TRUE/FALSE QUESTIONS

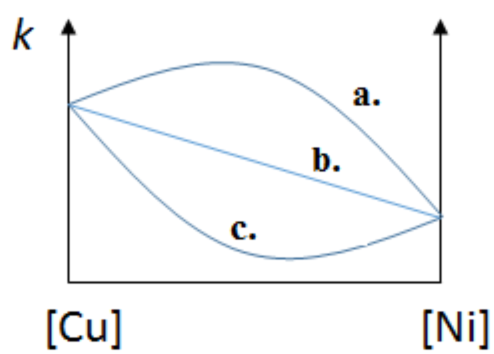
1. It is possible to produce a perfect crystalline solid that does not contain any vacancies. FALSE (All crystalline solids contain vacancies)
2. As temperature decreases, the fraction of the total number of atoms that are capable of diffusive motion increases. FALSE (Higher temperature promotes faster diffusion)
3. Two metal specimens, A and B, have ASTM grain size numbers of 3 and 8, respectively. That implies, Grain Size of A < Grain size of B. FALSE (As grain size number increases the actual grain size decreases)
4. Increasing the number of operable slip systems in a metal decreases the ductility. FALSE (Since you are increasing the possibility of deformation by increasing the number of slip systems therefore the metal becomes more ductile)
5. For a particular crystal structure, the slip planes are the crystallographic planes with highest planar density. TRUE
6. A metallic material typically exhibits substantial plastic deformation with high energy absorption before fracture. TRUE
7. The effect of a stress raiser (e.g. cracks) is more significant for brittle materials. TRUE
8. The modulus of resilience is a measure of the total capacity of the material to absorb energy up to the failure point. FALSE (up until the elastic limit)
9. The stress concentration factor for small radii of curvature is much larger than that of large radii of curvature. TRUE
10. Failure of a material due to the application of a cyclic stress is called creep. FALSE (That is fatigue)
11. The burgers vector of an edge dislocation is parallel to the dislocation line. FALSE (It is perpendicular)
12. Free surface of a material is considered a defect because it breaks the long-range order. TRUE
13. The activation energy for interstitial diffusion is generally higher than substitutional/vacancy diffusion. FALSE (They are lower for interstitial diffusion since less energy is required to squeeze an interstitial atom past the surrounding atoms)
14. Typically, polymers have lower thermal expansion coefficients than metals. FALSE (Polymers with weak, secondary, intermolecular bonds (low melting points) have very high expansion coefficients)
15. The electrical resistivity of metals increases with increasing temperature. TRUE
16. Magnetic susceptibility is a measure of how much a material will be magnetized in an applied magnetic field. TRUE
17. Phosphorescence is the prompt photoluminescence that occurs very shortly after photoexcitation of a substance. FALSE (That is fluorescence phosphorescence is long-lived photoluminescence that continues long after the photoexcitation has stopped.)
18. Fiber reinforced composites typically exhibit isotropic mechanical behavior. FALSE (Composites in general typically exhibit anisotropic behavior)
19. Steady-state diffusion is the situation wherein the rate of diffusion into a given system is different than the rate of diffusion out, such that there is a net accumulation or depletion of diffusing species--i.e., the diffusion flux is dependent on time. FALSE (steady state means that net output is equal to net input)

MULTIPLE CHOICE / SHORT ANSWER QUESTIONS

1. Under conditions of steady state diffusion:
   a. The positions of atoms are fixed in time.
   b. There is no net mass flux in a system.
   c. Individual atoms always move from regions of high concentration to regions of low concentration.
   d. Concentration profiles and mass fluxes do not change with time.

2. Which of the following techniques could increase the strength of a ceramic part?
   a. Polishing the ceramic to remove any surface flaws.
   b. Shot peening the ceramic to induce compressive strain at the surface.
   c. Cold-working the ceramic.
   d. Drawing the ceramic along a particular direction to orient its molecular structure.

3. Cu and Ni form a continuous solid solution. Thermal conductivity in Cu-Ni alloys will tend to follow which trend (circle on the figure to right)? C



4. Give two examples of each:

Point Defect: Vacancy, self-interstitial
Line Defect: Edge and screw dislocations
Area Defect: Grain and twin boundaries

5. Why can complete solid solubility occur for substitutional solid solutions but not for interstitial solid solutions?

Substitutional solid solution involves the substitution of a solvent atom by a solute atom whereas in the formation of interstitial solid solutions, there is no displacement of solvent atoms by solute atoms, instead the solute atoms fill the interstices (voids) found between the atoms, ions or ionic groups of a crystal structure, creating significant lattice distortion. This is the reason why Interstitial solid solutions always have limited solubility of the solute.

