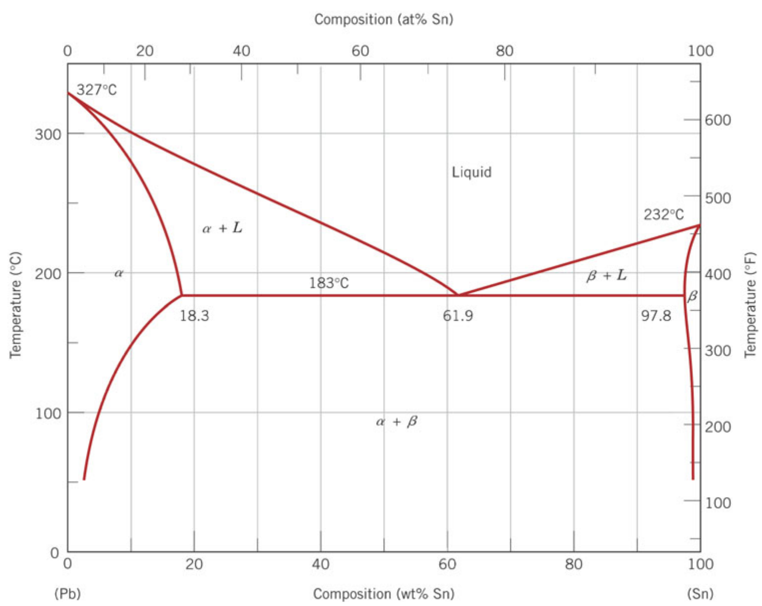
Problem 1. A phase diagram of tin and lead is shown below.

For Part 1a-1d, we examine the slow cooling of a 30 wt% Sn-70 wt% Pb mixture from the liquid phase to 150 °C.



Phase diagram of Sn and Pb

1a. Determine the temperature at which the first solid phase is formed.

258 °C

1b. Determine the composition of the last drop of liquid in the alloy before complete solidification.

61.9 wt% Sn

1c. Determine the i) phase(s), ii) their respective weight fractions, and ii) their composition(s) of the alloy when the temperature reaches 150 °C.

Phase(s): α,β

Weight Fraction(s): α=(97-30)/(97-10)=0.77

β =1-0.77=0.27

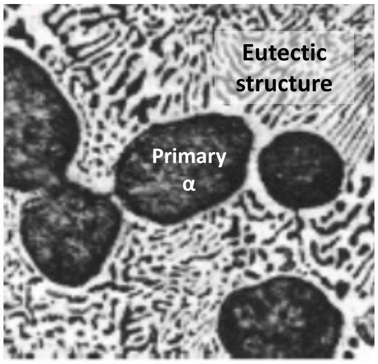
Composition(s): α=10% Sn, 90% Pb

β =97 % Sn, 3% Pb

1d. What is the minimum weight fractions **of β in the solid mixtures during the cooling process (from liquid phase to150 °C)** that can be formed from this 30 wt% Sn-70 wt% Pb mixture?

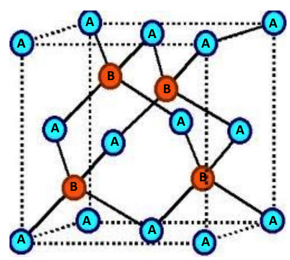
β =(30-18.3)/(97.8-18.3)=0.147

1e. The micrograph of a Sn and Pb alloy **with unknown compositions** at 100 ^{o}C is shown below. Two phases (primary alpha and eutectic micro-constituent) are clearly visible. Indicate on the phase diagram (given above) the point (**estimated** composition) that corresponds to this micrograph.



α=35% primary alpha
Locate the point at 100 ^{o}C
~ 27 % Sn

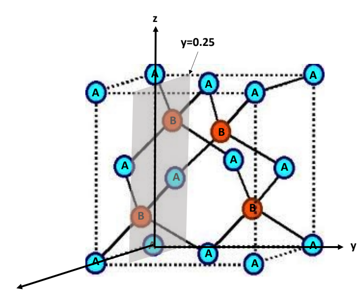
Problem 2. The crystal structure of Mercury(II) Telluride ($Hg^{2+}Te^{2-}$) is shown below. The radius of Mercury(II) ion is 116 pm and that of the Telluride ion is 211 pm.



