# ME 240 Materials Science – Spring 2017

## Problem Set 5

## Due Tuesday, February 28th, at the beginning of class

Problems are either the original work of the NAU instructors, modified from a number of materials science texts or taken directly from your Introduction to Materials Science textbook. It is required that these problems are solved without referring to any answer key. Referring to an online answer key or keys from prior semesters is considered a form of academic dishonesty and will be handled according to University policy that is located in the syllabus.

**Be sure to start each new problem on a new page. Don't be surprised if a single problem extends past one page of work.**

You are encouraged to work in teams, but turn in your own work. You are encouraged to get stuck and ask questions. Give yourself time to do so. Follow systematic steps to solve each of the problems. When working on a quantitative problem, use the GIVE-FIND-SOLVE and REFLECT method. Identify what is given and what must be found. Do not simply rewrite the question. Show all work and carry units across work when appropriate. You will not get full credit if you do not include units. Keep three significant digits in your final answer and place a box around the answer and units.

**5.1** A random poly(styrene-butadiene) copolymer has a number-averaged molecular weight of 425,000 g/mol and a degree of polymerization (DP) = 6500. What is the fraction of styrene and butadiene repeat units in this copolymer? (15 pts)

**5.2a** Calculate the energy for vacancy formation ($Q_v$) in copper, given that the equilibrium number of vacancies is $3.4 \times 10^{22}$ $m^{-3}$ at 800 °C. The density of copper at this temperature is 8.34 $g/cm^3$. **5.2b** Use your answer and plot the fraction of lattice sites that are vacant as a function of temperature. (Use Microsoft Excel or Matlab to make your plots). (16 pts)

**5.3** Recall the $CeO_2$ crystal structure from your Problem Set 3.2. Often impurity ceramic oxides are doped into the ceria to amplify certain properties, such as ion conductivity for solid oxide fuel cells (SOFC). When samaria ($Sm_2O_3$) is doped into $CeO_2$, the $Sm^{3+}$ cation substitutes for $Ce^{4+}$. What other crystal defects will form to accommodate the $Sm^{3+}$ cation, and what are the relative ratios of these defects? See example problem 12.5 for guidance. (4 pts)

**5.4** Dr. Wade has used the above material (samarium-doped ceria), in combination with molten salts, to selectively separate carbon dioxide ($CO_2$) from other gases. A target steady-state flux of $CO_2$ is 0.1 mg $CO_2$ $cm^{-2}$ $s^{-1}$. Consider the following. The United States' Environmental Protection Agency (EPA), under the new Clean Power Plan legislation, may require coal-fired power plants to eliminate or capture up to half (50%) of their carbon dioxide emissions. The Navajo Generating Station in Page, AZ, a 2 GW coal-fired power plant, emits roughly 500 kg $CO_2$ per second How much surface area (in $m^2$) of the above membrane material would be necessary to meet the above regulatory requirement? Reflect on the magnitude of the number. (12 pts)

**5.5** Consulting Figures 4.3a and b in your book (and review example problem 4.2) (16 pts)

a) Compute the radius, r, of an impurity atom that will just fit into an FCC octahedral site in terms of the atomic radius, R, of the host atom. (i.e. host atom radius = R; impurity/solute atom radius = r).

b) Compute the radius, r, of an impurity atom that will just fit into a BCC tetrahedral site in terms of the atomic radius, R, of the host atom. (i.e. host atom radius = R; impurity/solute atom radius = r).

c) Based on these results, explain why a higher concentration of carbon will dissolve in FCC iron than BCC iron.

**5.6** The diffusion coefficients for carbon in nickel are given at two temperatures, as follows (15 pts)

T = 600 °C, D = 5.5 x $10^{-14}$ $m^2/s$ and T = 700°C, D = 3.9 x $10^{-13}$ $m^2/s$. From this data, determine:

a) $D_o$ and $Q_D$
b) Magnitude of D, the diffusion coefficient, at 850 °C.
c) Reflect: Comment on how D changes as temperature increases.

**5.7** For a BCC iron-carbon (steel) alloy, it has been determined that a carburizing heat treatment of 15 h duration at 500 °C will raise the carbon concentration to 0.35 wt% at a point 2.0 mm from the surface. (See Example Problems 5.2 and 5.3 from your text) (18 pts)

a) Estimate the time necessary to achieve the same concentration at a 6.0mm position for an identical steel and at the same carburizing temperature. Reflect by comparing your answer to the original time.

b) Using the original data, how long would it take to reach the same concentration (0.35 wt%) at the same depth (2.0 mm) when heating at 600 °C? Reflect by comparing your answer to the original temperature condition.


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