6. The recrystallization temperatures of metals such as lead and tin lies below room temperature. Do you expect these metals to strain harden at room temperature? Why or why not? These materials do not strain harden at room temperature because any strain hardening effect after deformation will be erased as a result of recovery and recrystallization because of the relatively elevated temperature.

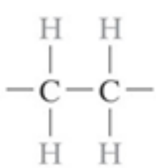
7. Fluorine anions (F^-) have an ionic radius of 0.133 nm. Circle those cations (if any) which will likely adopt the CsCl structure with F^-. *(4 pts)*

Coordination number (CN) of CsCl structure is 8. Cation-anion ratio should be 0.732-1 (This information will be given in the formula sheet in the instructions). Based on this, Na and Ca cations are likely to form the CsCl structure.

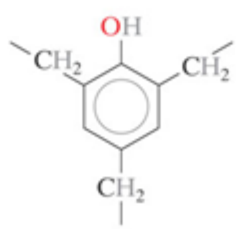
Ion:	Ionic radius (in nm):
Al 3+	0.053
Ca 2+	0.100
Na 1+	0.102
Cl 1-	0.181

8. The repeat units for polyethylene (PE) and Bakelite are shown below: *(4 pts)*

Polyethylene

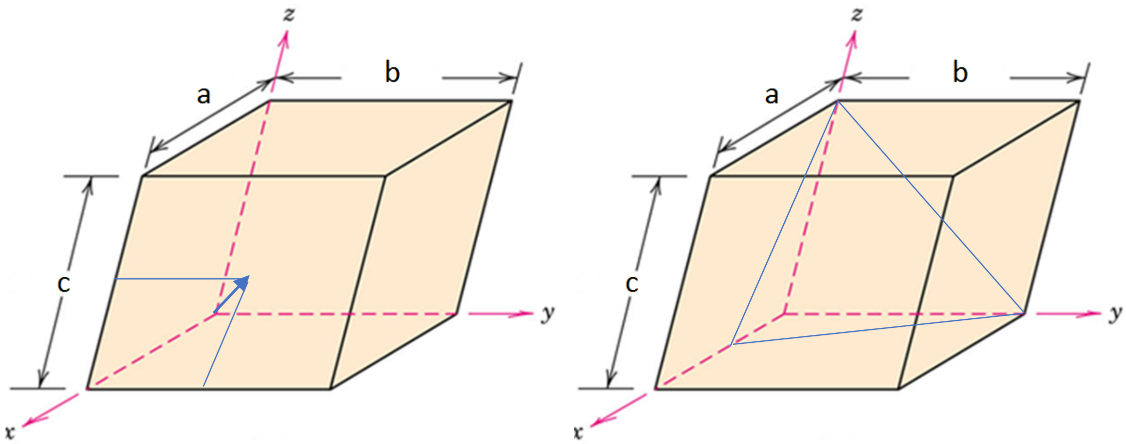


Bakelite



Circle the polymer that will tend to be more brittle. Explain why. Polyethylene is a linear polymer that has long chains capable of sliding past each other under loading. On the other hand, bakelite is a heavily cross-linked network polymer which is hard and very brittle.

