Suppose that liquid nickel is undercooled until homogeneous nucleation occurs. Calculate:

a. the critical radius of the nucleus required; and
b. the number of nickel atoms in the nucleus.

Assume that the lattice parameter of the solid FCC nickel is 0.356 nm.

The critical radius is found from equation 9-2 (5th edition)

\[ r^* = \frac{2\sigma_i T_m}{\Delta H_f \Delta T} \]

We can find the values to plug in from the table

\[ r^* = \frac{2 \times 255 \times 10^{-7} J/cm^2 \times (1453 + 274)K}{2756 J/cm^3 \times 480K} = 6.65 \times 10^{-8} cm \]

We find the corresponding number of Ni atoms by first finding the volume of the nucleus
\[ V_{\text{nucleus}} = \frac{4}{3} \pi r^3 \]

\[ V_{\text{nucleus}} = \frac{4 \pi \left(6.65 \times 10^{-8}\right)^3}{3} = 1.2318 \times 10^{-21} \text{cm}^3 \]

and finding the volume of a unit cell... and dividing... which gives us the number of unit cells

\[ V_{\text{cell}} = a_0^3 = \left(3.56 \times 10^{-8} \text{cm}\right)^3 = 4.5118 \times 10^{-23} \text{cm}^3 \]

\[ N_{- \text{cells}} = \frac{V_{\text{nucleus}}}{V_{\text{cell}}} = 27.3 \text{cells} \]

Notice that the lattice parameter used is not the same as that reported in the textbook appendix. This is because the textbook values are at room temperature... but nucleation occurs at the melting point... in this case 1453 \text{C}.

Now to find the number of atoms we need to realize that the FCC structure contains 4 atoms per unit cell

\[ N_{- \text{atoms}} = \frac{4 \text{atoms}}{\text{cell}} \times 27.3 \text{cells} = 109 \text{atoms} \]

2) Suppose that solid nickel was able to nucleate homogeneously with an undercooling of only 22 \text{0C}. How many atoms would have group together spontaneously for this to occur:

Assume that the lattice parameter of the solid FCC nickel is 0.356 nm.

This problem is similar to problem one. The only difference is the amount of undercooling

\[ r^* = \frac{2 \sigma_{sl} T_m}{\Delta H_f \Delta T} \quad \text{and} \quad r^* = \frac{2 \times 255 \times 10^{-7} J/\text{cm} \times (1453 + 274) K}{2756 J/\text{cm}^3 \times 22 K} = 145.18 \times 10^{-8} \text{cm} \]

\[ V_{\text{nucleus}} = \frac{4}{3} \pi r^3 = \frac{4 \pi \left(145.18 \times 10^{-8}\right)^3}{3} = 1.282 \times 10^{-17} \text{cm}^3 \]

\[ V_{\text{cell}} = a_0^3 = \left(3.56 \times 10^{-8} \text{cm}\right)^3 = 4.5118 \times 10^{-23} \text{cm}^3 \]

\[ N_{- \text{cells}} = \frac{V_{\text{nucleus}}}{V_{\text{cell}}} = 2.84 \times 10^5 \]

\[ N_{- \text{atoms}} = \frac{4 \text{atoms}}{\text{cell}} \times 2.84 \times 10^5 \text{cells} = 1.136 \times 10^6 \text{atoms} \]
3) Calculate the fraction of solidification that occurs dendritically when iron nucleates
   a. at 10°C undercooling
   b. at 100°C undercooling
   c. homogeneously
      The specific heat of iron is 5.78 J/cm³°C.

      The dendritic fraction can be estimated with
      \[ f = \frac{c\Delta T}{\Delta H_f} \]
      for 10 degrees of undercooling
      \[ f = \frac{5.78 J/cm^3 \cdot °C \times 10°C}{1737 J/cm^3} = 0.0333 \text{ or } 3.3\% \]

      Similarly for 100 degrees of undercooling
      \[ f = \frac{5.78 J/cm^3 \cdot °C \times 100°C}{1737 J/cm^3} = 0.333 \text{ or } 33\% \]

      The amount of undercooling for homogeneous nucleation is 420°C (Table 9-1)
      \[ f = \frac{5.78 J/cm^3 \cdot °C \times 420°C}{1737 J/cm^3} = 1.4 , \text{ which is clearly ridiculous. It says that 140% of the iron is dendritic. We should interpret this result as all (100%) of the iron is dendritic} \]

4) What are the two steps encountered in the solidification of molten metals? As a function of time, can they overlap with one another?
   The two steps are nucleation and growth… and yes… they can overlap each other.

5) During solidification, specific heat of the material and the latent heat of fusion need to be removed. Define each of these terms.
   The specific heat is the heat necessary to change the temperature of the material. The latent heat is the heat necessary for a phase change. In particular, the latent heat of fusion is the heat that needs to be removed to go from the liquid phase to the solid phase.

6) Describe under what conditions we expect molten metals to undergo dendritic solidification.
   Molten metals undergo dendritic solidification when the melt is undercooled. This happens when the material is not adequately inoculated.

7) Describe under what conditions we expect molten metals to undergo planar front solidification.
   Planar front solidification occurs when there are plenty of places for nucleation to occur… in other words when the melt is well inoculated. In this case there is no undercooling.
8) Analysis of a nickel casting suggests that 28% of the solidification process occurred in a dendritic manner. Calculate the temperature at which nucleation occurred. The specific heat of nickel is 4.1 J/cm³ °C.

