



12. Set Phasers to Fun: Phase Equilibrium and Phase Diagrams



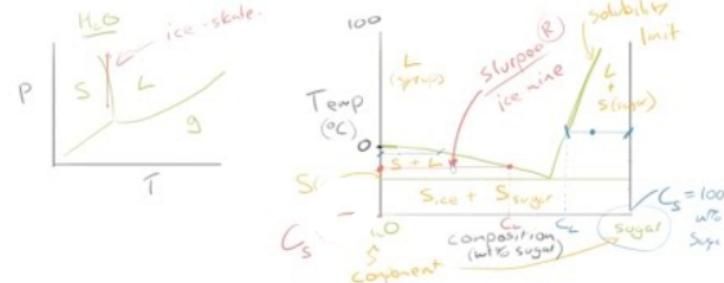
LEARNING GOALS

Learning Objectives

1. Identify the two-phase regions on the water-sugar or the iron-carbon phase diagram
2. Determine the phase(s) present under equilibrium conditions given a set of temperature and composition
3. Evaluate the weight fraction of a given phase within a two-phase region of either the water sugar or the iron carbon phase diagram
4. Use a binary phase diagram to determine the following for a given overall composition and temperature: what phases are present, the composition of each phase, the amount of each phase
Contrast the amount of a phase in a system with the composition of that phase
5. Derive the lever rule for determining the amount of a phase present within a two-phase region



Getting Started



[Link to this video on U of T servers.](#)

Okay, I know the title of this chapter is terrible. The worst of the worst dad jokes, but I'm laughing right now, and I just had to. Let me know if you think of a better title. Phase diagrams can be a very



challenging topic to wrap your head around when you are first beginning to learn about them. Try not to let yourself get discouraged. The sections that follow should help you to understand this potentially challenging and frustrating topic.

The Temperature Axis

In materials science the ordinate, or "y-axis", is normally used to convey the temperature. Lets begin by considering a very simple one-dimensional phase diagram that most people will be familiar with already. It is the phase diagram for pure water at varying temperature and is shown in Figure 1.

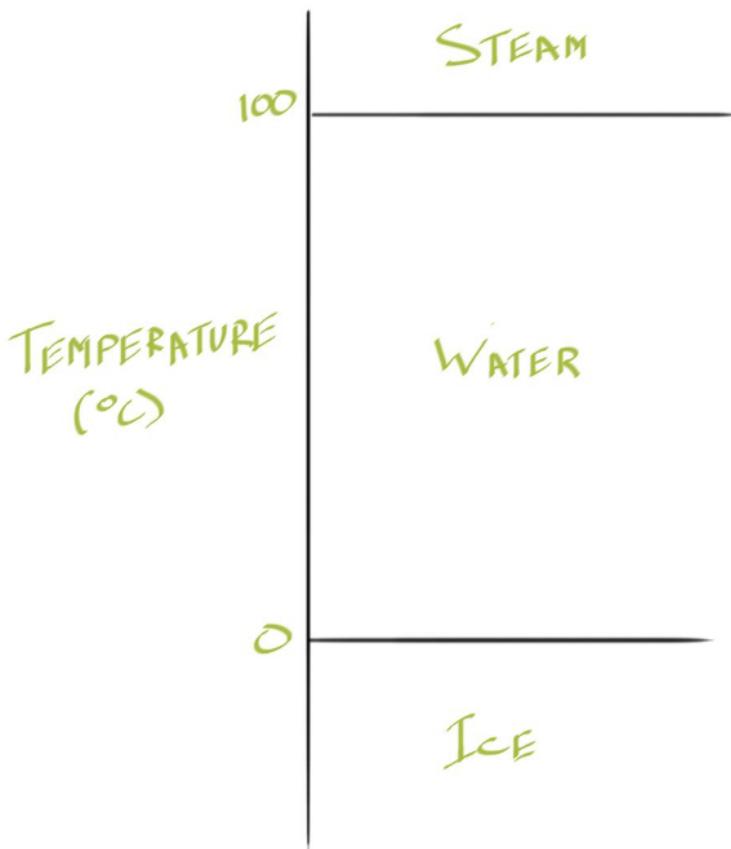


Figure 1: A phase diagram for pure water showing only the temperature axis. Since there is only one component, water, this could be called a unary phase diagram. You are likely familiar with the phase transformations that occur at 0°C and 100°C, defining the ranges of temperature where water is present as a solid, a liquid, and a gas.

As you can see, this simple phase diagram tells us that water below 0°C will exist as ice, between 0°C and 100°C it will form liquid water, and above 100°C it will exist as water vapour.

These phases at these specific temperature ranges are the phases that result in the system being at the lowest energy level (the most thermodynamically stable). An analogy that you will be familiar with is that of mechanical stability (instead of thermodynamic stability).

Consider a ball held at some height above the floor and then released. If you allow this system to achieve equilibrium, the ball will fall to the floor and eventually come to rest (mechanical equilibrium).

achieve equilibrium, the ball will fall to the floor and eventually come to rest (mechanical equilibrium) on the floor because this represents a lower potential energy.

The Composition ("compo - si - shun") axis

Now lets consider what would happen if we added another dimension to this phase diagram. We could add an "x-axis" (or abscissa) that would represent the amount of sugar that we are adding to water (think of making a cup of coffee). This is what I've done in Figure 2.



Figure 2: A schematic two-component (binary) water-sugar phase diagram. At sufficiently high sugar concentrations (compositions) we know from experience that solid sugar will persist, in equilibrium with the sweet water.

This axis would be called the composition axis since it would indicate the amount of the second component, sugar, that we are adding to our first component, water. You see, the term composition derives from the word component (in fact, with my students I like to intentionally mis-pronounce composition to ensure this is clear, as I indicate in the heading of this section). For simplicity, lets restrict the temperature axis to only include the area where water is liquid (and not where it is a gas or a solid).

I haven't yet added values to the composition axis, but you likely know that if we add enough sugar, eventually we won't be able to dissolve any more. In fact, you've seen this if you've ever seen a jar of honey that has sat on the shelf for several months and sugar crystals have precipitated out. Thinking of honey is a good way to begin to understand phase diagrams because you may also know that if you

want to get rid of these sugar crystals in a jar of honey you need to heat the honey up. This means that we should be able to dissolve more sugar in hot water than in cold water, and of course, this is true.

Saturation: The Solubility Limit (or Solvus)

As you may know, this maximum amount (limit) of solute that can be dissolved in a solvent is known as the solubility limit, or the solvus. Now we can add this line to our phase diagram, remembering that we know it must increase (towards higher compositions) as the temperature is raised. That is, it will slope to the right.

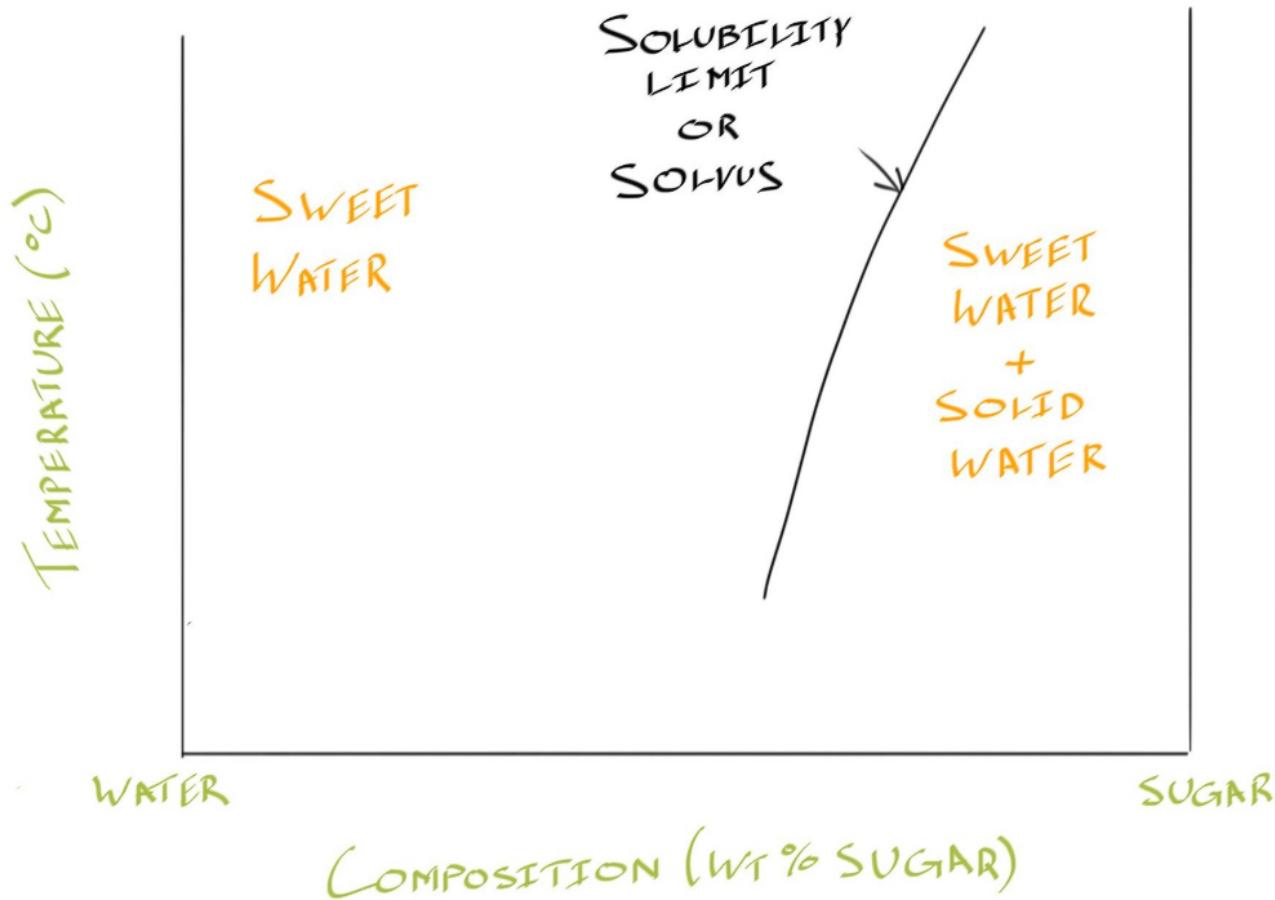


Figure 3: A schematic two-component (binary) water-sugar phase diagram. At sufficiently high sugar concentrations (compositions) a phase boundary, the solubility limit exists, above which solid sugar will persist, in equilibrium with the sweet water.

You will notice that our composition axis is still without actual values, but that is fine for our purposes. We've got the solvus generally in the right place, with the right slope. Hopefully this is making some sense to you.

Equilibrium Phase Diagrams

Generally speaking, most phase diagrams in materials science are so-called "equilibrium phase diagrams." This means that the phases that are indicated are the ones that would form if the reaction

was allowed to run for as long as it needed to achieve equilibrium. Another way of saying this is if a phase diagram tells us that a tea-spoon of sugar should dissolve in hot coffee it does not tell us how long we need to stir the coffee for this to happen.

Some Terminology

It is worthwhile to introduce some terminology here. First, I should really address the issue of what a phase is. A phase is part of the system we are looking at that looks and behaves the same way. There are no separate parts in a single phase region. It all looks and behaves the same. For example, if you add sugar to your coffee and stir it it forms a single phase, namely sweet water. All of the sweet water looks and behaves the same as any other bit of the sweet water, because it is all the same phase. On the other hand, if we added sand to our coffee we would find that there were two phases, namely water and solid sand. The water looks and behaves differently from the sand. Now that we understand what a phase is, at least as opposed to a solution, we can take a look at the various regions that we encounter on a phase diagram. We refer to areas on a phase diagram as regions or fields, so we can describe the area labelled as Sweet Water as a single-phase region or single-phase field, and the area labelled as Sweet Water + Solid Sugar as a two-phase region or two-phase field. Remember that an area on a phase diagram bounded by lines, or phase boundaries is nothing more than a bunch of combinations of temperature and composition ("coordinates") that have the same phase or phases as the stable phase.