9. For the monoclinic system shown below, draw in the crystal direction [211] and the plane (211)

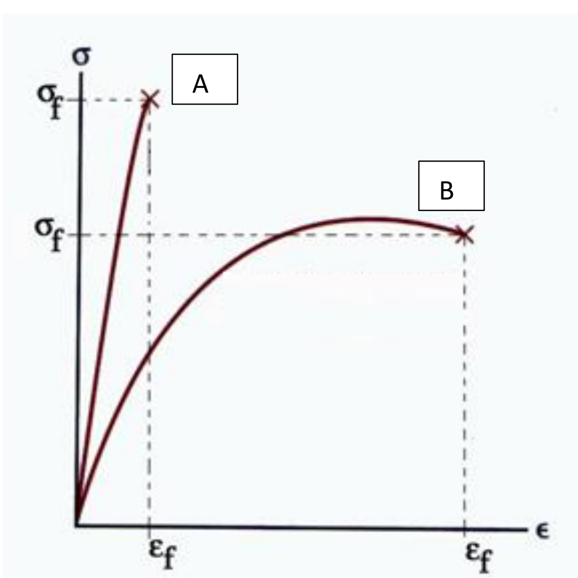


10. A typical stress-strain diagram is illustrated below for a brittle ceramic and for a ductile metal. *(4 pts)*

a. Label which curve represents which material. A: ceramic, B: metal

b. The brittle ceramic is sintered at a higher pressure and temperature. Draw the new stress-strain curve for this material (on the original figure). High temperature sintering reduces the porosity of the ceramic, increasing its strength, toughness and ductility. Note that since porosity decreases, elastic modulus of the material will increase. Material will still yield without a sign of plasticity (i.e. brittle fracture)

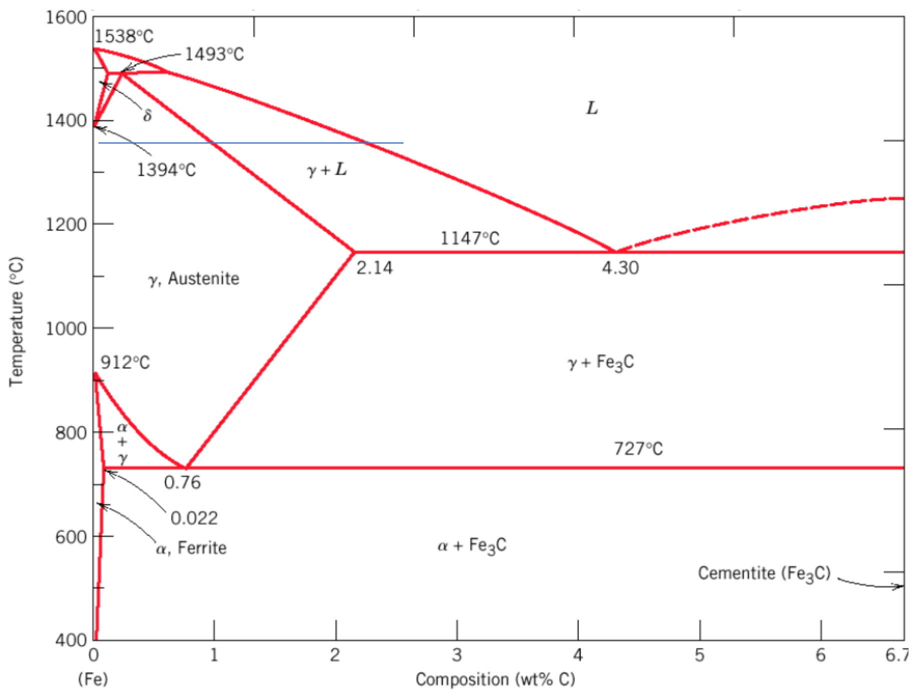
c. The ductile metal undergoes 50% cold working. Draw the new stress-strain curve for this material (on the original figure). Elastic modulus of the material won't change with cold working. However, its yield/ultimate tensile strength will increase and ductility will decrease.



11. Can a material have an index of refraction less than unity? Why or why not?
In order for a material to have an index of refraction less than unity, the velocity of light in the material would necessarily have to be greater than the velocity of light in a vacuum. This is not possible.

PROBLEMS:

1. The Fe-C binary system has the following phase diagram



a. What is the melting point of pure iron?
The melting point of pure iron (0 wt% C) is 1538 C

b. What are the temperatures of the peritectic/eutectic/eutectoid reactions?
Peritectic reactions: $\delta + L \rightarrow \gamma$ @ 1493 C
Eutectic reactions: $L \rightarrow \gamma + Fe_3C$ @ 1147 C
Eutectoid reactions: $\gamma \rightarrow \alpha + Fe_3C$ @ 727 C

c. For a system with 1.5 wt% C, write down
   1. The phase(s) present
   2. The compositions of each phase.
   3. The weight fraction of each phase

starting at 1500 ˚C, cooling down to 1400 °C, 1200 °C and 800 °C

1. Phases @
   1500 C: Liquid
   1400 C: $Liquid$ & $Austenite\ (\gamma)$
   1200 C: $Austenite\ (\gamma)$
   800 C: $Austenite\ (\gamma)$ & $Cementite\ (Fe_3C)$