2a. Name the crystal structure. _______________Zincblende____________________

2b. The coordination number of atom A in the figure is _____4__________________________

2c. The Planar (Miller) Indices of the plane highlighted below is:



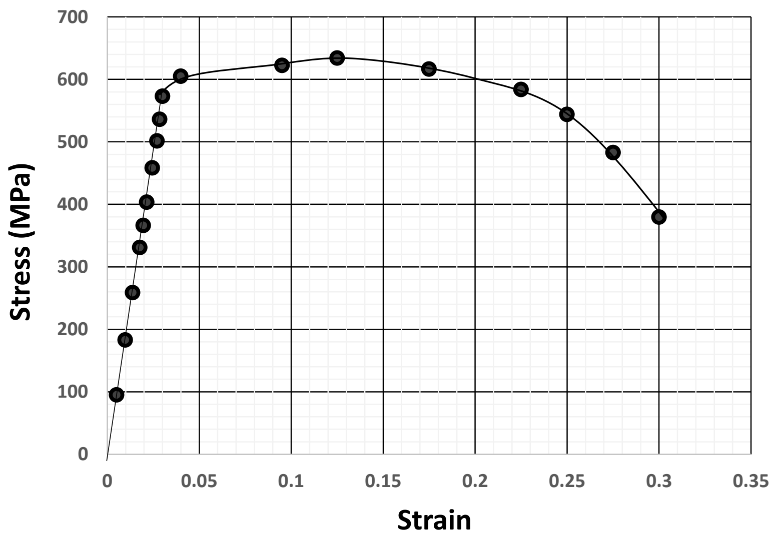
x y z
∞ 0.25 ∞
(0 4 0)

2e. Determine the theoretical density of the HgTe, in g cm^{-3}.

$$5.063\ \frac{g}{cm^3}$$

Problem 3 (Part 3a-3d). You are evaluating a bronze alloy specimen with a cross-sectional area of 500 mm^2 and length of 6 mm. You are given:

1) stress-strain behavior (see figure below) and
2) a Poisson's ratio of 0.30.



Stress-strain behavior of a bronze alloy specimen.

3a. What is the maximum load that can be sustained by the specimen? **F = 319000N**

3b. Determine the maximum load that may be applied to the bronze alloy specimen without plastic deformation.

$\frac{F}{A} = 575MPa$

$F = 575 \times 1E6 \frac{N}{m^2}\ 0.0005\ m^2 = 287500N$

3c. Determine the specimen cross-sectional area when the specimen is pulled in tension with a force of 200 000 N.

cross sectional area at F=200000N

$\pi\left[12.62 - \frac{0.151}{2}\right]^2 mm^2 = 494.4mm^2$

3d. What is the ductility, in percent of elongation?

Ductility $\%E = \frac{L_f - L_o}{L_o} \times 100$ degree of plastic deformation

$= 0.27$

3e. Determine the modulus of resilience (U_r).

U_r=0.5 (stress*strain)=0.5(575 MPa)(0.03)=8.625 MPa

3f. Select the correct answer:

i. Brittle materials generally never exhibit higher tensile strengths than ductile materials

ii. During plastic deformation, the bonds between original atom neighbors are broken and new bonds are formed.

iii. Ceramics typically absorb large amount of energy than metal before their catastrophic fracture.

iv. When porosity increases, the flexural strength also increases accordingly.

Question on equilibrium and ΔG°

(a) A 1-L vessel contains 0.8 M $H_2S(g)$ and 0.2 M $CH_4(g)$ at 973 K. Assume the process given below reaches equilibrium when 30% of the $CH_4(g)$ reacts with the $H_2S(g)$ present and produces $H_2(g)$ and $CS_2(g)$ products. Calculate the equilibrium constants (K_c and K_p) and ΔG° for this reaction at 973 K [6 marks].

$$2H_2S\,(g) + CH_4\,(g) \rightleftharpoons 4H_2\,(g) + CS_2\,(g)$$

CH_4 consumed $= 0.2 \times 0.3 = 0.06\ M \rightarrow [CH_4]_{\text{remained}} = 0.2 - 0.06 = 0.14\ M$

H_2S " $= 2 \times 0.06 = 0.12 M \rightarrow [H_2S]_{\text{remained}} = 0.8 - 0.12 = 0.68\ M$

H_2 produced $= 4 \times 0.06 = 0.24\ M$

CS_2 " $= 0.06\ M$

$$K_c = \frac{[H_2]^4[CS_2]}{[H_2S]^2[CH_4]} = \frac{(0.24)^2(0.06)}{(0.68)^2(0.14)} = 3.075 \times 10^{-3}$$

$K_p = K_c(RT)^{\Delta n} \longrightarrow K_p = 3.075 \times 10^{-3}\left[(0.08206)(973)\right]^2 = 19.6$

$\Delta n = 1 + 4 - 1 - 2 = 2$ (0.5 mark)

$\Delta G = -RT \ln K_p = -8.314(973)\ln(19.6) = -24072\ J/mol$ or $-24.072\ \frac{kJ}{mol}$

(0.5 mark)

(b) Calculate K_c for the following reactions at 973 K [2 marks].

