

## Lab 15A • 03/21/12

[Lab exam review][can't sleep because of seeing molecules][sotally tober]

### Kinetic versus thermodynamic control

The situation is this: we have a compound, 1,3-butadiene, that if you allow it to undergo some kind of electrophilic addition, that you do form one and only one kind of carbocation. There are two resonance structures we could write for that carbocation, but they're misleading, because it makes it look like you could have either a primary carbocation – if you put the carbocation at the very end of the molecule – or two carbons over – where it would be at a secondary position, that would be another kind of carbocation. But, those structures don't exist, because it really is a delocalized ion in real life. I normally do not write dotted lines, I recommend against it; the only reason I think it's good in this one case is because it emphasizes the fact that there's only one energy level. Once, though, you start to finish the reaction ... the example we did was to add HBr, so there's a bromine that's going to come in and form a bond. As the bond forms, you lose delocalization; in fact, you have localization of charge. Were you to form the bond to a primary position, the positive charge starts to accumulate on that primary position. If you're going to form the bond at the secondary position, the delta positive, the positive charge ends up at the secondary position. It is still true that primary carbocations – or the semblance of a primary carbocation – is not as good as having a secondary – which means as this common intermediate starts to react, there's going to be two different activation energies: one corresponding to forming at the primary, which will mean a higher activation energy; and one corresponding to forming a bond at the secondary position, which would be the lower activation energy.

So we have the following: one curve up to the carbocation, two curves progressing away from it. For the transition state for the higher-energy curve, that would correspond to bond formation beginning at the primary position, which means the double bond becomes localized internally. That's the higher-energy transition state. The lower-energy transition state would be where the double bond becomes localized terminally, and the bromine starts to attach at the secondary position. But once this process is over, you have two different products: an internal alkene and a terminal alkene. Those have different energies to them, and it turns out terminal alkenes are not thermodynamically as favorable, normally, as internal alkenes. Let me write those two products.

The whole point is: the reaction pathway that has the higher activation energy ends up making the more-favorable product, and the one that has the lower activation energy makes the less-favorable product. Because these paths cross, that's why we have some interesting behavior that occurs as temperature changes. Because, if you have two reactions, competing reactions, where the rougher reaction, the tougher reaction is also the less-favorable reaction, changing temperature would only change the rate at which the product form, possibly a little bit in the product distribution as well. But here, we have a total flip-flop, because at low temperature, there's not much energy around. So, if there are two competing processes that have two different activation barriers, we could show that, at some fixed temperature that's going to have a certain energy distribution to it, that if we have a low activation barrier, that there's going to be a lot more molecules that would have the energy to be able to react, compared to a high activation barrier. This is just talking about the forward reaction. For an exothermic process like this, the reverse reactions automatically have large activation barriers, which means the reverse reaction rates are automatically lower. At low enough temperature, we presume that the reaction, overall, is irreversible, and that, therefore, the product is going to be determined by which of the two activation barriers can be overcome. On the basis of this graph below, because the lower activation barrier has more molecules that would have the energy to react, we make more of that product, which is not the most favorable product. That's why we call it the kinetic product.

As we increase temperature, what happens? If we were just looking at one activation barrier and looking at how temperature would affect reaction rate, we can see that at low temperature, the distribution is narrower, the curve is less broad, and it is, of course, shifted to lower energy. As we raise temperature, the distribution broadens, and the average energy shifts higher, because we're at higher temperature. The point of drawing that graph is to show that, at low temperature, there's not as many molecules that have the energy to react; at higher temperature, there are more molecules able to react. As you keep increasing temperature, reverse reaction rate becomes higher and higher; so does the forward reaction rate – meaning, you have reversibility possible. But now, even though the kinetic product may have formed more easily, reversibility is also more possible, and if it reacts to make thermodynamically more favorable product, that product doesn't really want to reverse, cause it is the lowest energy of all of the species on this graph, so it has the highest activation energy to reverse. Increase the temperature, increase the reversibility, influence and favor the formation of that more-favorable product, which we therefore call the thermodynamic product.

I've described two extremes, but you could have some situation between. In other words, if you heat it up a little bit, you'll make it a little bit more reversible, and a little bit more likely that the thermodynamic product will form. That means you could end up with a lot of both products. It's only when you're at extremely higher or extremely lower temperature that you can more successfully target just the formation of one product.