2. Compositions @
   1500 C: Liquid = 1.5 wt% C
   1400 C: Liquid = 1.8 wt% C & Austenite = 1 wt% C
   1200 C: Austenite = 1.5 wt% C
   800 C: Austenite = 1.2 wt% C & Cementite = 6.7 wt% C

3. Weight fractions @
   1500 C: W_L= 1.00 or 100%
   1400 C: $W_L = \frac{1.5-1}{1.8-1} = 0.625 \text{ or } 62.5\%$ & $W_{Austenite} = \frac{1.8-1.5}{1.8-1} = 0.375 \text{ or } 37.5\%$
   1200 C: $W_{Austenite}$ = 1.00 or 100%
   800 C: $W_{Austenite} = \frac{6.7-1.5}{6.7-1.2} = 0.945 \text{ or } 94.5\%$ & $W_{Cementite} = \frac{1.5-1.2}{6.7-1.2} = 0.055 \text{ or } 5.5\%$

d. For a project, you would like to cast a liquid FeC alloy that remains liquid at as low of a temperature as possible. What composition would you choose to work with?

I would choose to work with 4.3 wt% C since that it the composition in which a FeC alloy would remain a liquid at the lowest temperature possible 1147C..

2. Two previously undeformed specimens of the same metal are to be plastically deformed by reducing their cross-sectional areas. One has a circular cross section, and the other is rectangular; during deformation the circular cross section is to remain circular, and the rectangular is to remain as such. Their original and deformed dimensions are as follows:

	Circular (diameter, mm)	Rectangular (mm)
Original dimensions	15.2	123 × 172
Deformed dimensions	11.78	78 × 182

Which of these specimens will be the hardest after plastic deformation and why?

The hardest specimen will be the one that has experienced the greatest degree of cold work.

$$\% \, CW = \frac{A_0 - A_d}{A_0} \times 100$$

For the Circular specimen:

$$\% \, CW = \frac{\pi\left(\frac{d_0^2}{4}\right) - \pi\left(\frac{d_d^2}{4}\right)}{\pi\left(\frac{d_0^2}{4}\right)} \times 100 = \frac{\pi\left(\frac{15.2^2}{4}\right) - \pi\left(\frac{11.78^2}{4}\right)}{\pi\left(\frac{15.2^2}{4}\right)} \times 100 = 39.9\%$$

For the Rectangular specimen:

$$\% \, CW = \frac{(L_0 \times W_0) - (L_f \times W_f)}{(L_0 \times W_0)} \times 100 = \frac{(123 \times 172) - (78 \times 182)}{(123 \times 172)} \times 100 = 32.9\%$$

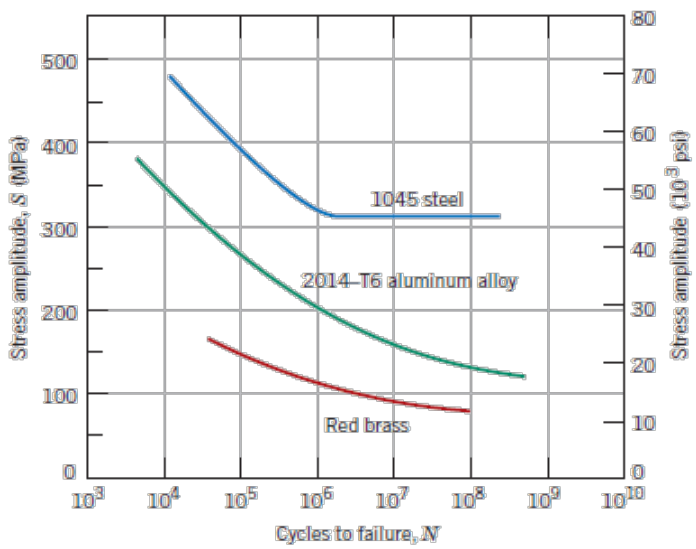
Therefore, the deformed circular specimen will be harder.

3. A material has K_{IC}=60.4MPa $m^{1/2}$ and a yield strength of 1515 MPa. The material is subjected to a stress half of its yield strength with Y=1.12. If we use an instrument to detect flaws with a resolution of 3 mm, will we be able to detect a critical surface crack?

$$K_{IC} = Y\sigma\sqrt{\pi a} = (1.12)\left(\frac{1515}{2}\right)\sqrt{\pi(a)} = 60.4 \rightarrow a = 1.6 \times 10^{-3} m = 1.6 \, mm$$

The critical surface crack will not be detected since it is less than the given resolution of 3mm.

