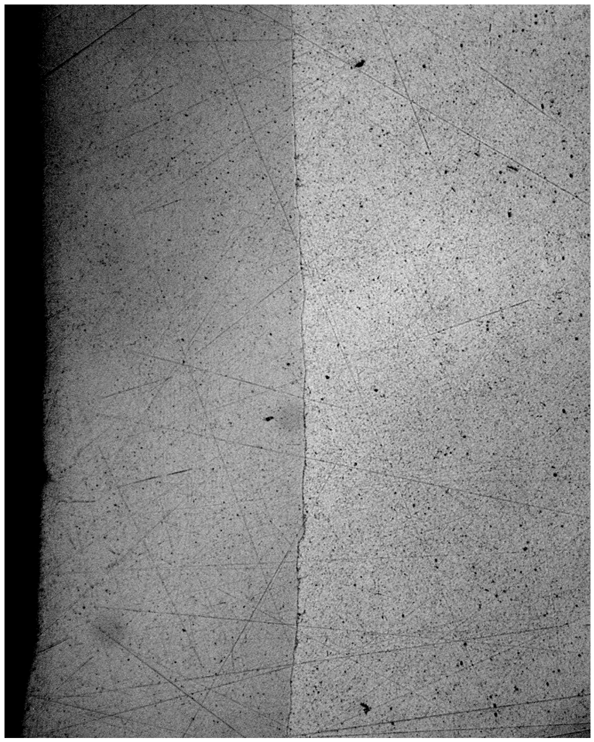
$$D = D_0 \exp\left(-\frac{Q}{RT}\right)$$

D_o = constant (cm^2/sec), Q = activation energy (cal/mol),
R = gas constant (1.987 cal/mol °K), T = absolute temperature (°K)

In the laboratory we will be observing the diffusion of a Copper Nickel system. A good system to use is something that we use every day; coins. Quarters have a copper core surrounded by a copper nickel alloy and are stamped together.

Inside the Quarter:

25%Cu – 75% Ni **100% Cu**



Each coin has been heat treated at a two different temperatures and at each temperature has been held for two different times.

a) 900ºC for 2 hrs, and 10 hrs.

b) 1000ºC for 2 hrs and 10 hrs.

After heat treatment, the coins were cut and prepared for observation under the optical microscopes.

For this system, we would normally use Fick's 2nd law to determine the exact equation applicable to our scenario. However, the solution is much too complicated for our purpose. Therefore, we are going to make some assumptions and simplify our task. We are going to assume that the diffusion constant 'D' does not change with concentration, which is highly inaccurate.

Our Method:

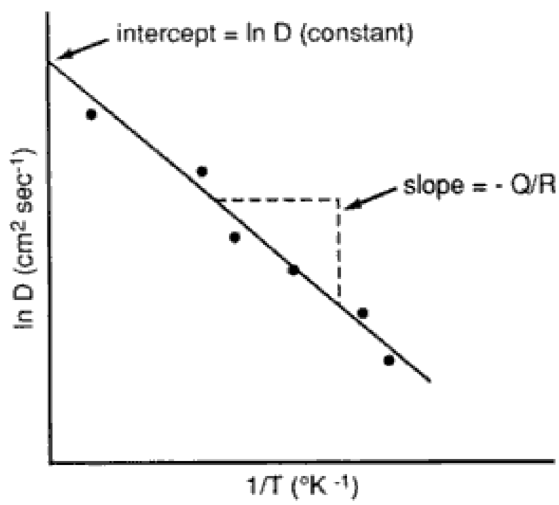
The depth of diffusion can be approximated using the diffusion coefficient and the diffusion time. We will be using the following equation to determine the diffusion coefficient.

$$x \approx \sqrt{Dt}$$

For each sample, you will measure the depth of diffusion and will use the following equation to determine the activation energy. This equation is of a known form which may be transformed into a linear form and solved with a plot, as shown in Figure 1. Make 2 plots, one for 2hr samples and one for 10hr samples. Plot lnD versus 1/T, so each plot will have 2 points. Draw a line connecting these 2 points and estimate D_o from the y-intercept and Q from the slope. Each plot will give a value of Q and D_o. Since these are constants you may average the values together for your final Q and D_o values.

$$D = D_0 \exp\left(- \frac{Q}{RT} \right)$$

Figure 1: The schematic shows a plot relating ln D and 1/T from which Q and D_o may be determined. Note that D_o is written as D (constant) on the plot.



(Source: Introduction to Engineering Materials: Behavior, Properties, and Selection, G.T. Murray, Pg. 164)

Table 1: These are the tabulated values for the diffusion constant and activation energy.

Diffusing Species (Solute)	**Host Metal (Solvent)**	**D_0 (cm^2/sec)**	**Q (kcal/mol)**
Cu	Ni	2.3	61.5
Ni	Cu	0.65	57.9

<u>NOTE:</u> THESE ARE NOT TO BE USED FOR ANY CALCULATIONS!

Instructions:

1. Measure from the inclusion layer to the etchant line in the copper using the scale in one of the microscope eyepieces. This is the diffusion of Ni into the Cu core.

2. Take digital images of each sample.

<u>HINT:</u> READ LAB CAREFULLY BEFORE ANSWERING QUESTIONS!

Questions:

1. Make a table for each sample and tabulate temperature, time, diffusion width.

2. Determine Q and D_0 using the method described.

3. How do these values compare with the tabulated values in Table 1?

4. Explain why the activation energies are not the same for Cu->Ni and Ni->Cu.