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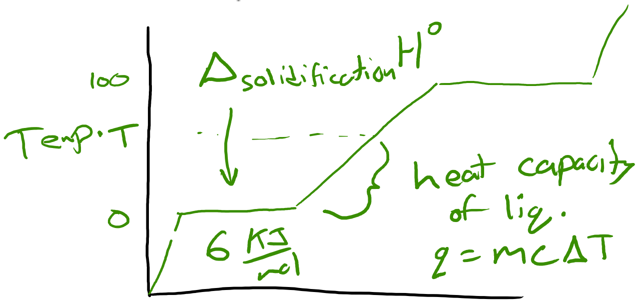
B

Part B.

1. (20) Many ski resorts currently utilize snowmaking systems to make snow even when there is no natural precipitation. There are many important factors involved in effective snowmaking, however in this question we will simplify the system and assume that a fine mist of spherical water droplets is sprayed into the air and allowed to freeze. Make the following assumptions: water droplets having 0.5 mm diameter are created, 15% of the water evaporates, the temperature of the water droplets is equal from surface to interior (high heat transfer).
What is the maximum temperature the water can be maintained at in order for the droplets to remain at 0ºC after freezing completely?
   a. (10) Describe the process, conceptually, that you would follow to solve this problem.



1) Liquid drop forms.
2) 15% of each drop evaporates
3) evaporation cools drop. by $\Delta_{vaporization} H^o$
4) cooling liquid water requires heat. $q = mc\Delta T$
4) drop solidifies.
5) Solidification heats drop by $\Delta_{solidification} H^o = -\Delta_{fus} H^o$
6) snow at 0°C

Liquid water evaporates, cooling the remaining water by enthalpy of vaporization (endothermic), then enthalpy of solidification (exothermic) supplies heat to raise temp.

so $\Delta_{vaporization} H^o$ (15% of mass drop) $= \Delta_{fus} H^o$ (85% of mass drop) $- mc\Delta T$ (85% of drop mass)

Grade H/M/L (9/7/5)

10/10 - addresses all points clearly.

5/10 addresses 1 point with some grasp of concept.

$[=]$ $\frac{J}{\cancel{mol}} \cdot \frac{\cancel{g}}{\frac{\cancel{g}}{\cancel{mol}}}$ $\frac{J}{mol} \cdot \frac{g}{\frac{g}{mol}}$ ① $g \frac{J}{g \cdot K} \cdot K$ ①

b. (6) Calculate the temperature.

$\frac{3}{\text{setl}}$ b. (6) Calculate the temperature.

$$(10^3)0.15\Delta_{vap}H^\circ \frac{m}{MW} = (10^3)\,0.85\,\Delta_{fus}H^\circ \frac{m}{MW} - 0.85\,mc(-T)$$

$$= 0.85(10^3)m\frac{\Delta_{fus}H^\circ}{MW} + 0.85\,mcT$$

① ① ② work

$$T = \left[0.15(10^3)\Delta_{vap}H^\circ\frac{\cancel{m}}{MW} - 0.85(10^3)\Delta_{fus}H^\circ\frac{\cancel{m}}{MW}\right]\cdot\frac{1}{0.85\,\cancel{m}c}$$

$|\ \Delta_{vap}H^\circ = 40.7 \qquad \Delta_{fus}H^\circ = 6.01 \qquad c = 4.184 \qquad MW = 18$

$$T = \left[0.15(10^3)\frac{40.7}{18} - 0.85(10^3)\frac{6.01}{18}\right]\cdot\frac{1}{0.85(4.184)} = 15.6\,^\circ C$$