$$4H_2S\,(g) + 2CH_4\,(g) \rightleftharpoons 8H_2\,(g) + 2CS_2\,(g)$$

$$K_c = (3.075 \times 10^{-3})^2 = 9.456 \times 10^{-6}$$

$$4H_2\,(g) + CS_2\,(g) \rightleftharpoons 2H_2S\,(g) + CH_4\,(g)$$

$$K_c = \frac{1}{3.075 \times 10^{-3}} = 325.2$$

(C) If K_p for the reaction "$2H_2S\ (g) + CH_4\ (g) \rightleftharpoons 4H_2\ (g) + CS_2\ (g)$" is 3.02×10^{-5} at 25°C, calculate $\Delta H°_{reaction}$ (assumption: $\Delta H°_{reaction}$ is independent of temperature)

$$\ln \frac{K_p(T_2)}{K_p(T_1)} = -\frac{\Delta H°_{reaction}}{R}\left(\frac{1}{T_2} - \frac{1}{T_1}\right)$$

$$\ln \frac{19.6}{3.02\times10^{-5}} = -\frac{\Delta H°}{8.314}\left(\frac{1}{973} - \frac{1}{298}\right)$$

$$13.38 = -\frac{\Delta H°}{8.314}\left(-2.328\times10^{-3}\right) \rightarrow \Delta H°_{react} = 47784.98\ J/mol$$

0.5 mark

or

$47.78\ \frac{KJ}{mol}$

(D) How would the equilibrium position change, if the following actions are performed on the reaction "$2H_2S\ (g) + CH_4\ (g) \rightleftharpoons 4H_2\ (g) + CS_2(g)$" system? Circle the correct response [4 marks].

1) Addition of iron mixed with metal oxides catalyst	*move to right*	*move to left*	*doesn't shift*
2) Decreasing temperature	*move to right*	*move to left*	*doesn't shift*
3) Increasing the volume of the vessel	*move to right*	*move to left*	*doesn't shift*
4) Increasing the partial pressure of $CS_2(g)$	*move to right*	*move to left*	*doesn't shift*

(C) If K_p for the reaction "$2H_2S\ (g) + CH_4\ (g) \rightleftharpoons 4H_2\ (g) + CS_2\ (g)$" is 3.02×10^{-5} at 25°C, calculate $\Delta H^\circ_{reaction}$ (assumption: $\Delta H^\circ_{reaction}$ is independent of temperature) [3 marks].

$$\ln \frac{K_p(T_2)}{K_p(T_1)} = -\frac{\Delta H^\circ_{reaction}}{R}\left(\frac{1}{T_2} - \frac{1}{T_1}\right)$$

$$\ln \frac{2.012 \times 10^{5}}{3.02 \times 10^{-5}} = -\frac{\Delta H^\circ}{8.314}\left(\frac{1}{973} - \frac{1}{298}\right)$$ (1 mark)

$$22.623 = -\frac{\Delta H^\circ}{8.314}\left(-2.328 \times 10^{-3}\right) \longrightarrow \Delta H^\circ_{reaction} = 807951\ J/mol$$

or

807.95 KJ/mol

(2 marks)

(D) How would the equilibrium position change, if the following actions are performed on the reaction "$2H_2S\ (g) + CH_4\ (g) \rightleftharpoons 4H_2\ (g) + CS_2(g)$" system? Circle the correct response [4 marks].

1) Addition of iron mixed with metal oxides catalyst	*move to right*	*move to left*	*doesn't shift*	1 Mark
2) Decreasing temperature ~~(exothermic)~~ (endothermic)	~~*move to right*~~	correct *move to left*	*doesn't shift*	1 Mark
3) Increasing the volume of the vessel	*move to right*	*move to left*	*doesn't shift*	1 Mark
4) Increasing the partial pressure of ~~$CH_4(g)$~~ $CS_2(g)$	*move to right*	*move to left*	*doesn't shift*	1 Mark

Question on thermodynamics

One mole of a diatomic gas is compressed from an initial pressure and temperature of 1 bar and 300 K to a final pressure of 4 bar in three different process paths given below. For each path, calculate w, q, ΔU, ΔH, and ΔS of the process.

ideal

reversible

$C_p = \frac{7}{2} R$

(a) the process is adiabatic

$$\rightarrow T_2 = (300)\left(\frac{4}{1}\right)^{2/7} = 445.8 \text{ K}$$

$q = 0$

$\Delta U = n\bar{C}_V \Delta T = 3030.45 \text{ J}$

$\Delta U = q + w \rightarrow w = 3030.45 \text{ J}$

$\Delta H = n\bar{C}_p \Delta T = \cancel{4} 4242.6 \text{ J}$

$\Delta S = \frac{q_{rev}}{T} = 0$

(b) the process takes place at constant volume

$\Delta V = 0 \rightarrow w = 0$

$q = \Delta U = n\bar{C}_V \Delta T = 1 \times \frac{5}{2} R \times (1200 - 300) = 18706.5 \text{ J}$