[lab – part A: formation of cyclohexanone semicarbazone MP 166 °C; part B: formation of furaldehyde semicarbazone MP 202°]  
[part C: competitive formation of semicarbazones at differing temperatures][part D: reversal of semicarbazone formation]  
[check-out]

## NMR

Name the compound that you think it is: trans-hex-2-ene. [cis versus trans coupling constants] What's the degree of unsaturation that we have here? We have one degree of unsaturation. We also have no heteroatoms; we only have carbon and hydrogen, so the only way we can get a chemical shift that is this high is to have an alkene or benzene. Of course, we have enough carbons for benzene, but way too many absorbances and too many hydrogens, and not enough degrees of unsaturation. Because we have degree of unsaturation = 1 and chemical shift > 5, it means it's an alkene – which since  $J = 15$  Hz, that means it is a trans alkene. Coupling constants exist any time that splitting happens, so all of these have coupling constants. But, I've only been reporting coupling constants for alkenes, because for all these other cases, for our purposes, it doesn't matter to know the coupling constants, it's not useful information. For alkenes, it is, because it lets us know if we have geminal, cis, or trans protons. Since we do have an alkene, that means there's no ring, because there's only one degree of unsaturation.

[How should we approach this problem?] An alkene is going to have one hydrogen on each position of it if you know that you have a trans [or cis] alkene. But let me emphasize – we only have two hydrogens that have an integral of one. If this was a terminal alkene, you'd have to have a third hydrogen there – or, this is one other situation in which you can only have two hydrogens, but then you'd only have geminal splitting. So, the fact that we have trans and we only have two hydrogens that integrate to one, means there has to be an alkyl group on each of the other positions of that double bond. The top peak, which is the doublet of triplets: what's the implication of that? All of the positions of an alkene are chemically unique from each other, even if I did have a hydrogen on the same carbon, because they're permanently in different relationship to the other groups on the double bond, they're all different from each other. If you look at the first two peaks, the ones that do have such a high chemical shift, one of them has to be this hydrogen, one of them has to be the other hydrogen. I'm going to arbitrarily make this top absorbance correspond to this bottom carbon, which means the next peak is the other alkene hydrogen. The first peak is split by the second; the second peak is split by the first.

What does the other information from the first peak tell us? Next to the bottom hydrogen, which is the first peak, we do have one neighbor on one side that causes the doublet, but then we have to have two different neighbors – equivalent to each other – that are on the other side – in other words, we have this. That's the significance of a triplet. How is that useful at all? We know that the chain has to keep going, cause we only have carbon, we can only have two hydrogens at this position, which means there must be a carbon that continues on. The next position also has to have two hydrogens: how do we know that from splitting? Which one of the remaining peaks corresponds to the green hydrogens? It has to correspond to one of the peaks that only integrates to two, cause there's two hydrogens. One of those is a doublet of triplets, one of those is a triplet of quartets; which one must it be? The doublet of triplets, because from the green hydrogen's perspective, look back where we came from: there only one neighbor on the lefthand side; one neighbor means splitting into a doublet. We fail to have a doublet in the other peak that integrates to two, so that other peak that integrates two cannot be the green hydrogens.

We started with a trans alkene. Then we choose one place to start. The other way to work this problem is start with the things that integrate to three, because they're methyl groups; they're at the end of a molecule. Then, you can work your way inward. This approach works, because if we start out with that top hydrogen, we know there's a doublet of triplets. Doublet means one here; triplet means two here. That's what we've got: one and two. We then need to figure out which one corresponds to the green ones. There's only two peaks that integrate to two. I know which one it is because it has to have a doublet, because from the green proton's perspective, there is only one neighbor on one of the sides. We've identified which of the peaks that integrates to two would correspond to the green hydrogens. Now we can see that there's also a triplet for those hydrogens, which is confirmation that, yes, we do have more neighbors down the chain, and, because there's only two neighbors, we know the chain goes forward at least one more position. We only have one more peak that integrates to two, so that must be the red hydrogens, which split the green ones into a triplet and which are split by the green ones into a triplet. Notice what other splitting we have at that location: we have a quartet. That means the neighbor must be a methyl group. There are only two peaks that integrate to three; one or the other of them must be the methyl group. Which one is it? The bottom one, because it is only split into a triplet, which would match having those two red hydrogens as neighbors. That matches, because those three hydrogens only have the two red hydrogens, so they are split into a triplet, so it is self-consistent. We only have one other peak, which is good because we only have one carbon left; we've used five of the six carbons. Automatically, that means the last thing to put on there is a methyl group, which corresponds to the other peak that integrates to three, and which will be split into a doublet due to the one neighbor on the alkene that it has.

Second problem. What's the name? DHP. Let's see how we get to this answer. What degree of unsaturation do we have? 2. Which means there's several possibilities: it could be a triple bond; it could have two alkenes; it could have an alkene and a carbonyl; it could have an alkene and a ring; it could have a carbonyl and a ring; or it can have two rings. You might think: wow, that doesn't do us any good. Not necessarily, because given the degree of unsaturation, and the fact that we have a chemical shift above five, what functional group likely do we have? An alkene.