① K okay

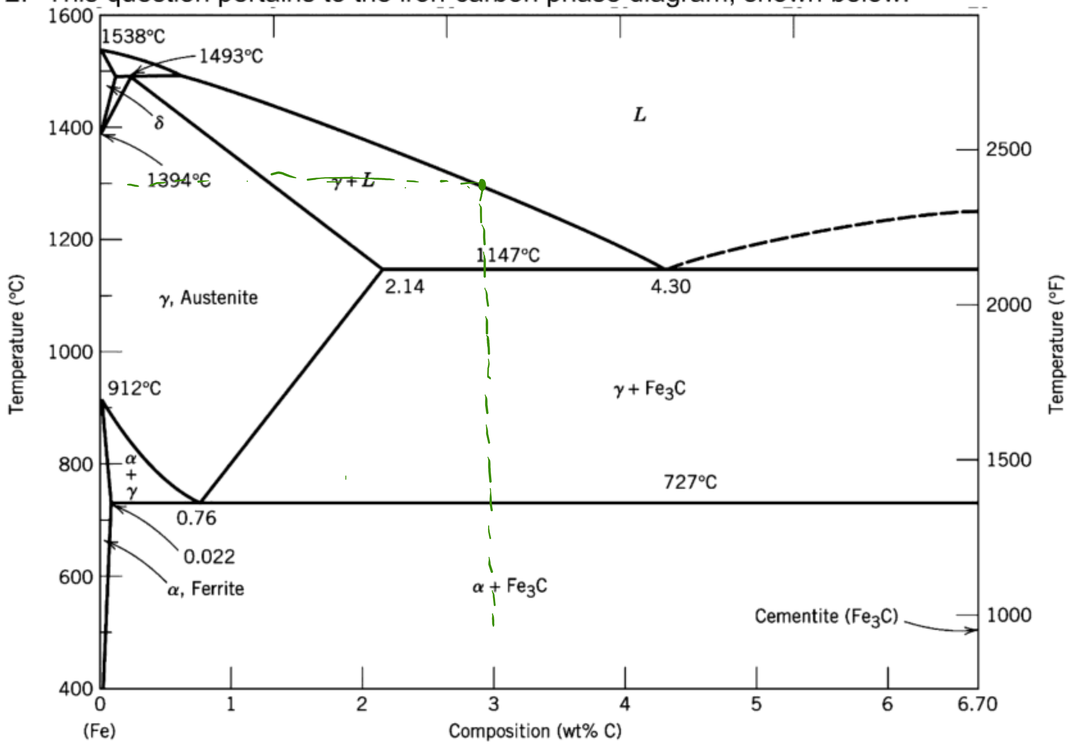
if take full mass of water, not 85%, Then $T = 1.26\,^\circ C$

c. (4) Identify and explain two other factors that would need to be involved in a more detailed solution to this problem.

- surface area to volume ratio increases as drop diameter decreases, so more evaporation with smaller drops.
- heat transfer to air must be considered
- Nucleating agents will allow higher temp.
- chance of drop containing a nucleating agent will decrease with decreasing drop diameter.

② each, any correct & reasonable.

2. This question pertains to the iron-carbon phase diagram, shown below.



a. For a sample of 0.25 wt% C steel at 1200°C, what phase or phases will be present, and what will be the composition of each phase, in wt% C? (2)

① γ @ 0.25 wt% ①

b. For a 1 kg sample of 1.25 wt% C steel at 728°C, what will be the mass, in grams, of α ferrite? (2)

0 g ②

c. For a 1 kg sample of 0.75 wt% C steel at 728°C, what will be the mass, in grams, of α ferrite? (2)

① $\left\{\frac{0.76-0.75}{0.76-0.022}\right\} \times 1000\,g = 13.6\ g$ ①

d. For a 1 kg sample of 4.5 wt% C cast iron at 726°C, what will be the mass, in grams, of carbon that is present as point defects in iron? (2)

$m_\alpha \cdot C_\alpha \;\Big|\; \frac{6.7-4.5}{6.7-0.022} \cdot 1000 \cdot 0.022 = 7.2\ g$ ① ①

e. For a sample of 3 wt% C cast iron, what will be the minimum temperature to which this sample would need to be heated to ensure no solid remained? (2)

1270 – 1330 °C

②

3. (10) A footbridge is produced from concrete. The bridge has a rectangular cross-section with height 20 cm and width 100 cm and is designed to cross a span of 3 m. Assume a typical value for the bending strength of concrete of 0.5 MPa, and an acceleration due to gravity of 9.8 N/kg.

   a. (5) What would be the maximum mass, in kg, that could be supported at the middle of this bridge?

$\sigma_{3\text{-pt}} = \frac{3FL}{2bd^2}$ (1)

$F = ma$ (1)

$m = \frac{F}{a}$

$b = 1\ m$ $\quad L = 3\ m$

$d = 0.2\ m$ $\quad a = 9.8\ \frac{N}{kg}$

$\sigma = 0.5(10^6)\ Pa$

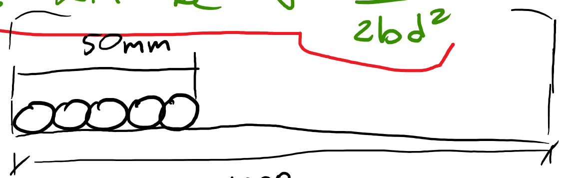
$\Rightarrow F = \frac{2bd^2\sigma}{3L}$ $\quad m = \frac{2bd^2\sigma}{3La}$ (1) work.