"Coordinates" on a Phase Diagram

You probably won't hear anyone else using this terminology, but I find it very useful to refer to all the possible combinations of temperature and composition on a phase diagram as coordinates. This is useful when first learning about phase diagrams because you are already familiar with the concept of Cartesian coordinates and it reminds you of the simple fact that at its most basic level, a phase diagram is nothing more than a graphical depiction of the equilibrium phases for all the possible combinations of temperature and composition.



How Very Techie - A "Binary" Phase Diagram

Well, its not ones and zeroes, but a binary phase diagram is one that has two components: this is what the prefix "bi-" prefix refers to. A unary system would have only one component (such an example was given with pure water in the introduction to phase diagrams) and a ternary system would have three components. Ternary phase diagrams are quite common, although it is also common to fix the composition of one component in order to create a so-called *pseudo-binary* system. Anyway, binary systems are important and useful. Lets begin by considering a simple binary phase diagram involving two components A and B.

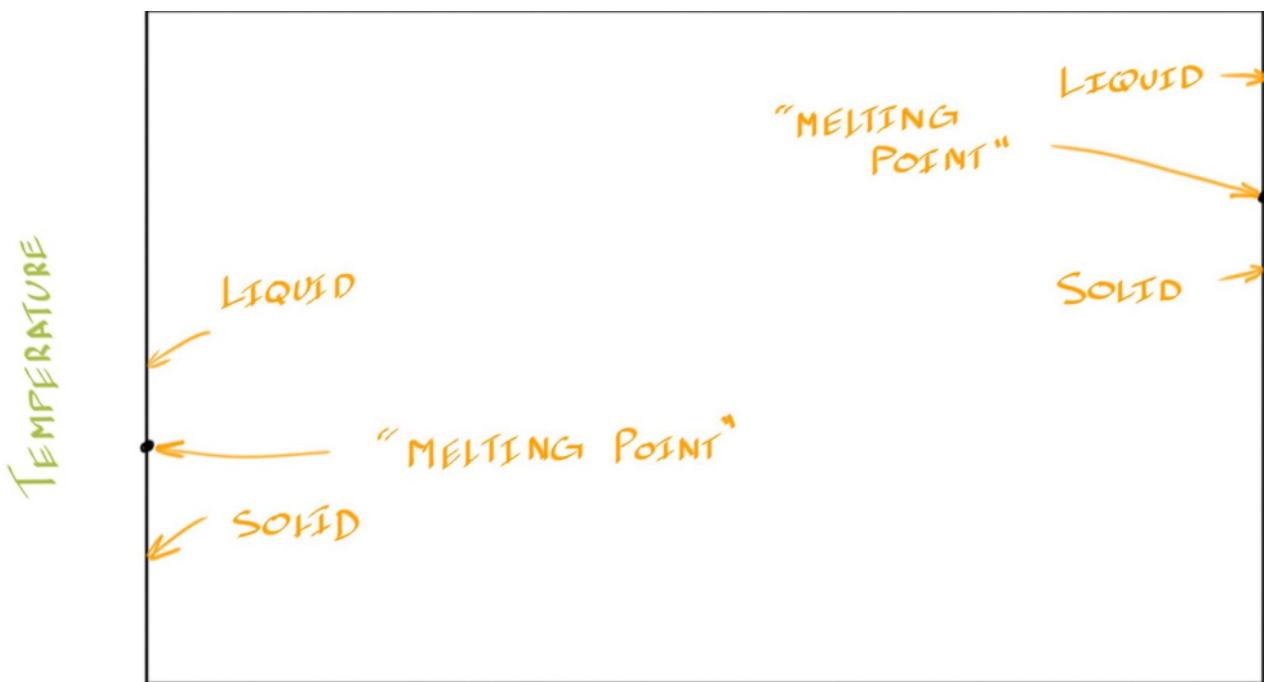


Figure 4: A schematic binary isomorphous phase diagram for the hypothetical two-component A-B system, showing only the melting points of the pure components.

In Figure 4, you can see that I've identified the melting points of components A and B. But what happens at compositions other than pure A or pure B? Where does melting occur for a 50:50 mix of A and B? It turns out that there is actually a range of temperatures over which the process of melting (or solidification if you're decreasing the temperature) normally occurs, and if we're considering an *isomorphous*^① system, it will look something like this.

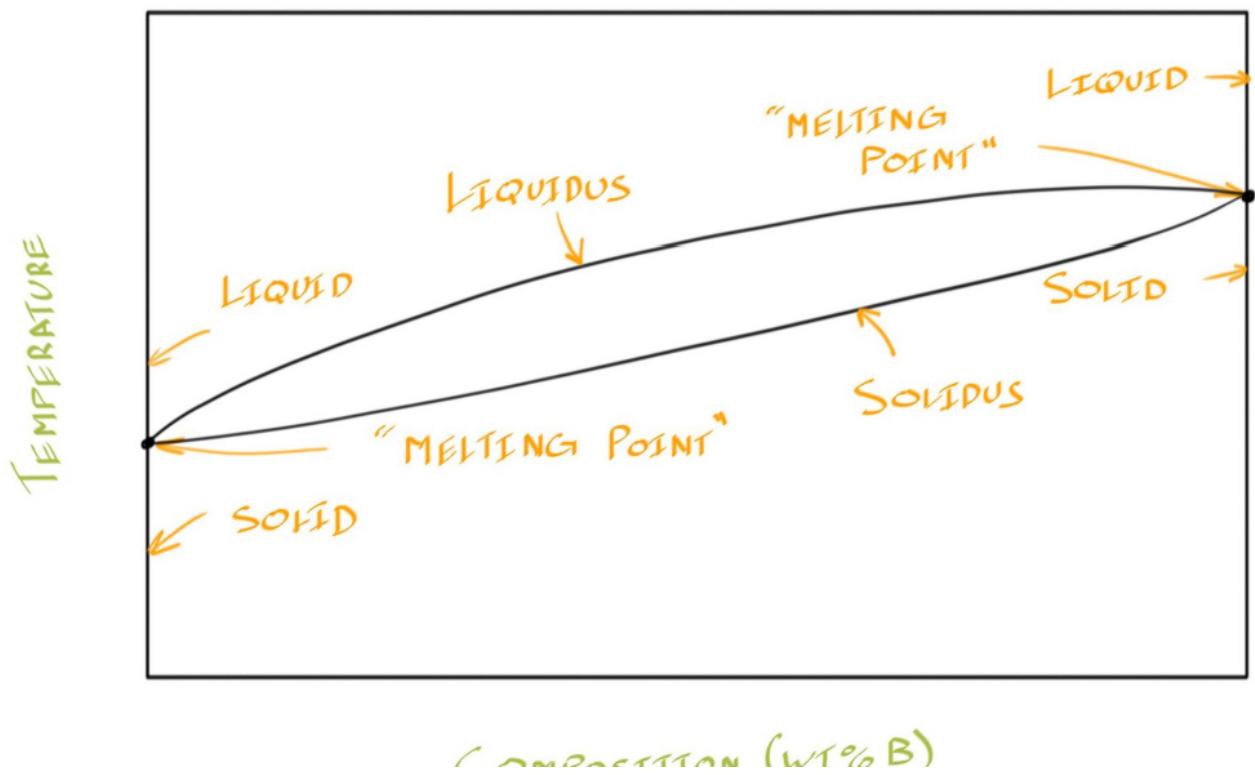


Figure 5: A schematic binary isomorphous phase diagram for the hypothetical two-component A-B system, showing the liquidus and solidus.

An "Isomorphous" Phase Diagram

The term isomorphous roughly means that there is only one structure in the solid phase. Notice that in Figure 5 there is one area for the solid phase, with no phase boundaries breaking it up.

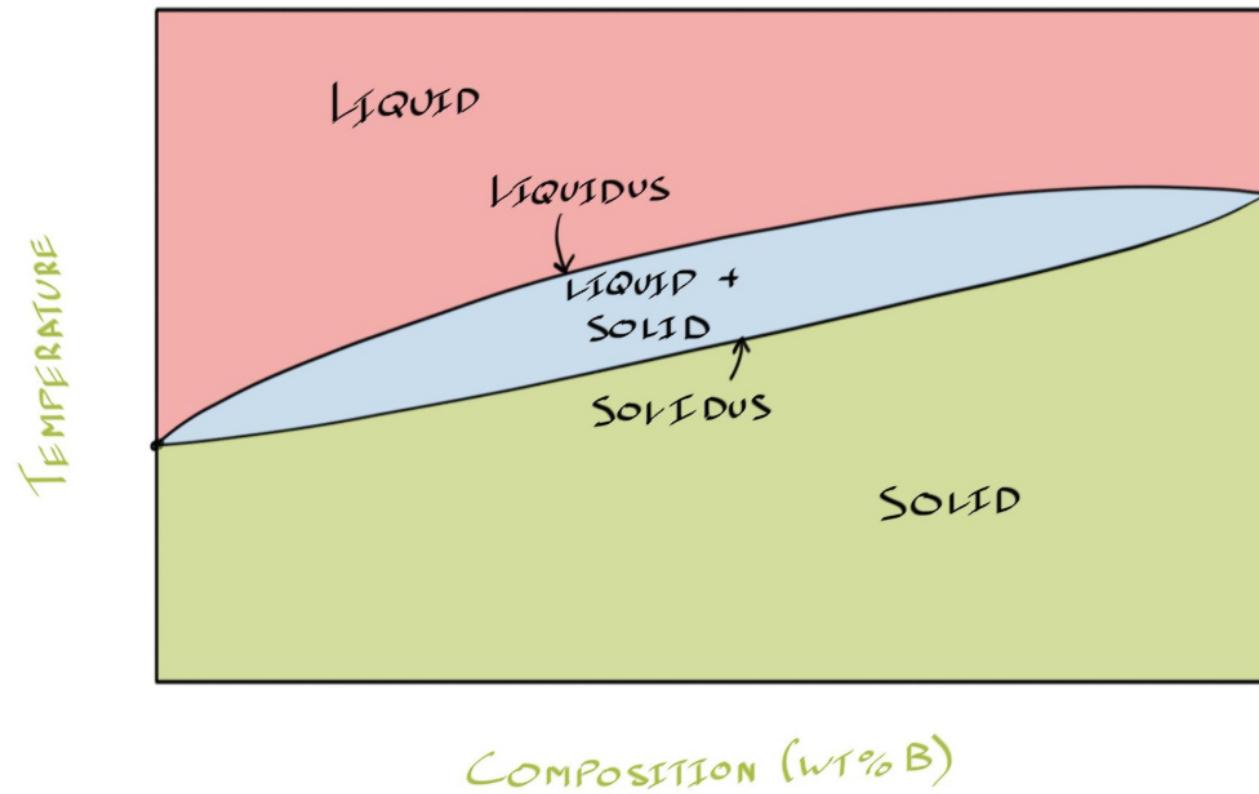


Figure 6: A schematic binary isomorphous phase diagram for the hypothetical two-component A-B system, showing the liquidus and solidus. The single phase solid region has been shaded in green and the single phase liquid region has been shaded in red, for clarity. (Note that phase diagrams are not normally colored.)

