

## Melting Range

**Background Information** The melting range of a pure solid organic is the temperature range at which the solid is in equilibrium with its liquid. As heat is added to a solid, the solid eventually changes to a liquid. This occurs as molecules acquire enough energy to overcome the intermolecular forces previously binding them together in an orderly crystalline lattice. Melting does not occur instantaneously, because molecules must absorb the energy and then physically break the binding forces. Typically the outside of a crystal will melt faster than the inside, because it takes time for heat to penetrate. (Imagine an ice cube melting from the outside in, and not doing so instantly...)

The melting range of a compound is one of the characteristic properties of a pure solid. The melting range is defined as the span of temperature from the point at which the crystals first begin to liquefy to the point at which the entire sample is liquid. Most pure organics melt over a narrow temperature range of 1-2°C, if heated slowly enough. Impure samples will normally have melting ranges that are both larger (>1°C) and begin lower.

### **Taking the melting range of a sample is useful for two reasons:**

1. Identification of an unknown sample (compare its observed melting range with that of known compounds)
2. Assessment of sample purity for a known substance. By comparing observed range for an actual sample to the known range for a pure sample, you can tell whether your actual sample is pure or contaminated (the range is depressed and broadened)

### **The presence of impurity has two effects on a substance's melting range:**

1. Melting range depression (lower end of the range drops)
2. Melting range broadening (the range simply increases. Often the low end drops a lot, the high end less so or sometimes not much at all.) A melting range of 5° or more indicates that a compound is impure.

**Why? The reason for this depression/broadening** is that contaminants disrupt the consistency and organization of the crystal lattice at the molecular level. Contaminants don't "fit" correctly into what would be the normal pure lattice. **How does this manifest itself?**

1. The disruption weakens the lattice, so that the lattice can be broken down more easily; the weakened structure melts more easily at reduced temperature (depression).
2. Disruption of the lattice makes it non-uniform. At the molecular level, the molecules closest to the impurities melt fastest. Further away from the impurities, the crystal lattice is relatively undisturbed and therefore melts at or nearer the normal temperature.

### **Miscellaneous notes on melting range depression/broadening:**

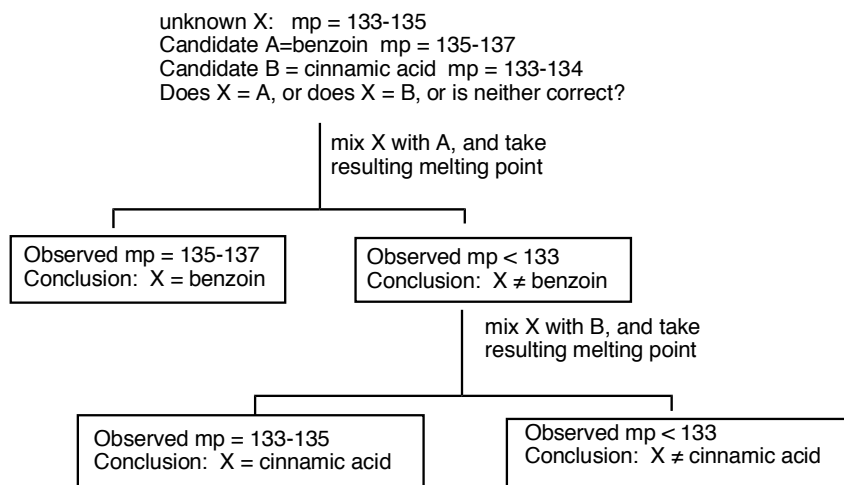
1. Only "soluble" impurities, which are incorporated into the crystal structure at the molecular level, cause depression and broadening. An insoluble piece of metal or wood ionic salt crystal has negligible effect, because only a few organic molecules will be in contact and will be affected.
2. At the chemical level, it is impossible to "raise" the melting point of an already pure substance. Its melting point can be depressed by contamination, but not raised. Practical: If the melting point for an unknown sample is observed to be in between that of two candidates whose pure mp's are known, the unknown can't actually be equal to the lower-melting candidate. (Short of the rapid-heating effect, see later.) Most likely the unknown sample is an impure version of the higher melting candidate.