$m = \frac{2 \cdot (0.2)^2 \cdot 0.5(10^6)}{3 \cdot 3 \cdot 9.8} = 454\ Kg$ (1) (1)

   b. (5) Another bridge was built having the same dimensions, however with 5 lengths of steel rebar (reinforcing bar) embedded along the lower surface, aligned with the long axis, of the beam. Assume that the rebar has a 10 mm diameter and a yield strength of 500 MPa, that the entire tensile stress on the lower surface of the beam is supported by the rebar and none by the concrete. What would be the maximum mass, in kg, that could be supported at the middle of this bridge without the rebar experiencing any plastic deformation?

max stress will be $\sigma = \frac{3FL}{2bd^2}$ (2)

supported by 5 cylinders. (1)



supported on 5% of width

$m = \frac{2bd^2}{3La}\sigma \cdot 0.05 \simeq 2(10^4)\ Kg$ (1)

estimate. (1)

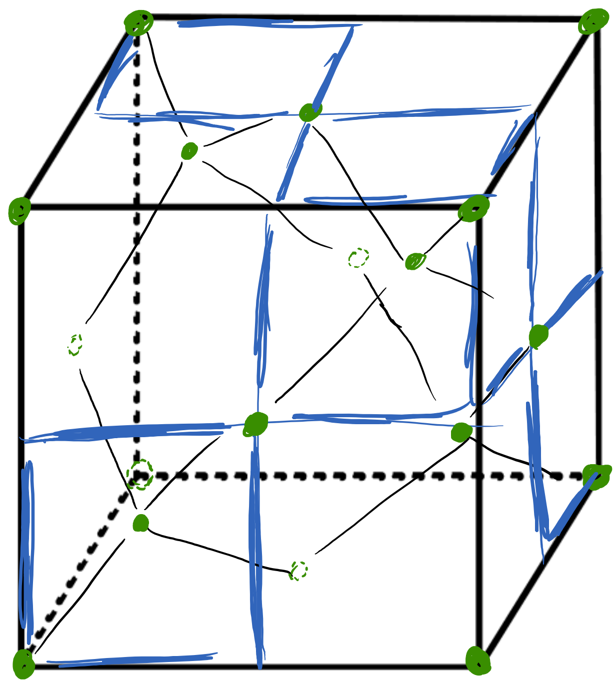
accept wide range.

4. (10) This question pertains to the crystalline structure of silicon.

a. (5) Name the crystal structure of crystalline silicon and in the unit cell below sketch the structure.

Diamond cubic (1)

atom positions
corners. (1)
faces (1)
tetrahedral sites. (2)



b. (5) If the lattice parameter for solid crystalline silicon is 5.4×10^{-10} m, calculate the theoretical density of silicon.

(1)

$$\rho = \frac{nA}{V_c \cdot N_A} \quad \Big| \quad n = 8 \;(1) \quad A = 28.068 \quad N_A = 6.022(10^{22}) \quad V_c = a^3 \;(1) \quad \Big| \quad a = 5.4(10^{-10})\,m$$

$$= \frac{8 \cdot}{[5.4(10^{-10})]^3 \cdot 6.022(10^{23})} = 2.37(10^6)\,\frac{g}{m^3} = 2.4\,\frac{g}{cm^3}$$

or

$$\underbrace{2400}_{(1)}\;\underbrace{\frac{kg}{m^3}}_{(1)}$$

5. (10) Methane is a widely used fuel for residential heating systems.
   a. (2) In the box below write the balanced chemical equation for the combustion of 1 mol of gaseous methane(CH_4) with 2 mols of gaseous oxygen to form carbon dioxide gas and water vapour.

$$\boxed{CH_{4(g)} + 2\,O_{2(g)} \rightarrow CO_{2(g)} + 2H_2O_{(g)}}$$ 2

   b. (2) Determine the standard combustion enthalpy for one mol of gaseous methane.

$$\Delta_{comb.}H = \underbrace{2(-241.8) - 393.5 + 74.81}_{1} = \underbrace{-802.3\ \text{kJ}}_{1}$$

   c. (6) Assuming all of the heat from the combustion of 1 mol of methane goes to heating a 45 m^2 room with 3 m ceilings, what will the resulting temperature change be to the room? Assume a density of air of 1.225 kg/m^3.