Referring to Figure 6 you'll notice that I have shaded the single phase solid region in green, to make this obvious. Another way of saying this is that we can dissolve as much component B in component A as we want without forming a second phase. Note that this is different from what we saw with water and sugar. Remember in the sugar-water system that when we added enough sugar to water we reached a solubility limit and the excess sugar formed a second phase. If you took a close look (with a microscope, for example) at the solid phase at a number of different compositions you would find that it looked generally the same in terms of its structure.

The Two-Phase Region

Lets turn our attention now to the little region between the liquidus and the solidus. What's going on here?

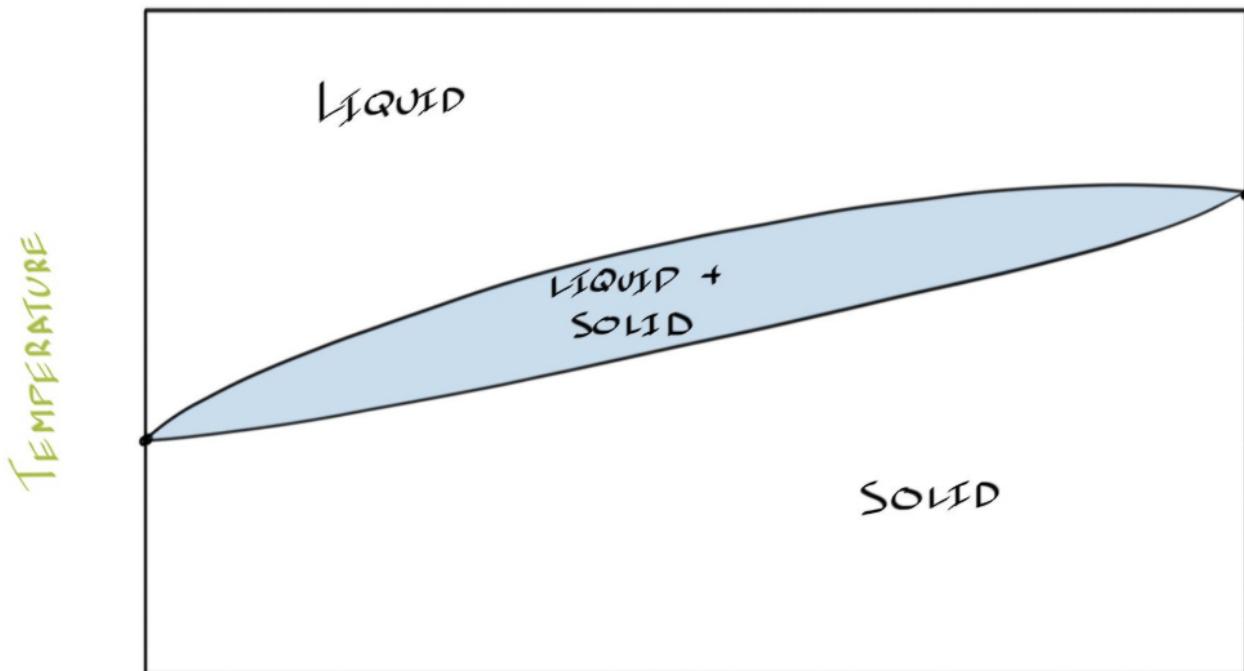


Figure 7: A schematic binary isomorphous phase diagram for the hypothetical two-component A-B system, showing the liquidus and solidus. The two-phase region has been shaded in blue.

Well, the phase diagram is telling us that for any combination of temperature and composition points that reside inside the little blue area in Figure 7 our system will contain two phases in equilibrium, namely the liquid and the solid.

You could say that the system was partly melted, or partly solidified in that region. And it would stay that way forever if you didn't change the temperature or composition.

The Compositions of Each Phase

If we had a system of some composition between pure A and pure B and we heated it into the two-phase region (shaded blue), could we determine the composition (recall that I would pronounce this "compo-si-shun")?



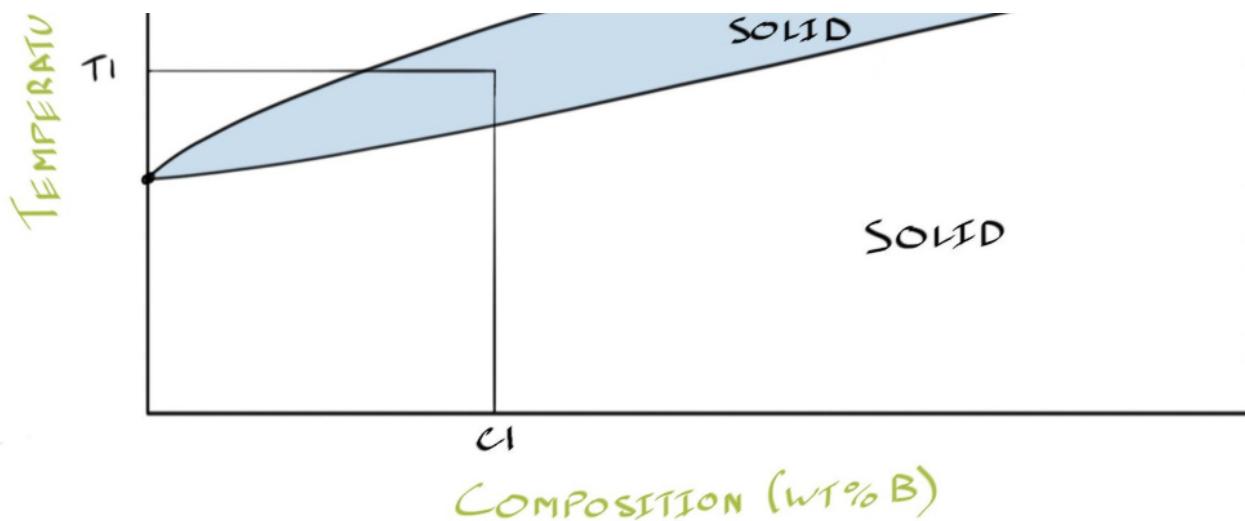


Figure 8: A hypothetical alloy of composition C1, heated to a temperature T1 is shown to exist as two-phases on this schematic binary isomorphous phase diagram for the two-component A-B system.



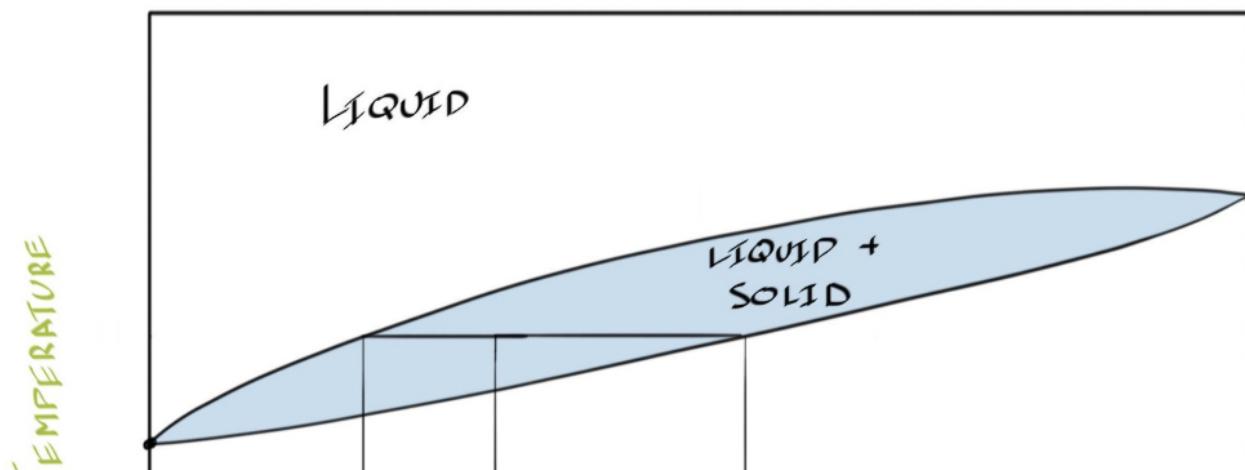
That is, how much component A and component B are in each of the liquid and the solid. First, we would need to identify the temperature and composition on the phase diagram to confirm we were in the two phase region, as shown by the point at composition C1 and temperature T1 in Figure 8.

The Tie-Line

On a binary phase diagram, a tie line is simply a fancy term for a horizontal line spanning a two-phase region from a phase boundary (line) on one side to the phase boundary on the other side. Drawing a tie line from a given temperature and composition point does several things:

1. Tells us what phases are in the two-phase region
2. Tells us how much of each component is in each of the two phases (that is, the composition)
3. Forms the basis for our lever rule calculation, derived and explained in the next section.

As shown in Figure 9 a tie line from our C1 and T1 point in this example intercepts the liquidus (liquid phase boundary) on the left and the solidus (solid phase boundary) on the right, confirming that we have two phases: a liquid and a solid phase.



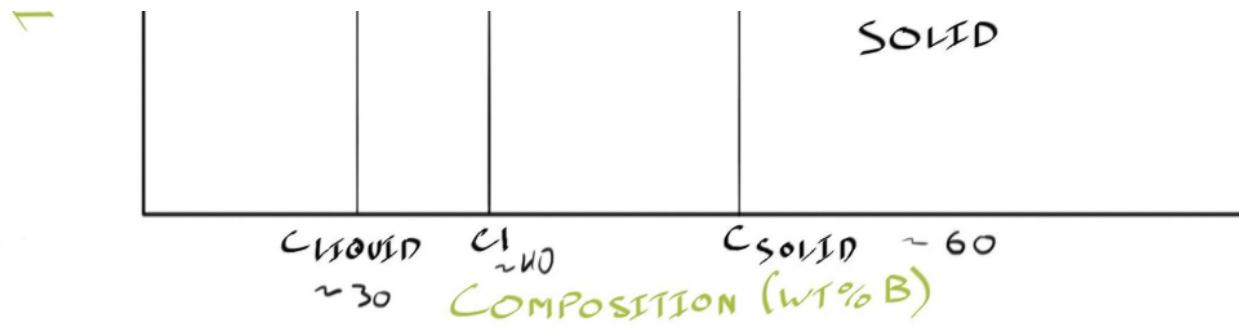


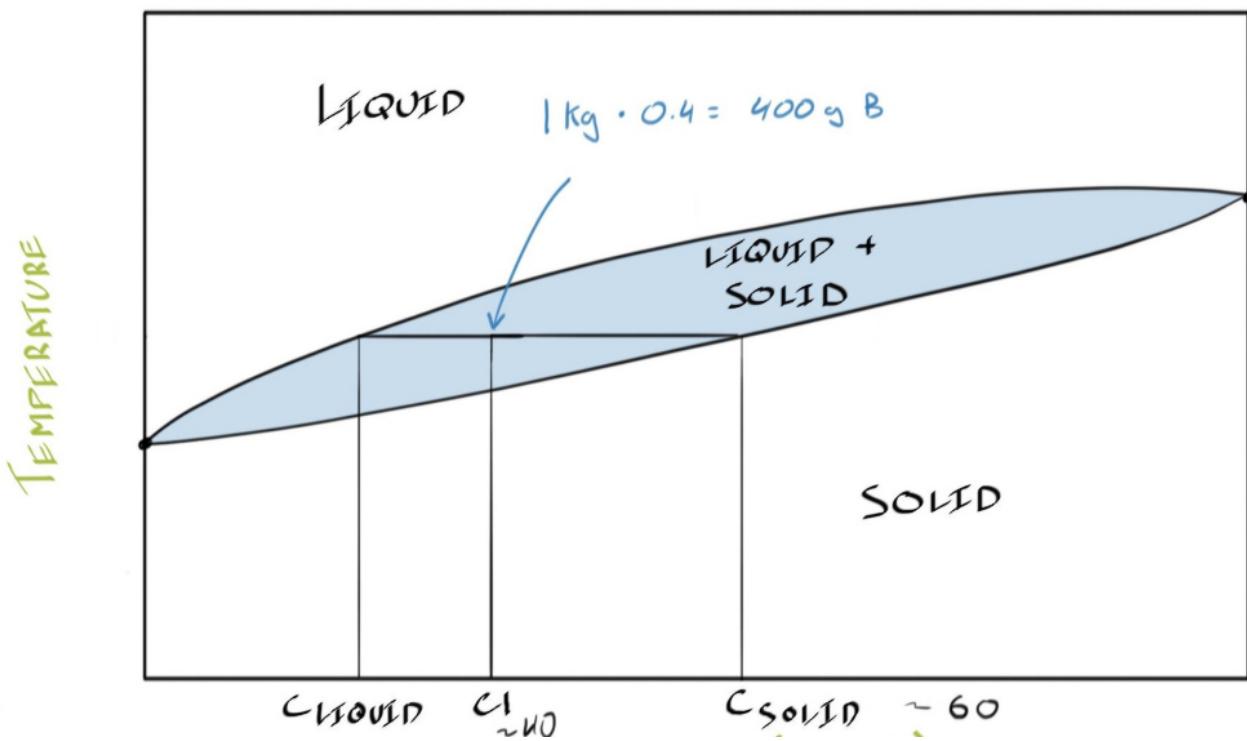
Figure 9: A tie line drawn in the two-phase region of the hypothetical two- component A-B system gives the composition of each phase of the two phases.