For example: suppose an unknown sample X melts at 148-152°, and is thought to be either candidate A (known range is 141-142°) or B (known range is 161-162°). Sample X cannot be candidate A, but it can be an impure and thus depressed version of candidate B.

3. Often contaminated solids are purified by recrystallization. If the resulting melting range is unchanged, the original sample probably was pure to begin with. But if the resulting melting point gets higher, the original sample was obviously impure.
4. When crystals are isolated by filtration from a solvent, it is important to allow complete drying/evaporation of the solvent in order to get a good melting range. Residual solvent functions as a contaminant and will depress/broaden the melting range for a crystal.
5. When two chemicals are mixed, the resulting melting point is **not** the average of the two mp's. It is always depressed from the melting point of the major component in the mixture. This is true even if the impurity is higher melting (when pure) than the major component. For example, if a chemical that normally melts at 130° is contaminated by a small amount of material that when pure melts at 200°, the resulting mixture will not melt between 130° and 200°. Rather, the melting point of the major component will be depressed, and the observed melting range will begin lower than 130°.
6. Even when two chemicals with exactly the same melting point when pure are mixed, the resulting melting point is depressed.

### Mixed Melting Points

That mixtures have depressed melting points, even when both components have comparable melting points when each is pure, provides a useful laboratory technique. Consider the following situation and flow chart. If an unknown candidate X melts at a temperature close to that of two potential candidates A and B, you can identify it by taking X+A mixed melting point, and X+B mixed melting point. If X is equal to either candidate, one of these mixed melting points will not be depressed. If the mixture with X+A is not depressed, X = A. if the mixture with X+B is not depressed, X = B. If both mixtures are depressed, then X ≠ A or B.



### The Rate of Heating, and Some Practical Tips

It takes time for a crystal to absorb heat and to melt, from the outside in. Just as when you place an ice-cube into a liquid that is  $>0^\circ$ , it doesn't melt instantly. To get maximal accuracy in taking a melting range, heating should proceed at only  $1^\circ/\text{minute}$ ! This is the standard heating rate when publishing melting ranges in scientific journals. This is also inconveniently slow, especially if you don't know where your sample is likely to melt (as when examining an unknown).

- Q: What happens if I heat too fast? A: Your melting range will be too broad, but this time on the high end! If a sample should melt at  $130\text{-}131^\circ$ , but you are heating fast, it will still probably begin to melt at about  $130^\circ$ , but the full sample won't have time to absorb heat and finish melting by  $131^\circ$ . Instead, the heating device may have warmed well above  $131^\circ$  before the interior liquefies, so the observed range may appear to be  $130\text{-}136^\circ$ . Both the magnitude of the range and the high end of the range may be misleading.
- For doing routine samples, it is appropriate to be warming at 5 degrees per minute around the temperature at which melting occurs. This broadens the range somewhat, but not badly. And it keeps the melting point experiment from taking forever.
- Practical tip 1: If the approximate temperature at which your sample should melt is known, the sample can be quickly heated to within  $10\text{-}15^\circ$  of its melting point. Then the heating rate can be slowed to  $2\text{-}4^\circ$  per minute until the sample melts. For example, if you know your material should melt around  $180^\circ$ , but you are just trying to check the purity, you can heat rapidly until you are up to  $165^\circ$  or so, and only when you are getting close turn the heating rate down.
- Practical tip 2: If you have no clue where your sample will melt, it's common to heat rapidly to get a ballpark estimate of where melting will occur.  $60^\circ?$   $140^\circ?$   $240^\circ?$  If it turns out to be  $240^\circ$  and you heated only cautiously from the beginning, it will take a loooooong time to get to the measurement. By heating rapidly, you can get an "orientation melting point" quickly, and then repeat with more care for a more precise reading. Often you don't even need to prepare a fresh sample, because after cooling the melted sample often recrystallizes.
- Practical tip 3: Heat transfer problems are minimized if the sample is ground finely. If the particles are too coarse, they do not pack as well, causing air pockets that slow heat transfer. Because the thermometer keeps heating while the sample is melting rather slowly, the high end of your range will be inflated.
- Practical tip 4: Loading too much sample makes it harder for the interior to get heated and melted. Because the thermometer keeps heating while the sample is melting rather slowly, the high end of your range will be inflated.