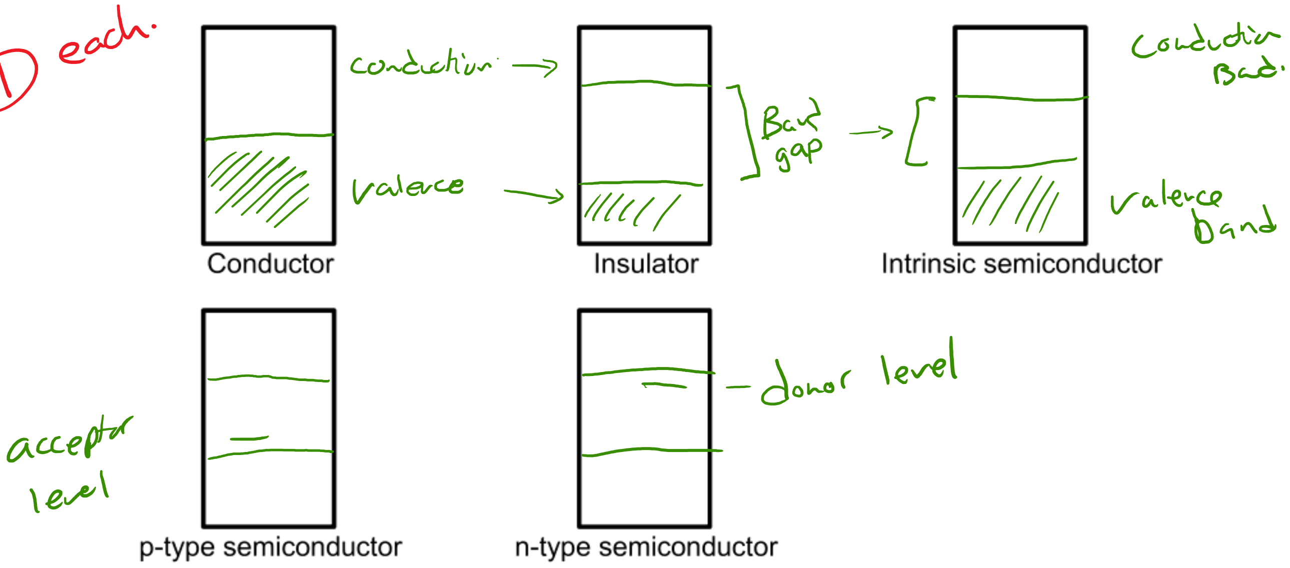
$$q = mc\Delta t = \left(\underbrace{45 \cdot 3\ m^3}_{1} \cdot \underbrace{1.225\ \frac{kg}{m^3}}_{1}\right) \cdot \underbrace{1\ \frac{kJ}{kg \cdot K}}_{1} (\Delta T)$$

answer.

$$\underbrace{\Delta T = \frac{802.3}{45 \cdot 3 \cdot 1.225}}_{\text{work } 1} = \underbrace{4.85\,^\circ C}_{1}\ 1$$

6. (5) This question pertains to the band theory of solids. In the boxes below, sketch the generalized band structure for conductors, insulators, and intrinsic semiconductors, p-type and n-type semiconductors. On your sketches, label all important features, including donor and acceptor levels.

(1) each.



7. Correctly identify each of the following by indicating the matching number in the box beside each description. Numbers may be used more than once. (1 each)

(1) each

1. N-type
2. P-type
3. Point defect
4. Linear imperfection
5. Interfacial defect
6. Volume defect
7. 0.414
8. 0.225
9. 0.732
10. Conduction band
11. Valence band
12. Increase
13. 4
14. 6
15. 8
16. 12
17. Chain orientation
18. Increasing molecular weight
19. Cross-linking
20. Intrinsic

a. The crystalline imperfection responsible for plastic deformation in metals.

4

b. Carbon present in iron at compositions above 0.022 wt% carbon.

6

c. The coordination number of cations in the rock salt crystal structure.

14

d. The strengthening mechanism in polymers chiefly responsible for continued load bearing beyond necking.

17

e. The coordination number of atoms in the HCP crystal structure

16

f. The change that will occur to the strength of a metal when grain size is decreased

12

g. The donor level is close to this in a n-type semiconductor.

10

h. The minimum size of a cation as a fraction of the anion size for a coordination number of 6.

7

i. Arsenic (As) added as a dopant to silicon will create this type of semiconductor.

1

j. Arsenic (As) added as a dopant to silicon will create this type of crystalline imperfection.

3