Next, drawing vertical lines down to the composition axis tells us the composition of each of those two phases. Namely, that the liquid exists at composition C_{Liq} and the solid exists at composition C_{Solid}. Remember that these compositions are conventionally given in units of wt% "component-on-the-right," that is, wt% B. So you can see that the liquid phase has less B and more A, while the solid has more B and less A, but both the liquid and the solid phases do contain atoms of component A and of component B.

Now we are ready to answer the question, "how much of the system is liquid and how much is solid?" This is what the lever rule tells us.

The Lever Rule: The Amount of Each Phase or How Much Has Melted?

Let's begin by considering our example from the end of the previous section and let's also assign some reasonable values to the compositions and take a basis of 1 kg.



~30 COMPOSITION (wt% B)

Figure 10: A 1 kg sample having a composition of 40 wt% B contains 400 grams of component B, separated into the liquid and the solid phases.

If we then wanted to know how much component B was in our system, we could easily do this by multiplying our overall composition by 1 kg, as shown in Figure 10.

The next question that we can ask is, "how much B is there in the liquid?" or, "how much B is there in the solid?" If we knew the mass of the liquid phase and the mass of the solid phase we could easily answer these questions, as shown in Figure 11.

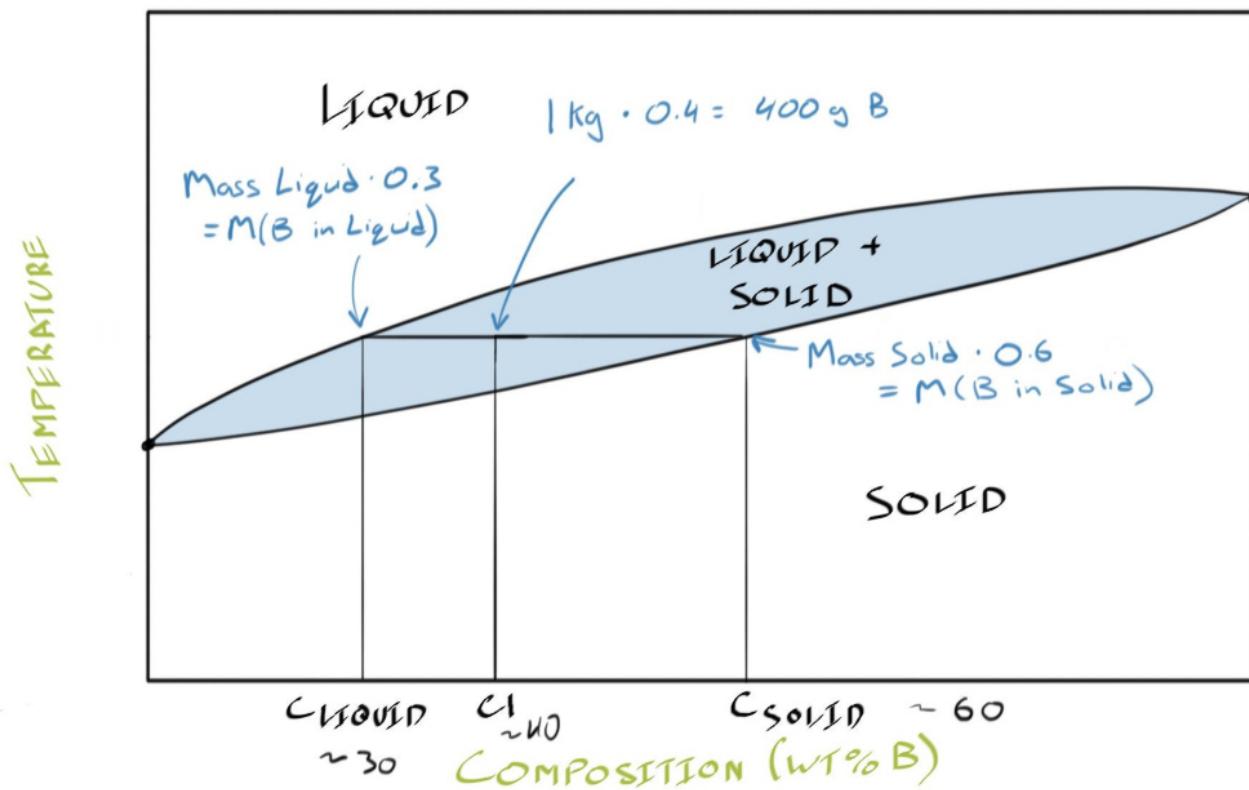
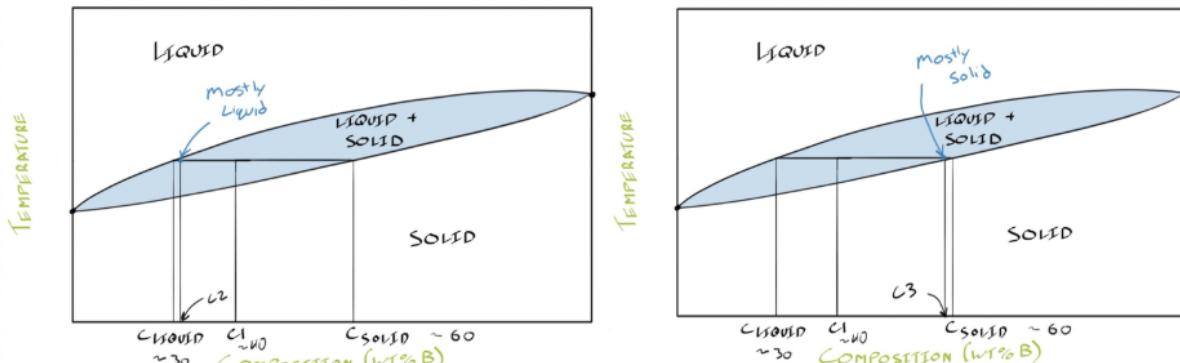


Figure 11: A 1 kg sample having a composition of 40 wt% B contains 400 grams of component B, separated into a mass of B in the liquid, $M(\text{B in Liq})$ and a mass of B in the solid, $M(\text{B in Solid})$.

We're getting closer to making sense of this now. In fact, now is a very good time to pause for an intuitive sense check: should there be more solid, or more liquid phase present? Well, let's make things a little easier and consider some extreme cases, say if we changed the composition to something lower C_2 or to something higher C_3 that was very close to the liquidus or the solidus, respectively? This scenario is drawn in Figure 12 where it can be seen that if the overall composition is very close to the liquidus the system should be mostly liquid (more liquid, less solid) and if the overall composition is very close to the solidus then the system should be mostly solid.



(a) Mostly liquid, only a little solid.

(b) Mostly solid, only a little liquid.

Figure 12: A sample having a composition very close to the liquidus will contain "mostly liquid" plus a little solid, while a sample having a composition very close to the solidus will contain "mostly solid" plus a little liquid.

Another way of expressing this same, perhaps obvious result, is to ask what would happen if we heated our original system of composition C₁ to just below the liquidus? Clearly, we would have a system that was almost entirely liquid (almost completely melted), as shown in Figure 13.

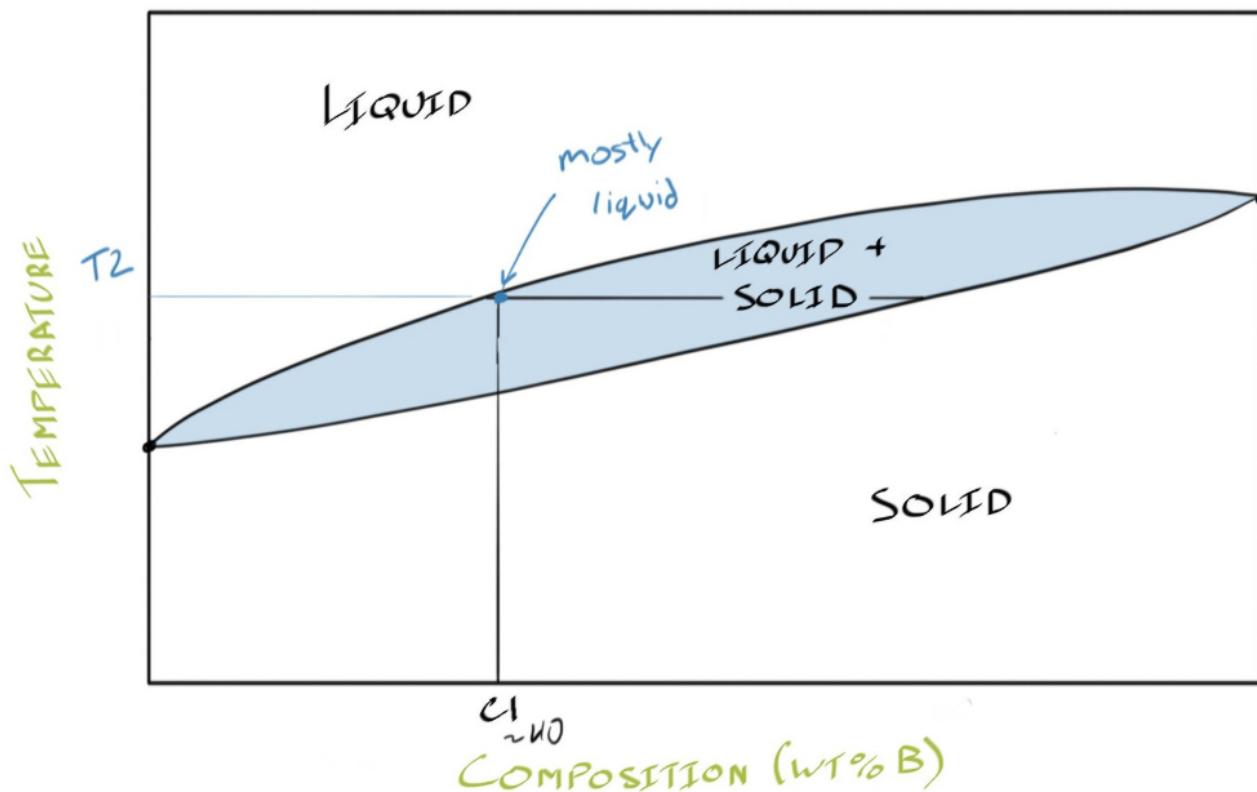


Figure 13: A sample having a composition of C₁ that is heated very close to the liquidus will contain "mostly liquid" plus a little solid. Note also, that the compositions of the liquid and of the solid have changed.