4. A cylindrical 1045 steel bar (Figure below) is subjected to repeated compression-tension stress cycling along its axis. If the load amplitude is 22,000 N (4950 lb_f), compute the minimum allowable bar diameter to ensure that fatigue failure will not occur. Assume a factor of safety of 2.



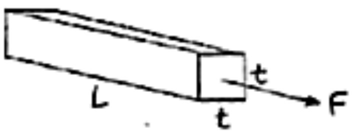
For 1045 steel the fatigue limit is approximately 320 MPa, thus taking factor of safety into account our target for our cylindrical specimen is 160 MPa. Therefore, the minimum allowable bar diameter is:

$$\sigma = \frac{F}{A} \rightarrow 160 \times 10^6 = \frac{22{,}000}{\pi(\frac{d^2}{4})} \rightarrow d = 0.0132m = 13.2 \, mm$$

5. A square bar loaded in axial tension: F= 30,000 N, L= 100 mm, t= 10 mm (See figure below)

Design criteria:
There should be no plastic deformation
$\Delta L < 0.3$ mm,
$\Delta t < |0.008 \text{ mm}|$

Which materials from the given table are possible candidates?



Material	Modulus of Elasticity (GPa)	Yield Strength (MPa)	Poisson's Ratio
Aluminum alloy	70	250	0.33
Titanium alloy	105	850	0.36
Steel alloy	205	550	0.27
Magnesium alloy	45	170	0.20

$$\sigma = \frac{F}{A} = \frac{30{,}000}{(10\times10^{-3})^2} = 300\ MPa$$

Thus you can eliminate Aluminum and Magnesium since their yield strength is below 300 MPa.
Afterwards, calculate longitudinal and transverse strains (using poissons ratio) for both steel and titanium.

For titanium:

$$\varepsilon = \frac{\sigma}{E} = \frac{300}{105\times10^3} = 0.00285$$

$\varepsilon = \frac{\Delta L}{L} = 0.00285 \rightarrow \Delta L = 0.285\ mm$ which is less than 0.3mm thus it fits the criteria

$$\varepsilon_t = -\nu\varepsilon_l = -(0.00285)(0.36) \rightarrow \varepsilon_t = 0.001\ mm$$

$\varepsilon_t = \frac{\Delta t}{t} \rightarrow \Delta t = 0.01\ mm$ which is larger than 0.008 mm thus titanium is not a possible candidate.

For Steel:

$$\varepsilon = \frac{\sigma}{E} = \frac{300}{205\times10^3} = 0.00146$$

$\varepsilon = \frac{\Delta L}{L} = 0.00146 \rightarrow \Delta L = 0.146\ mm$ which is less than 0.3mm thus it fits the criteria

$$\varepsilon_t = -\nu\varepsilon_l = -(0.00146)(0.27) \rightarrow \varepsilon_t = 0.000395\ mm$$

$\varepsilon_t = \frac{\Delta t}{t} \rightarrow \Delta t = 0.00395\ mm$ which is smaller than 0.008 mm thus steel is a possible candidate.

6. a) A bar of steel with a cross section of 0.1 m^2 with both ends fixed rigidly in place is heated to 125 ˚C. What is the resulting compressive stress on the bar? The steel has the following properties: E_{steel} = 200 GPa, $\alpha_{l,steel}$ = 12 x 10^{-6} K^{-1}, T_0 = 25 ˚C b) If the yield stress of this particular material is 500 MPa, what is the maximum temperature to which it can be heated to before undergoing permanent deformation?

a) $\sigma_t = E\alpha\Delta T \rightarrow 200\times10^9\times12\times10^{-6}\times((125+273)-(25+273)) = 240MPa$

b) $\sigma_t = E\alpha\Delta T \rightarrow 500\times10^6 = 200\times10^9\times12\times10^{-6}\times\Delta T \rightarrow \Delta T = 208.3K$

Thus, the maximum temperature the bar can be heated before undergoing permanent deformation is 233.3 C.