$\text{Const. } V \rightarrow \frac{P_2}{T_2} = \frac{P_1}{T_1} \rightarrow T_2 = P_2\left(\frac{T_1}{P_1}\right) = 1200 \text{ K}$

$\Delta H = n\bar{C}_p \Delta T = 1 \times \frac{7}{2} R \times (1200 - 300) = 26189.1 \text{ J}$

$\Delta S = n\bar{C}_V \ln \frac{T_2}{T_1} = 1 \times \frac{5}{2} R \times \ln \frac{1200}{300} = 28.81 \text{ J/K}$

(c) the process takes place ~~at constant pressure~~ isothermally

$\Delta T = 0 \rightarrow \Delta U = 0$ $\Delta H = 0$

$q = -w = nRT \ln \frac{P_1}{P_2} = 1 \times 8.314 \times 300 \ln \frac{1}{4} = -3457.7 \text{ J}$

$w = +3457.7 \text{ J}$

$\Delta S = -nR \ln \frac{P_2}{P_1} = -1 \times 8.314 \times \ln \frac{4}{1} = -11.53 \text{ J/K}$

QUESTION 6: Electrochemistry (20 pts)

A voltaic cell with Ni/Ni^{2+} and Co/Co^{2+} half-cells has the following initial concenrations: $[Ni^{2+}]$=0.80 M; $[Co^{2+}]$ = 0.20 M.

$Co^{2+}(aq) + 2e^- \rightarrow Co(s)$ E° = -0.28 V
$Ni^{2+}(aq) + 2e^- \rightarrow Ni(s)$ E° = -0.25 V

(a) Write the overall reaction that occurs spontaneously under standard conditions and circle the reducing agent in the equation. [**3 pts**]

$Co(s) + Ni^{2+}(aq) \rightarrow Ni(s) + Co^{2+}(aq)$

(b) Write the cell notation for the voltaic cell that incorporates the above reaction. [**2 pts**]

$Co(s) | Co^{2+}(aq) || Ni^{2+}(aq) | Ni(s)$

(c) What is the initial E_{cell}? [**3 pts**]

$E°_{cell}$ = (-0.25 V)-(-0.28 V)= 0.03V

$$E = 0.03 - \frac{0.0592}{2}\log\frac{0.2}{0.8} = 0.048V$$

(d) What is $[Ni^{2+}]$ when E_{cell} reaches 0.03 V? [**4 pts**]

$$E = 0.03 - \frac{0.0592}{2}\log\frac{0.2+x}{0.8-x} = 0.03V$$
$$\log\frac{0.2+x}{0.8-x} = 0$$
$$x = 0.30M$$

$[Ni^{2+}]$ = 0.80M-0.30M = **0.50 *M***

(e) What are equilibrium concentrations of the ions? [**5 pts**]

$$E = 0.03 - \frac{0.0592}{2}\log\frac{0.2+x}{0.8-x} = 0.0V$$
$$\log\frac{0.2+x}{0.8-x} = \frac{2(0.03)}{0.0592}$$
$$x = 0.71163$$

$[Ni^{2+}]$ = 0.80M-0.71163M = **0.088 *M***

$[Co^{2+}]$ = 0.20M+0.71163M = **0.91 *M***

(f) If the cell was run from the initial conditions to equilibrium at 10A, how many hours will it take to reach equilibrium? Assume 1L volume in each half cell. [**3 pts**]

n(electrons) = 2(0.71163 mol)
Q = F× n =96500 C/mol e × 2(0.71163 mol of e) = 137344.6 C
t = 13734.5 s = 228.9 min = **3.82 hrs**

Problem 7: Electrical Properties

Assume that Indium contributes three free electrons per atom to electrical conduction. The density of In is 7.31 g/cm^3 and its resistivity is 8.37 x 10^{-8} Ω·m.

(a) what is the electron mobility of indium? [10 pts]

$$\mu_e = \frac{1}{\rho\, n|e|} = 6.5\times10^{-4}\,\frac{m^2}{V * s}$$

(b) How long would an In wire of 0.1 mm diameter have to be to have a resistance of 50Ω ? [4 pts]

$$L = \frac{7.85\times10^{-9}(50)}{8.37\times10^{-8}} = 4.69\ m$$

(c) Silicon has the following properties:

Calculate the conductivity of Silicon. [4 pts]

$$\sigma = n_i|e|(\mu_e + \mu_h) = 3.74\times10^{-4}\ (\Omega m)^{-1}$$

(d) Which of the following statements is true? Circle the correct answer. [2 pts]

- Electrons and holes contribute equally to conductivity in intrinsic Si
- Electrons contribute more than holes to conductivity in intrinsic Si
- Holes contribute more than electrons to conductivity in intrinsic Si