This intuitive understanding of what our system should contain is important and useful, but we need to do better. We need a quantitative relationship. This is actually fairly straight forward and relies on a mass balance of component B.

A Mass Balance Gives Us The Lever Rule

The diagram shows the derivation of the Lever Rule from mass balance equations. It starts with the total mass of sugar, $M_{\text{Sugar, total}}$, which is the sum of the mass in ice, $M_{\text{ice}} \cdot C_{\text{ice}}$, and the mass in syrup, $M_{\text{syrup}} \cdot C_{\text{syrup}}$. This is divided by the total mass, M_{total} . Below this, the overall composition C_0 is shown as a weighted average of the compositions of the two phases: $C_0 = w_s C_s + w_l C_l$. This is then expanded to include the total mass terms: $C_0 = w_s C_s + (1 - w_s) C_l = w_s C_s + C_l - w_s C_l = w_s(C_s - C_l) + C_l$. Finally, the weight fraction w_s is solved for, resulting in the Lever Rule equation: $w_s = \frac{C_0 - C_l}{C_s - C_l}$.

[Link to this video on U of T servers.](#)

Earlier in this section we calculated that there was 400 g of component B in our 1 kg system of a 40 wt% B sample. In Figure 11 we continued our calculations and said that component B was separated into the liquid phase and the solid phase, so we could write the total mass of component B as

$$M_{B,\text{Total}} = M_{B,\text{in Liquid}} + M_{B,\text{in Solid}} \quad (1)$$

and since the mass of component B in each phase is just the mass of that phase multiplied by the composition of that phase, as shown in Figure 11, we can write

$$M_{B,\text{Total}} = M_L C_L + M_S C_S \quad (2)$$

and in order to get this equation in terms of the weight fraction of each phase, which is actually what we're after ("how much is melted?"), we can divide both sides of Equation 2 by the total mass of the system

$$\frac{M_{B,\text{Total}}}{M_{\text{Total}}} = \frac{M_L}{M_{\text{Total}}} C_L + \frac{M_S}{M_{\text{Total}}} C_S \quad (3)$$

and since the mass of B divided by the total mass is just our overall composition, we can re-write Equation 3 as

$$C_0 = \frac{M_L}{M_{\text{Total}}} C_L + \frac{M_S}{M_{\text{Total}}} C_S \quad (4)$$

and we can simplify things a little further by substituting mass of a phase divided by the total mass as a weight fraction, like this

$$\frac{M_L}{M_{Total}} = W_L \quad (5)$$

$$\frac{M_S}{M_{Total}} = W_S \quad (6)$$

which we can substitute into equation 4 to give

$$C_0 = W_L C_L + W_S C_S \quad (7)$$

and since there are only two phases we know that the two weight fractions

must add to one

$$W_L + W_S = 1 \quad (8)$$

or, depending on whether we want to eliminate the solid or the liquid weight fraction (which doesn't really matter at this point since we'll generalize this equation at the end, so let's go with the solid)

$$W_S = 1 - W_L \quad (9)$$

which we can now substitute back into equation 7

$$C_0 = W_L C_L + (1 - W_L) C_S \quad (10)$$

and now a little bit of simple mathematical massaging should give us what we are after

$$C_0 = W_L C_L + C_S - W_L C_S \quad (11)$$

$$C_0 = W_L (C_L - C_S) + C_S \quad (12)$$

$$W_L = \frac{C_0 - C_S}{C_L - C_S} \quad (13)$$

and in this particular case, since C_S is larger than C_0 it makes a little more sense to multiply the top and bottom by -1 to give

$$W_L = \frac{C_S - C_0}{C_S - C_L} \quad (14)$$

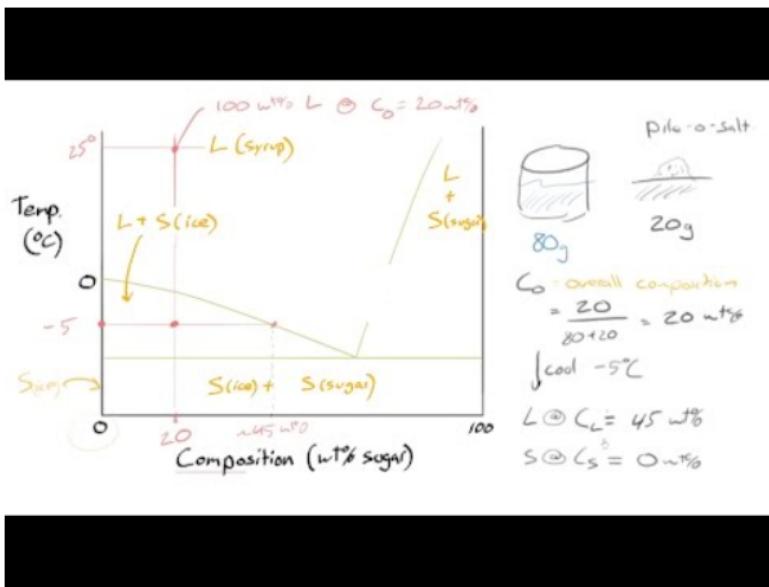
Which is the equation that we commonly call the *Lever Rule*. Considering this equation, you'll see that it is just defining the fraction of the tie line on one side of the overall composition (think of this as the fulcrum on a lever) divided by the total length of the line. In fact, since the composition axis is linear, we could actually use a ruler and measure the length in mm, say, since the units cancel out top and bottom and we are left with a fraction. The last thing to do now is to make the lever rule as general as possible so that we can apply it to anything phase diagram. Written out in words, in its most general form

possible so that we can apply it to any two phase region. Written out in words, in its most general form, the Lever Rule is

$$\text{Weight fraction of a phase} = \frac{\text{Opposite side of lever}}{\text{Total length of lever}} \quad (15)$$

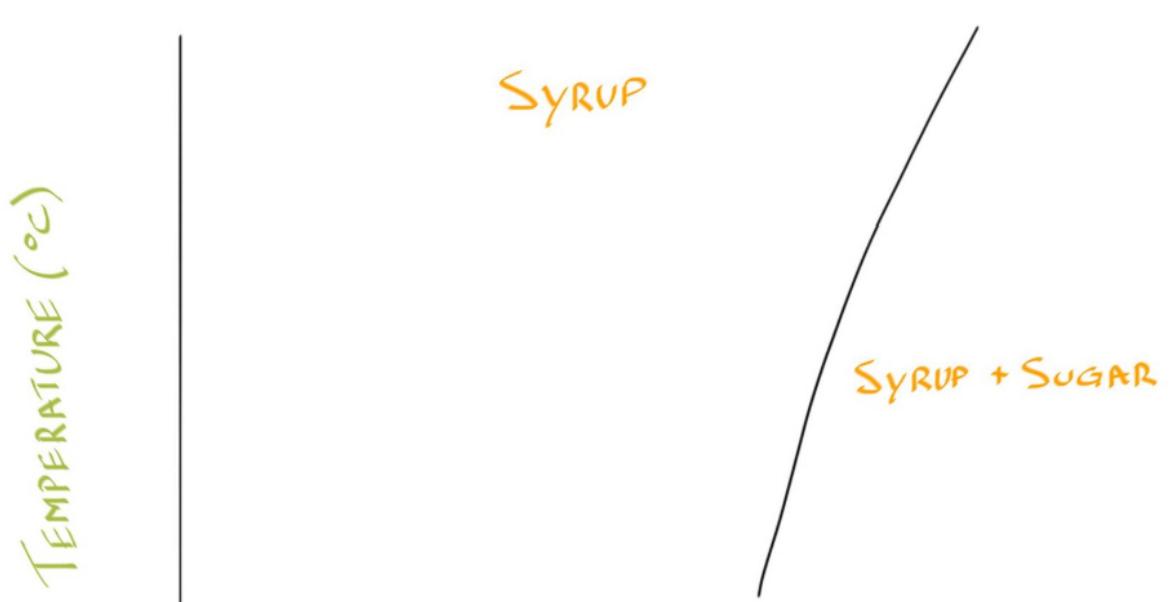
It is important to keep in mind that we will always take the opposite side of the lever, that is, the side farthest away from the phase you are interested in. One of the most common mistakes that students will make is to take the side closest to the phase they are interested in.

Slurpies®, Iced Capps® and Frappucinos® Delicious Binary Eutectic Systems



[Link to this video on U of T servers.](#)

Wow, that's a lot of registered symbols! Hopefully, you're familiar with one of these tasty iced drinks.



WATER

SUGAR

COMPOSITION (WT % SUGAR)

Figure 14: A schematic diagram of the water-sugar phase diagram showing only the solubility limit.

If not, please go an buy one now and write it off as an educational expense. Why so much interest in these iced drinks? Because they are an excellent illustration of phases present in a so-called *eutectic* system. Let's return to our familiar water-sugar phase diagram where we left it earlier, as in Figure 14.

As a quick reminder we know that quite a lot of sugar can dissolve in water, giving us syrup. Eventually, however, we can't dissolve any more sugar and we hit the point of saturation, or the so called *solubility limit*.

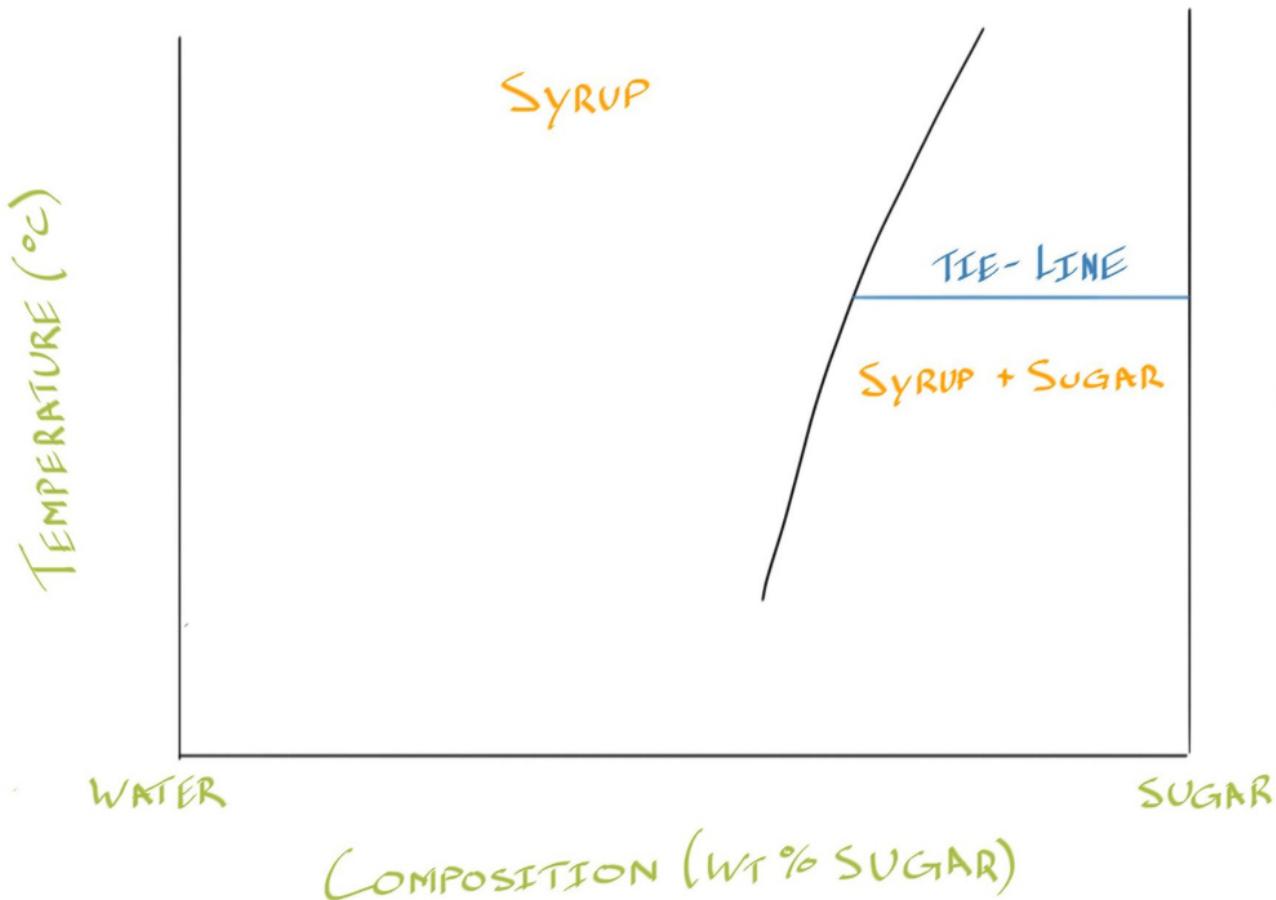


Figure 15: A schematic diagram of the water-sugar phase diagram showing the solubility limit and a tie-line across the two-phase Syrup + Sugar (solid) region.