7. A refrigerator door is made of a porous polymer foam with a low thermal conductivity of 0.01 W/m/K. If the interior of the fridge is kept at 10 C, the ambient kitchen temperature is 25 C, and the refrigerator door has an area of 0.8 m^2, and is 0.05 m thick, how much heat is lost through the door every hour?

$$q = -\frac{k \cdot \Delta T}{\Delta x} = -\frac{0.01 \cdot \left((10 + 273) - (25 + 273)\right)}{(-0.05)} = -3\; W/m^2$$

$$\frac{dQ}{dt} = qAt = (-3)(0.8)\left(60\frac{s}{min}\right)\left(60\frac{min}{h}\right) = -8640\; J/h$$

8. The magnetization within a bar of some metal alloy is 3.2 * 10^5 A/m at an H field of 50 A/m. Compute the following: (a) the magnetic susceptibility, (b) the permeability, and (c) the magnetic flux density within this material. (d) What type(s) of magnetism would you suggest as being displayed by this material? Why?

(a) This portion of the problem calls for us to compute the magnetic susceptibility within a bar of some metal alloy when $M = 3.2 \cdot 10^5$ A/m and $H = 50$ A/m. This requires that we solve for χ_m from Equation 18.6 as

$$\chi_m = \frac{M}{H} = \frac{3.2 \times 10^5 \text{ A/m}}{50 \text{ A/m}} = 6400$$

(b) In order to calculate the permeability, we must employ a combined form of Equations 18.4 and 18.7 as follows:

$$\mu = \mu_r \mu_0 = (\chi_m + 1)\mu_0$$

$$= (6400 + 1)(1.257 \times 10^{-6} \text{ H/m}) = 8.05 \times 10^{-3} \text{ H/m}$$

(c) The magnetic flux density may be determined using Equation 18.2 as

$$B = \mu H = (8.05 \times 10^{-3} \text{ H/m})(50 \text{ A/m}) = 0.40 \text{ tesla}$$

(d) This metal alloy would exhibit ferromagnetic behavior on the basis of the magnitude of its χ_m (6400), which is considerably larger than the χ_m values for diamagnetic and paramagnetic materials listed in Table 18.2.

9. Estimate the maximum and minimum thermal conductivity values for a cermet that contains 85 vol% titanium carbide (TiC) particles in a cobalt (Co) matrix. Assume thermal conductivities of 27 and 69 W/m-K for TiC and Co, respectively.

This problem asks for the maximum and minimum thermal conductivity values for a TiC-Co cermet. Using a modified form of Equation 15.1 the maximum thermal conductivity k_{max} is calculated as

$$k_{max} = k_m V_m + k_p V_p$$

$$= k_{Co} V_{Co} + k_{TiC} V_{TiC}$$

$$= (69 \text{ W/m-K})(0.15) + (27 \text{ W/m-K})(0.85) = 33.3 \text{ W/m-K}$$

Using a modified form of Equation 15.2, the minimum thermal conductivity k_{min} will be

$$k_{min} = \frac{k_{Co} k_{TiC}}{V_{Co} k_{TiC} + V_{TiC} k_{Co}}$$

$$= \frac{(69 \text{ W/m-K})(27 \text{ W/m-K})}{(0.15)(27 \text{ W/m-K}) + (0.85)(69 \text{ W/m-K})}$$

$$= 29.7 \text{ W/m-K}$$

10. A sheet of steel 1.5 mm thick has nitrogen atmospheres on both sides at 1200 °C and is permitted to achieve a steady-state diffusion condition. The diffusion coefficient for nitrogen in steel at this temperature is $6 \cdot 10^{-11}$ m^2/s, and the diffusion flux is found to be $1.2 \cdot 10^{-7}$ kg/m^2-s. Also, it is known that the concentration of nitrogen in the steel at the high-pressure surface is 4 kg/m^3. How far into the sheet from this high-pressure side will the concentration be 2.0 kg/m^3? Assume a linear concentration profile.

This problem is solved by using Equation 6.2 in the form

$$J = -D\frac{C_A - C_B}{x_A - x_B}$$

If we take C_A to be the point at which the concentration of nitrogen is 4 kg/m^3, then it becomes necessary to solve for x_B, as

$$x_B = x_A + D\left[\frac{C_A - C_B}{J}\right]$$

Assume x_A is zero at the surface, in which case

$$x_B = 0 + (6 \times 10^{-11}\ m^2/s)\left[\frac{4\ kg/m^3 - 2\ kg/m^3}{1.2 \times 10^{-7}\ kg/m^2\text{-s}}\right]$$

$$= 1 \cdot 10^{-3}\ m = 1\ mm$$