### "Sagging"

Sometimes slight changes, such as shrinking and sagging, occur in the crystalline structure of the sample before melting occurs. The temperature at the bottom end of the melting range corresponds to the first appearance of liquid within the sample mixture; if the crystals are changing their appearance, but you don't yet see any actual liquid, you should not record this as the lower end of the melting range yet.

**The Experiment:** (Work alone or with One Partner)**Overview, if working with a partner: You will run three samples.**

1. One will be either pure urea (mp = 132-133) or pure cinnamic acid (mp = 133-134). Whichever you run should be the opposite of what your partner runs. Share your observed results with your partner
2. The second will be mixture of the two, either 4:1 cinnamic acid:urea or 1:4 cinnamic acid:urea. Whichever mixture you run should be the opposite of the mixture that your partner runs. Share your observed results with your partner.
3. The third will be an unknown. (You and partner must run different unknowns. You do not need to share this result with your partner.)

**If working alone: You will run five samples.**

4. Run both pure urea (mp = 132-133) and pure cinnamic acid (mp = 133-134).
5. Run both the 4:1 cinnamic acid:urea and the 1:4 cinnamic acid:urea mixtures.
6. Run one unknown. (You and partner must run different unknowns.)

**Goals:**

- Learn how to run a melting point device and measure melting range
- By comparing results for the two mixtures, see how not all mixtures depress/broaden to the same extent.
- Identify your unknown from the list shown below.

**Unknown Candidates**

Acetanilide 112-115

Benzoic Acid 118-123

Cinnamic acid 131-134

Salicylic acid 155-160

Sulfanilamide 163-166

Succinic acid 184-185

**Lab Report Requirements**

No introduction or procedure write-up is required.

Fill in the data section on the report hand in, and answer the questions.

Melting Point Lab Report. Chem 355

Name:

Partner's Name (if you shared data with a partner:

Experimental Datamelting range

- My Known: (U or C or both)
- My mixture: (4:1 C:U or 4:1 U:C or both)
- Partner's mixture (4:1 C:U or 4:1 U:C)
- My Unknown: (A, B, C, or D...)
- Which compound is your unknown? (from the list on page 4)
  
- Any doubts, discussion, or logic on your identification of unknown. (Not necessary, but if you have a tricky one or one that for whatever reason you get wrong, if your discussion shows some reasonable analysis or logic, it may help you get partial credit! 😊)

Discussion questions:

1. Compare the ranges observed with the two mixtures.
  - a. Did they depress and broaden about the same, or different?
  
  - b. What does that say about the degree of depression and broadening that occurs when mixtures are used? Do all impurities depress to the same degree, or by some predictable formula? Or do you think it's more of a case-by-case deal?
  
2. Strictly speaking, why is it incorrect to speak of a melting "point"?
  
  
3. How will your melting range be perturbed if you haven't completely dried your sample? (For example, after you've filtered crystals away from a solvent, and/or have washed the crystals with solvent...)

4. What's the advantage of a finely powdered sample over a coarser sample? How will your melting range be perturbed with coarse sample?
  
5. What's the advantage of putting in a relatively small amount of sample as opposed to putting in lots and lots of sample? How will your melting range be perturbed with huge sample?
  
6. Why is it desirable to heat the sample relatively slowly? How will your melting range be perturbed by heating too fast?
  
7. You have a sample that you are sure is Jaspersium, which has a list melting range of 145-146.
  - Suppose you run your sample and observe a melting range of 145-151. Is your sample impure, or did you heat too fast?
  
  - Suppose you run your sample and observe a melting range of 139-145. Is your sample impure, or did you heat too fast?
  
8. You have isolated an unknown compound that shows an observed melting range of 90-94. Which is it more likely to be, candidate X (list mp 97-98) or candidate Y (list mp 86-87). Why might your sample not have the same melting range as either of the known compounds, given that it must be one of them?
  
9. Three test tubes labeled A, B, and C contain substances with approximately the same melting points. How could you prove the test tubes contained three different chemical compounds?