This is the sloped line in Figure 14. At concentrations, or *compositions* above the solubility limit we have two phases, syrup plus solid sugar.

A tie-line drawn anywhere in this two-phase region, as shown in Figure 15 would give us the compositions of each phase.

We already said that the syrup was saturated, so it shouldn't be a surprise that the syrup concentration is given by the point where the tie-line intersects the solubility limit, as shown in Figure 16.

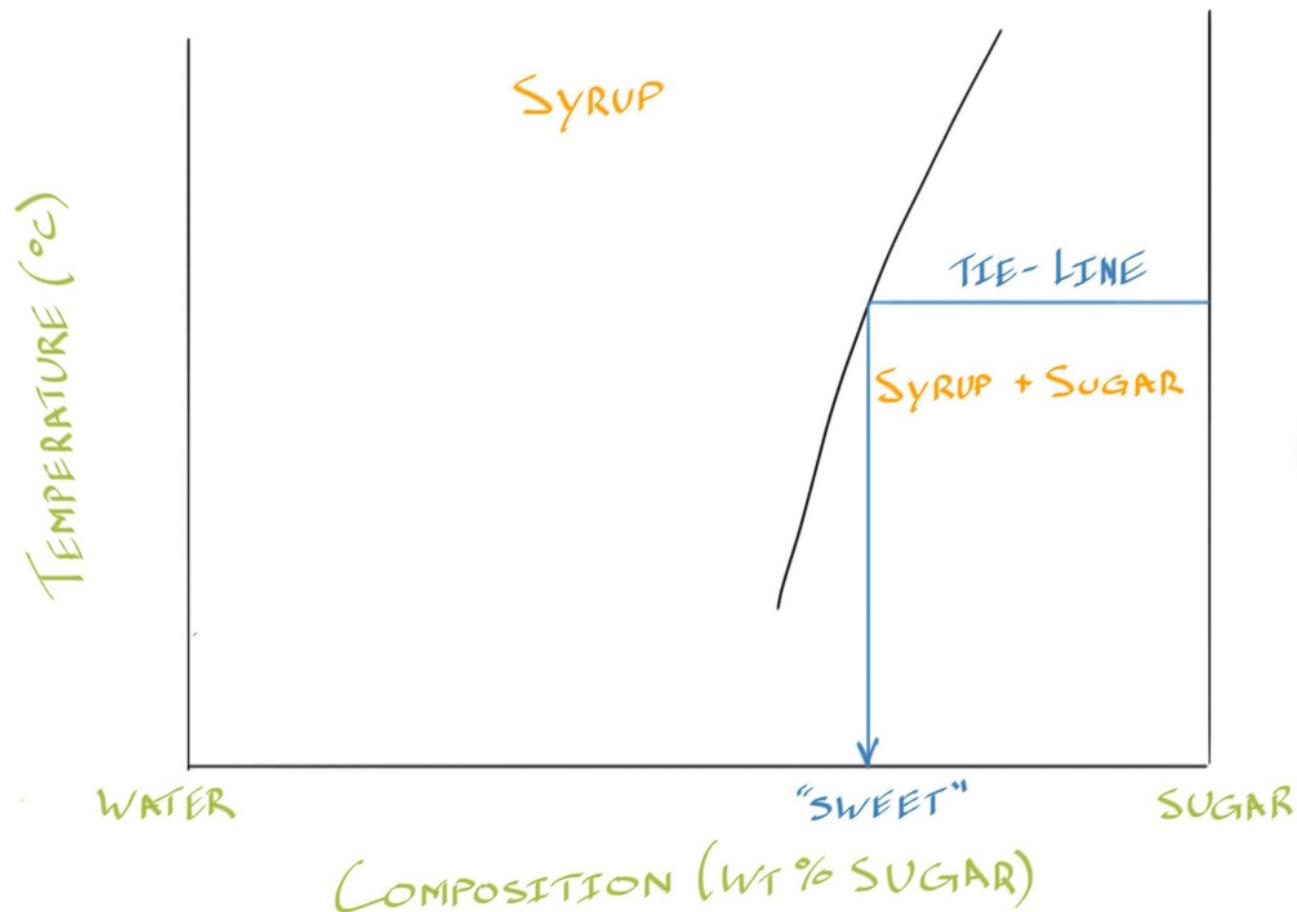


Figure 16: A schematic diagram of the water-sugar phase diagram showing the solubility limit and a tie-line used to determine the composition of the syrup. We would say that the syrup is "sweet".

You see, one of the reasons that I love this phase diagram, when teaching phase diagrams is that you very likely already have a fairly strong intuitive understanding for the system. If we were to dive straight into the iron- carbon system I think it would be much more difficult to develop that oh- so-important intuitive understanding of what these diagrams are actually telling us. So, with this in mind, I ask you, "what is the composition of the sugar that settles to the bottom of a glass of saturated syrup?" You are likely thinking now, "uh, the sugar is just sugar isn't it?" Yes! Absolutely, the sugar is just sugar, and we

can confirm that from the diagram by where the tie-line intersects with the phase boundary for the solid sugar region, as shown in Figure 17.

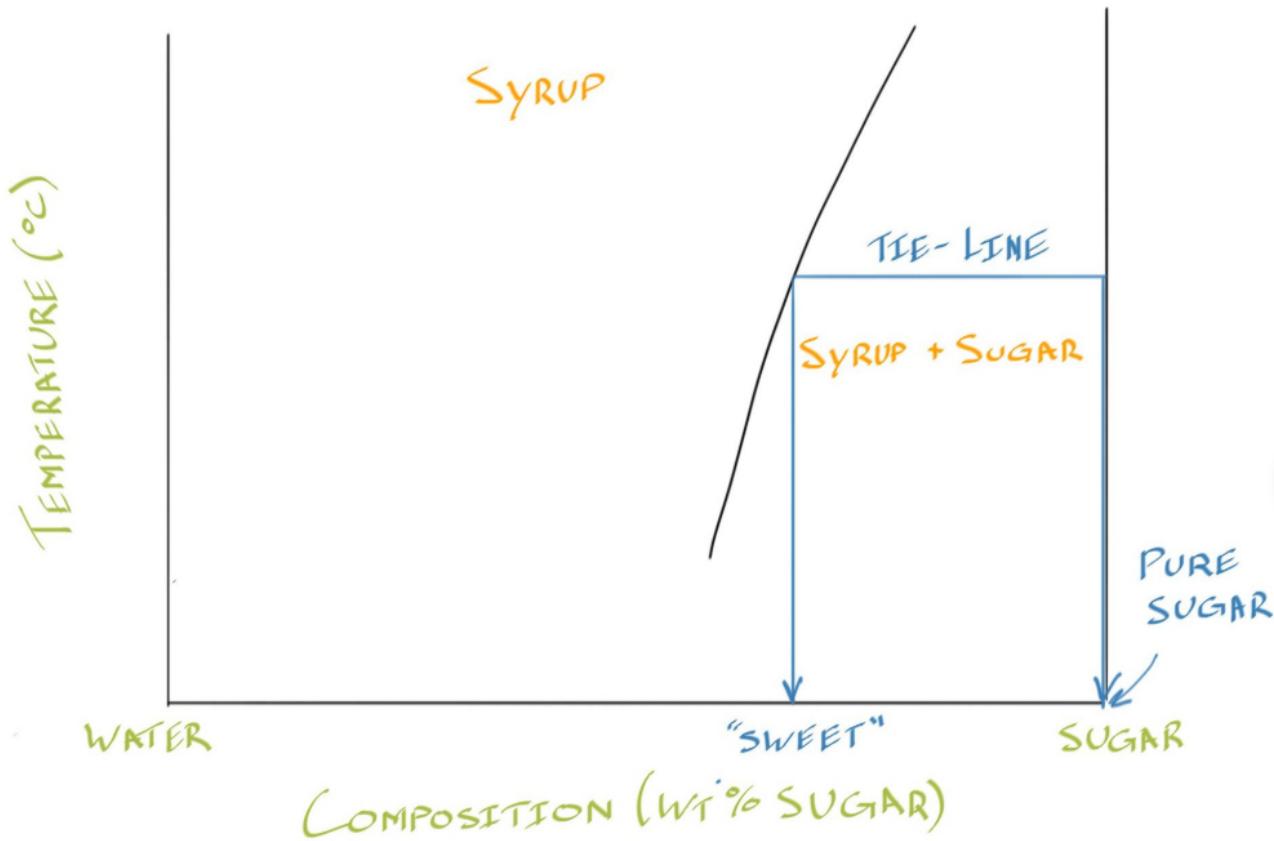


Figure 17: A schematic diagram of the water-sugar phase diagram showing the solubility limit and a tie-line used to determine the composition of the syrup and the composition of the sugar. We would say that there is essentially no water dissolved in the solid sugar (although there would actually be a few molecules of water in the sugar).

The composition of the sugar is 100% sugar, or, stated another way, there is essentially no water that is dissolved in solid sugar.

Alright, enough of this you say, "there is no solid sugar in the iced drink that you insisted that I buy!" Right again! See, you are really starting to get this whole phase equilibrium business! You see, our delicious iced drinks are not in this two-phase liquid plus solid region, they are in the other two-phase liquid plus solid region. To understand our iced drinks we need to move to the ice plus syrup region, as shown in Figure 18.



