Question 1. *Thermal Expansion of Two Glasses*

Consider two glasses. Glass A has a composition of 100% SiO2. Glass B has a composition of 25% Na2O - 75% SiO2.

(a) Which sample has a shorter average bond length r?

(b) Which sample has a higher thermal expansion coefficient?

(c) Which sample has a lower viscosity?

Solution 1.

Question 2. *Carburization of Iron*

"Carburization" of pure iron (Fe) is carried out at 950 degrees Celsius. It is desirable to achieve a carbon content of 0.9% at a depth of 0.1 mm below the surface. A constant supply of carbon at the surface maintains a surface concentration of 1.2%. Assuming the diffusivity of carbon in Fe is $10^{-1}\text{m}^2/\text{s}$ at this temperature; calculate the time (in seconds) required for this process.

Solution 2.

Question 3. *Hydrogen Diffusion in Steel*

An undesirable consequence of welding steel by acetylene torch is the rise in hydrogen concentration in the metal. That hydrogen contamination embrittles the steel. The metal is typically subjected to a vacuum heat treatment to restore ductility. A steel part is placed in a vacuum furnace at 600 degrees Celsius for one hour. The H concentration (initially uniform in the weld) falls to $1/2$ its initial value at a depth of 500 microns from the surface: It is known that the diffusivity of H in the steel at 600 degrees Celsius is $3.091 \cdot 10^{-4} \text{cm}^2/\text{sec}$. An identical part is heat treated at 700 degrees Celsius. Under these conditions H the concentration falls to $1/2$ its initial value at a depth of 500 microns in 50 minutes. What is the diffusivity of H in steel at 700 degrees Celsius?

Solution 3.

Question 4. *Nitrogen Diffusion in Cobalt*

You wish to remove nitrogen from the near-surface region of a plate of cobalt which is 1.0 cm thick. The plate is placed in a furnace at 417 degrees Celsius where an atmosphere of H_2 and NH_3 reacts with the nitrogen in the cobalt and fixes the surface concentration to 111 ppm (parts per million by mass). If the initial concentration is 3091 ppm, how long will it take to reduce the nitrogen concentration to 1662 at a depth of 10 microns? The diffusion of nitrogen in cobalt has an activation energy of 100 kJ/mol and a preexponential value D_0 of 0.01cm^2 sec.

Use the approximation $erf(z) = z$ for $z < 0.6$. Use the erf table found in Witt notes for all other values.

Solution 4.

Question 5. *Aluminum Diffusion in Silicon*

The Gaussian error function can be approximated for small values of x as $erf(x) \approx x$. Suppose a silicon wafer is exposed to aluminum vapor at 1300 degrees Celsius. At what distance (in centimeters) will the concentration of Al be 35% of the surface concentration in 164 hours? Assume the diffusivity of Al in Si is $10^{-10}\text{cm}^2/\text{s}$ at 1300 degrees Celsius.

Solution 5.

Question 6. *Chromium Diffusion in Steel*

To increase corrosion resistance, chromium is diffused into steel at 980 degrees Celsius. If the surface concentration of Cr is maintained constant at 100%, how long will it take (in days) to achieve a Cr concentration of 1.8% at a depth of 0.002 cm below the steel surface? ($D_0 = 0.54\text{cm}^2/s, E_A =$ 286kJ/mole

Solution 6.

Question 7. *Boron Diffusion in Silicon*

A p-n junction is to be created by diffusing boron (B) into an n-type silicon wafer with an existing carrier concentration of $10^{15}/\text{cm}^3$. The location of the junction will be 6 microns below the surface of the wafer. The surface concentration of boron will be maintained at $10^{20}/\text{cm}^3$ while the diffusion process is occurring. Assuming the diffusivity of B in Si is $3 \cdot 10^{-11}\text{cm}^2/\text{sec}$ at the process temperature, how many seconds will it take? (Hint: The junction is formed at a location where the boron concentration equals the donor concentration.) Assume no change in donor concentration occurs during the diffusion (ie: no outgassing).

Solution 7.

Question 8. *Surface Strengthening*

A glass of composition 85% SiO_2 - 15% K_2O is to be surface strengthened by ion exchange. To this end, two identical specimens approximately the size and shape of credit cards are soaked for the same amount of time at 850 degrees Celsius. Sample A is soaked in NaCl and sample B is soaked in KCl. From the list below, select the statements that are true.

- The yield strength of Sample A will decrease while the yield strength of Sample B will increase.
- The yield strength of Sample A will increase while the yield strength of Sample B will decrease.
- The yield strength of both Samples A and B will increase.
- The yield strength of both Samples A and B will decrease.
- The yield strength of Sample A will decrease. There will be no change in the yield strength of Sample B.

Solution 8.

Question 9. *Cooling Rates*

Consider two glasses. Glass A has a composition of 5% CaO - 95% B_2O_3. Glass B has a composition of 15% CaO - 85% B_2O_3. Both samples are cooled from their molten state to room temperature at rates that result in an identical glass transition temperature. Given this information, identify which melt was cooled at a higher cooling rate to achieve identical T_g.

Solution 9.

Question 10. *KCl Salt Bath*

Which of the following statements describes why ion exchange of 99% SiO_2 - 1% B_2O_3 in a salt bath of molten postassium chloride (KCl) is not an effective way to increase the surface strength of the glass sample?

- The ion exchange works correctly, however both air-cooling and water-quenching are more efficient ways to induce a surface strengthening effect.
- The glass is composed of only 1% B_2O_3, which is not a large enough proportion of B2O3 to undergo ion exchange, and therefore does not increase the surface strength of the sample effectively.
- The potassium ion is smaller than B_2O_3, so when ion exchange takes place the surface is actually being weakened instead of strengthened.
- The sample described above is composed of SiO_2 and B_2O_3. Neither of these components are network modifiers, so ion exchange does not take place to strengthen the surface of the glass.
- The surfaces of the glass sample are not cooled quickly enough to create a high internal strain energy that leads to strong surfaces.

In which of the following ways would you change the glass sample to make the ion exchange more efficient?

- Change the composition of the glass to increase the proportion of B2O3.
- Change the composition of the glass to add Na2O, Li2O, or MgO.
- Change the composition of the glass to add CaO.
- Change the composition of the salt bath (KCl) to an ion smaller than potassium, such as sodium chloride (NaCl).
- Lower the temperature of the salt bath to cool the sample more quickly.

Solution 10.