Recalling that the dendritic fraction can be approximated as

\[ f = \frac{c\Delta T}{\Delta H_f} \]

we can calculate the amount of undercooling

\[ \Delta T = \frac{f \cdot \Delta H_f}{c} = \frac{0.28 \cdot 2756 J/cm^3}{4.1 J/cm^3 \cdot °C} = 188 °C \]

Since the melting point of Nickel is 1453 °C, the temperature at which nucleation occurred is

\[ T_{nucleation} = T_{melting} - T_{undercooling} \]

\[ T_{nucleation} = 1453 - 188 = 1265 °C \]

9) Consider this photograph of an aluminum alloy

![Image of aluminum alloy](image)


a) Estimate the secondary arm spacing and

b) the local solidification time for that area of the casting.

This is tricky, since it will depend on what size the image is when you print it out. Find a place where there are several arms in a row, measure the length of a row of 5 or 6 arms, then divide by the number of arms.

16 mm / 6 arms = 2.67 mm
9 mm / 5 arms = 1.80 mm
13 mm / 7 arms = 1.85 mm
18 mm / 9 arms = 2.00 mm average = 2.08 mm = 0.208 cm
Dividing by the magnification of ×50:
SDAS = 0.208 cm / 50 = 4.16 × 10⁻³ cm

(b) From Figure 9–6, we find that local solidification time (LST) = 90 s

10) What is meant by the terms total and local solidification time?
Total solidification time is the amount of time it takes for the melt to solidify starting from the time it is poured into the mold

Local solidification time is the time required for complete solidification, starting from when the first crystal of solid forms

11) Consider the cooling curve below.

![Cooling Curve](image)

**Figure 9-27** Cooling curve for Problem 9-45.

Determine:

a) the pouring temperature \( \text{approximately 475 C} \)
b) the solidification temperature \( \text{approximately 330 C} \)
c) the superheat The amount of superheat is the difference between the pouring temperature and the solidification temperature \( 475 - 360 = 145 \) degrees of superheat
d) the cooling rate, just before solidification begins The cooling rate is the slope of the line \( (475 - 360)/170 \) min = 0.7 degrees/min
e) the total solidification time \( \text{approximately 470 minutes} \)
f) the local solidification time \( (470 - 170) = 300 \) minutes
g) the probable identity of the metal Since the melting temperature is approximately 330 we can go to Appendix A and find a metal with a similar melting point. Cadmium melts at 321 C and Lead melts at 327 C – either would be a good guess. Better melting point information would allow us to select between the two.
h) Is the solidification process homogeneous or non-homogeneous? Heterogeneous, (non-homogeneous) because there is no undercooling
12) Consider the cooling curve below.

![Cooling Curve](image)

**Figure 9-28 Cooling curve (for Problem 9-46).**

Determine:

i) the pouring temperature  \(900 \, ^\circ\text{C}\)

j) the solidification temperature  \(420 \, ^\circ\text{C}\)

k) the superheat  \((900-420)=480 \, ^\circ\text{C}\)

l) the cooling rate, just before solidification begins  \((900-420)/1.6 \, \text{min} = 312 \, \text{degrees} \, ^\circ\text{C/min}\)

m) the total solidification time  \(9.7 \, \text{min}\)

n) the local solidification time  \((9.7 - 1.6)=8.1 \, \text{min}\)

o) the probable identity of the metal  Since the melting point is approximately 420 \, ^\circ\text{C}, a good guess would be Zn

p) Is the solidification process homogeneous or non-homogeneous?  Homogeneous, because there is undercooling

13) What is a riser?  Why should it freeze after the casting?

A riser is a reservoir of molten metal that connects to the casting. If it freezes after the casting it can provide liquid metal to compensate for shrinkage.

14) How can gas porosity in molten alloys be removed or minimized?

Gas porosity is caused by bubbles of gas trapped within a casting during solidification, caused by the lower solubility of the gas in the solid, compared with that in the liquid. There are a number of ways to minimize the problem. Keeping the liquid temperature low will prevent the unwanted gas from dissolving in the first place. This can also be accomplished by working in a vacuum chamber. You could add materials that will react with the gas and form a solid. or you can remove the gas by bubbling a third gas through the melt in which the unwanted gas is more soluble.

15) Define the terms brazing and soldering

Both processes involve joining two pieces of metal, using a filler which is a different material. The filler acts like a glue. Brazing occurs at temperatures above 450 \, ^\circ\text{C} and soldering occurs at temperatures below 450 \, ^\circ\text{C}. In neither case does the base metal melt.

16) What is the difference between fusion welding and brazing and soldering?

In fusion welding, unlike brazing and soldering, there is no filler. Some of the base metal is melted to act as the ‘glue’ to join the pieces
17) What is a heat affected zone?

The heat affected zone is the portion of the base metal in a weld that was heated enough to cause a change in properties, such as stress relief, recrystallization and grain growth.

18) Explain why, while using low intensity heat sources, the strength of the material in weld regions can be reduced.

Creating a weld with a low intensity heat source requires more time …. and therefore the surrounding material heats up, which causes a large heat affected zone. One result is that the strength of the material is decreased due to recrystallization an grain growth. Welding with a high intensity source can generally be accomplished more quickly, and limits the heat affected area.

19) Why do laser and electron-beam welding processes lead to stronger welds?

See above