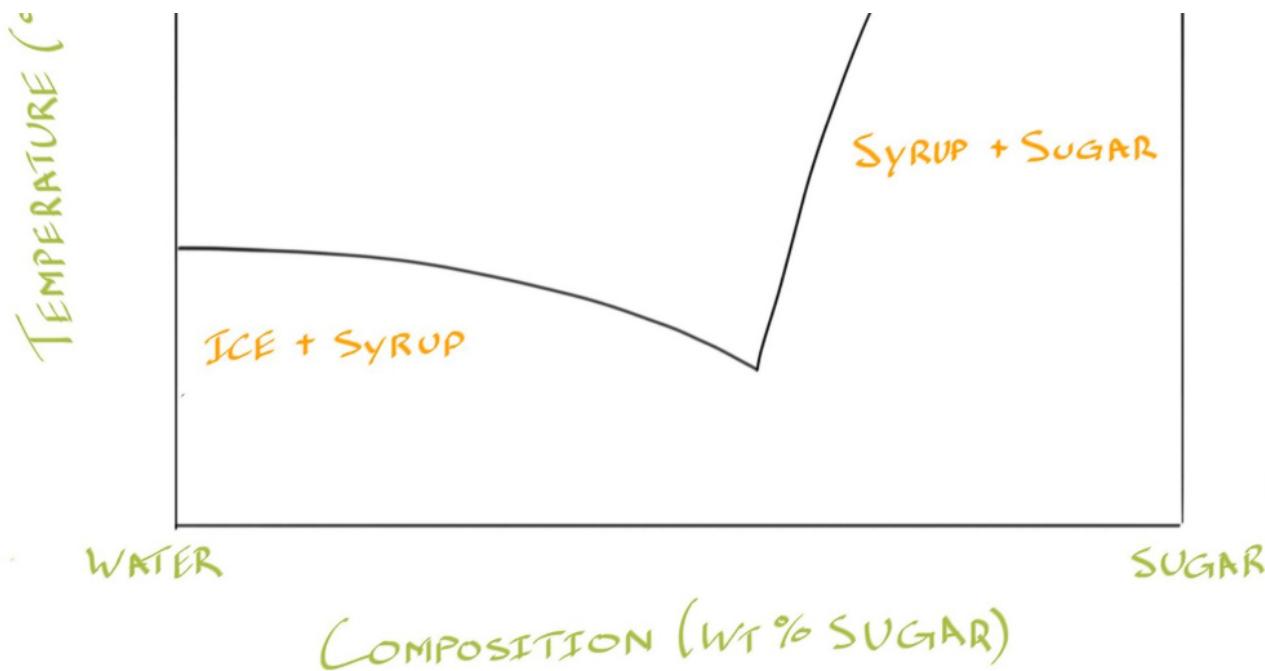
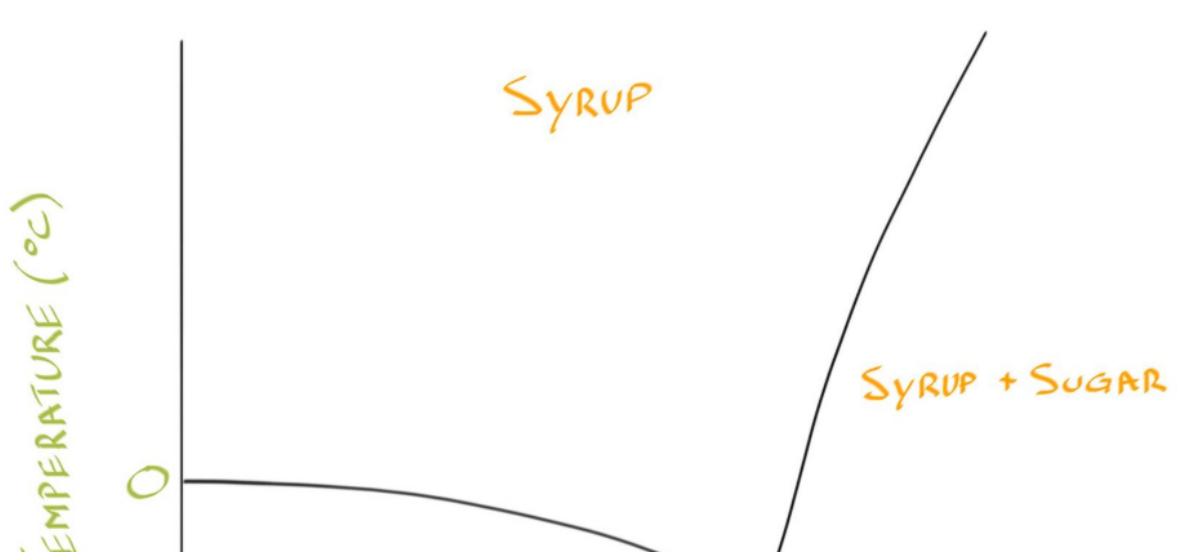


Figure 18: A schematic diagram of the water-sugar phase diagram showing the solubility limit and the liquidus - separating the two-phase Ice + Syrup region from the single phase Syrup.

Probably one of the first things to consider with this region is this, "what happens if you drink an Iced Capp® too quickly?" Yes, it may feel like your brain hurts if you are susceptible to *brain freezes*, but that's not what I'm talking about here. If you drink an iced drink quickly so that not all of the ice melts before you finish drinking it you'll find that you are left with ice. Just ice. Not delicious. Why is the ice that is left over not so tasty? Because it isn't sweet. You see, you already know that the composition of ice is just ice. That is, just like the solid sugar was 100% sugar, so is the solid water (ice) just water, or 0% sugar. You can confirm this by drawing a tie-line in the ice-plus syrup two phase region and noting the composition where the tie-line intercepts the water phase boundary.



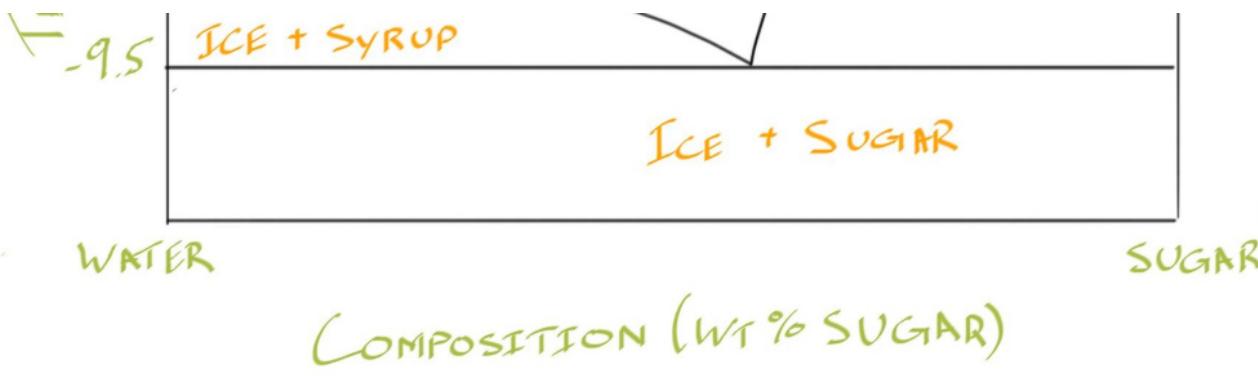


Figure 19: A schematic diagram of the water-sugar phase diagram. At temperatures below $-9.5\text{ }^{\circ}\text{C}$ the equilibrium phases are Ice and Sugar (solid), although in practice the kinetics of the nucleation of solid sugar is very slow.

The final phase boundary to draw on the water-sugar system is one that is likely a little unexpected. It is a horizontal line, as shown in Figure 19.

Since a horizontal line must have constant temperature anywhere along the line, we frequently call these sorts of lines *isotherms*. Below this temperature we find there is no liquid phase and we have only two equilibrium phases solid water and solid sugar.

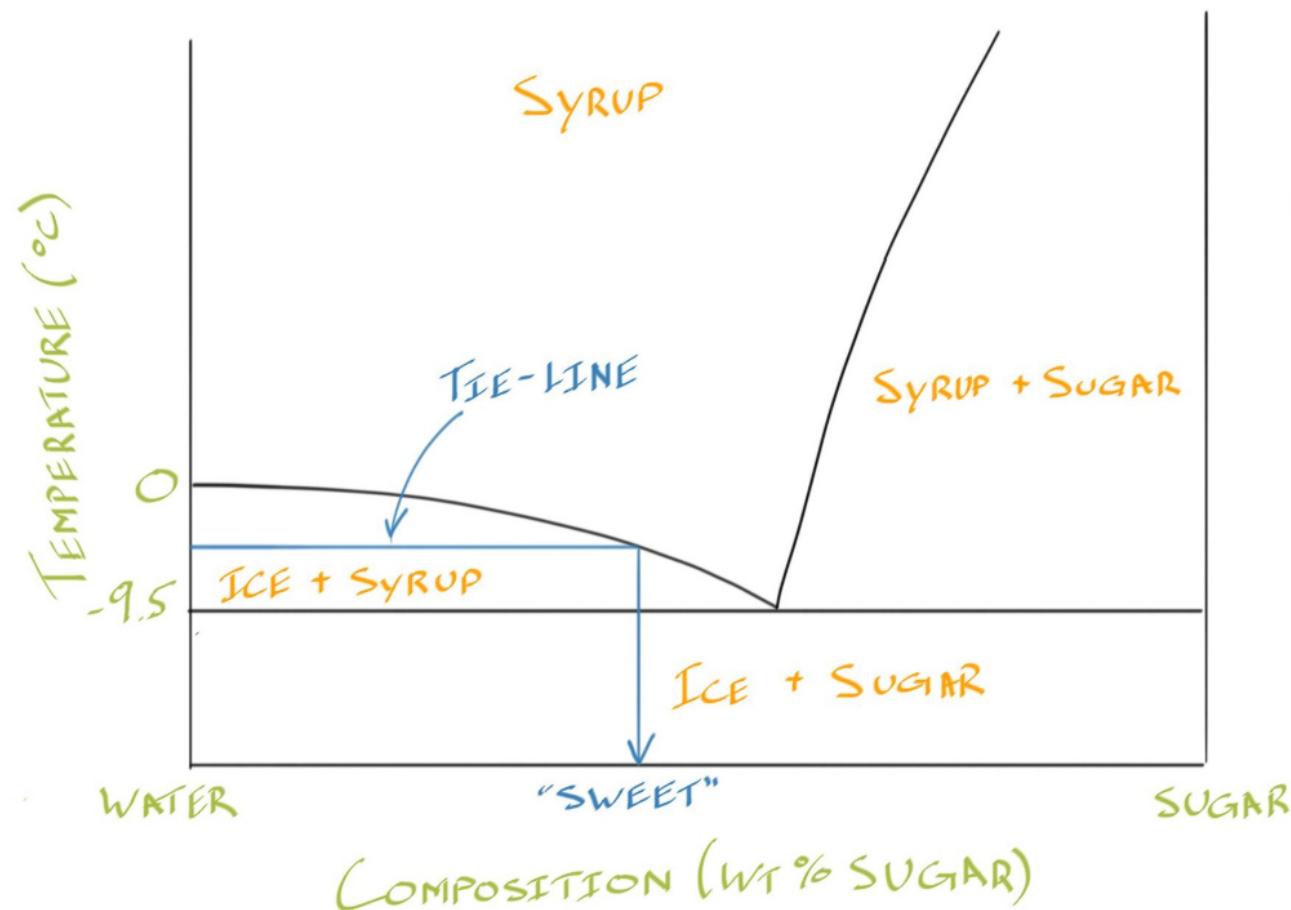


Figure 20: A schematic diagram of the water-sugar phase diagram showing a tie-line used to determine the composition of the syrup. Again, we would say that the syrup was "sweet".

The reason that our iced drinks taste so good is that we are drinking the liquid (syrup) phase and, as

The reason that our iced drinks taste so good is that we are drinking the liquid (syrup) phase area, as you can see in Figure 20, the liquid phase is enriched in solute.

That is, the composition of the liquid phase is higher than the overall composition.

And, as we discussed earlier, the composition of the ice is 0 wt% sugar, as shown in Figure 21.

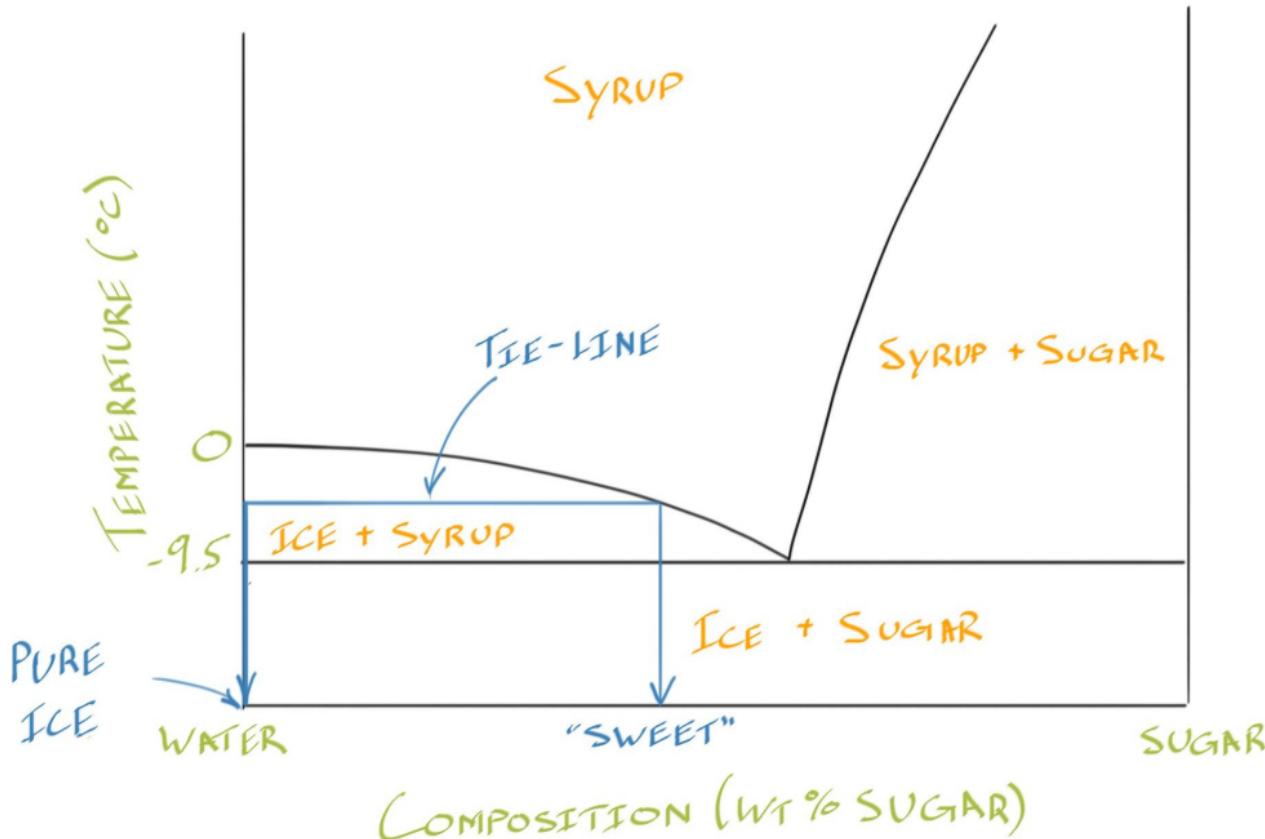


Figure 21: A schematic diagram of the water-sugar phase diagram showing a tie-line used to determine the composition of the ice. We would say that the ice was not at all sweet, although there would technically be some sugar molecules dissolved in the ice.



12.2.1
Review

Mark as: None ▾

50 g of water is added to 50 g of sugar, heated to 80 °C and allowed to reach equilibrium. What phase(s) is/are present?

Select an answer and submit. For keyboard navigation, use the up/down arrow keys to select an answer.

a Liquid syrup

b Solid sugar

c Solid ice

d Liquid syrup plus solid sugar

Correct Answer:

- ✓ a - Liquid syrup

[Show Submitted Answer](#)[Hide Correct Answer](#)[Check My Answer](#)

12.3.1

Review

Mark as: [None ▾](#)

50 g of water is added to 50 g of sugar, cooled to -30 °C and allowed to reach equilibrium. What phase(s) is/are present?

Select an answer and submit. For keyboard navigation, use the up/down arrow keys to select an answer.

- a Solid sugar plus liquid syrup

- b Solid sugar

- c Solid ice

- d Solid ice plus solid sugar

Correct Answer:

- ✓ d - Solid ice plus solid sugar

[Show Submitted Answer](#)[Hide Correct Answer](#)[Check My Answer](#)

12.5.1

Review

Mark as: [None ▾](#)

30 g of water is added to 70 g of sugar, cooled to -30°C and allowed to reach equilibrium. How many grams of ice will be present?

Select an answer and submit. For keyboard navigation, use the up/down arrow keys to select an answer.

- a 70 g

- b 30 g

- c 100 g

- d 0 g

Correct Answer:

✓ b - 30 g

Show Submitted Answer

Hide Correct Answer

Check My Answer



So, now you've got a really good understanding of the water sugar phase diagram, which is technically a binary eutectic phase diagram.

So, What is a Eutectic?

A binary eutectic phase diagram is a phase diagram for a system that has one specific melting point that is below the melting point for each of the components. A classic example is the lead-tin system which has been popular as a solder alloy due to it's low melting temperature (near the eutectic). Lead containing solders are being phased out for environmental reasons, but in any case the phase diagram looks similar to the generalized binary eutectic phase diagram shown in Figure 22.

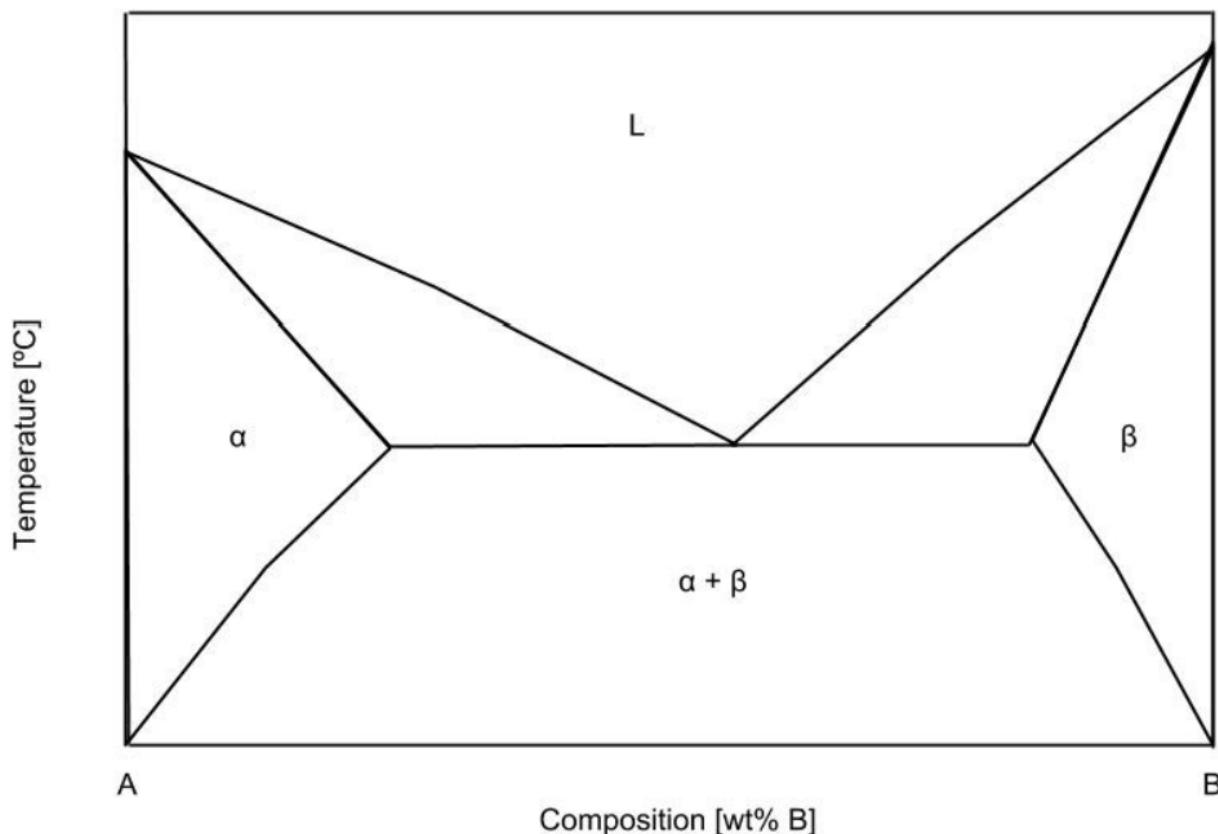


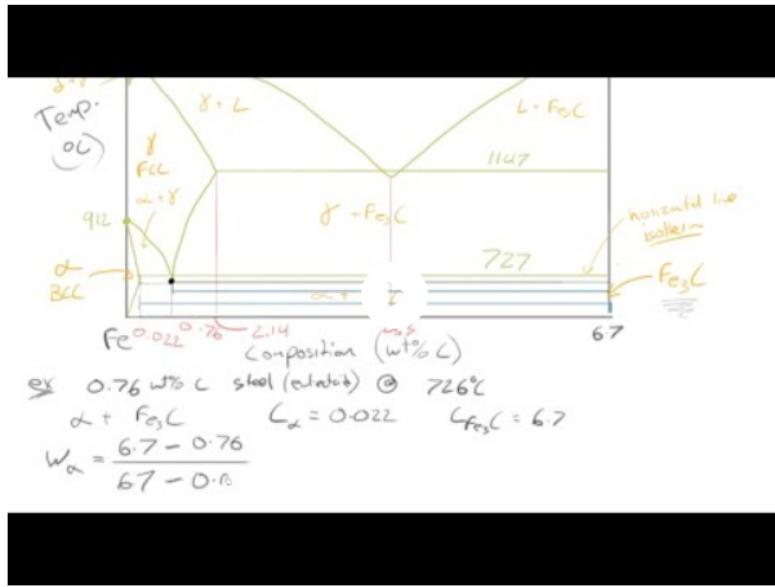
Figure 22: A schematic diagram of a generalized binary eutectic phase diagram. Note that the solid phases are named using lower case Greek letters and the liquid is just indicated with a capital L



The Iron Carbon System

If I had to pick only one phase diagram to be stranded in a hypothetical post-industrialized society with I'd probably chose the iron-carbon phase diagram. This is because the iron-carbon system gives us

Steel and steel is arguably the most important material. Depending on who you talk to you may hear that concrete or silicon are more important than steel, but hopefully we can all agree that steel is important.



[Link to this video on U of T servers.](#)



12.4.1

Review

Mark as: [None ▾](#)

Carbon present within iron at 0.01 wt% will be present as which of the following? (Hint, you may wish to refer to the iron-carbon phase diagram.)

Select an answer and submit. For keyboard navigation, use the up/down arrow keys to select an answer.

a As part of a compound

b A substitutional impurity in solid solution

c An interstitial impurity in solid solution

d As graphite

Correct Answer:

✓ c - An interstitial impurity in solid solution



Show Submitted Answer



Hide Correct Answer

Check My Answer



12.1.1

Review

Mark as: [None ▾](#)

A 1 wt% steel is heated to 1200 °C and allowed to reach equilibrium. What phase(s) is/are present?

Select an answer and submit. For keyboard navigation, use the up/down arrow keys to select an answer.

SELECT AN ANSWER AND SUBMIT. FOR KEYBOARD NAVIGATION, USE THE UP/DOWN ARROW KEYS TO SELECT AN ANSWER.

a Ferrite plus austenite

b Austenite

c Ferrite plus cementite

d Austenite plus cementite

Correct Answer:

✓ b - Austenite



Show Submitted Answer



Hide Correct Answer

Check My Answer

All images and videos are created by author.