If we have one alkene, that automatically means it can be the carbonyl and a ring, it can't be the ring and the ring, it can't be a triple bond, and, given that we only have two hydrogens, then I'm guessing that it's not a double alkene, either, because if we had two alkenes, with this limited number of carbons, we should have more alkene hydrogens. So, here are our only two possibilities: it's cyclic with an alkene, or it's got a carbonyl and an alkene.

What kind of alkene do we have? Cis. Let's start with that. Let's say that I arbitrarily start with one of these positions. I'll start with the top peak again. Notice that that is a doublet, which makes sense since we do have a neighbor there, which is the other alkene peak, which is, in fact, split by the first one. Notice that it's only a doublet, so what does that mean? There has to be something at this position; you can't have an alkene and just have a hydrogen, there has to be something there that's not a hydrogen, and there has to be something there that doesn't have hydrogens on it. In other words, there has to be some kind of structural feature that blocks splitting. There's only a very limited number of things that can block splitting. We could put an oxygen there, as long as it wasn't an alcohol. We can guess that it's not an alcohol, because there's nothing else that integrates to one, so it could be an ether. Maybe it's a carbonyl; carbonyls, if it's not an aldehyde, also lack the ability to split. I'll just suggest that's probably either a carbonyl or an oxygen.

Let's work on the other side of the molecule, though, and see if that helps us at all. If you go to the second peak, which is a doublet of triplets – the fact that it's a triplet also means it has two hydrogen neighbors. We have three peaks that integrate to two, but this can only be one of them – which one? From the green hydrogen's perspective, how many neighbors do you know it has up above? Right next door, there's only one neighbor, and if there's only one neighbor, what kind of splitting must it have? Doublet. One means doublet; two, triplet; three, quartet; four, quintet. If it has to have a doublet, the only peak that would work is this fourth one. What's the use of that? It's also a triplet, which means it has one more neighbor that has two hydrogens on it. Here's the tricky part of this question. I've so far used up four carbons. How many carbons do I have left? Only one. How many hydrogens have I used up? Six. How many more are left. Two. Both of those hydrogens have to be on that carbon, because if I have an oxygen, it's an ether, because I've already determined it's not an alcohol. If it's not an alcohol, if it is an ether, it can't hold any hydrogens, so the carbon must have both hydrogens. I've got three choices: one, which I think is the obviously wrong answer, is that the carbon is sitting out here in space, because how else could I have no splitting right here? If I put that carbon that has the two hydrogens on it at this position, I'm going to split this hydrogen, which it can't do, so that's the wrong answer. The only other choice is to put it down here, which works, because if I did put one more carbon with two hydrogens there, then the red hydrogens would have two neighbors on both sides, which would make it the triplet of triplets. There is only one more peak left, so it corresponds to those last two hydrogens. Now we've used up all of the atoms, except oxygen. Since we demonstrated, therefore, that there's no carbonyl, it has to be a ring, because that was the only other possibility that gives us two degrees of unsaturation.

This problem happens to have the same formula, and therefore degree of unsaturation, as the first problem – entirely different molecule, though. The spectral information for this one – 6.34, dd, 1H,  $J = 8.7$  Hz,  $J = 17.5$  Hz; 6.23, dd, 1H,  $J = 3.3$  Hz;  $J = 17.5$  Hz; 5.811, dd, 1H,  $J = 3.3$  Hz,  $J = 8.7$  Hz; 2.616, q, 2H; 1.112, t, 3H. Should we start with the methyl group? Yes, but you're not going to get very far. We do have something that integrates to three, so we know there's at least a methyl group. The methyl group has what kind of splitting? Triplet, which means it has how many neighbors? Only two neighbors. There is a peak that integrates to 2. The important realization there is the peak that does integrate to two only has a quartet, which means we're in the same situation again where we can't have any splitting. But, there's not quite enough information, per se, to figure out what would go here to block the splitting, although we might be able to make some educated guesses, because we could put one carbon there, which would leave two more carbons, so you could put two more carbons on that carbon, plus an oxygen, which would give us an alcohol, but we would have just created a molecule with no degrees of unsaturation. The only other logical choice would be an oxygen or a carbonyl, just like in the previous problem.

Let's leave that for a moment and look at the rest of the information that we have, because we have an alkene. Two degrees of unsaturation, chemical shift greater than 6 $\delta$ , and the fact that we have coupling information] means we have an alkene. What kind of alkene? Terminal. Why? If it's a terminal alkene, we have three different types of hydrogens. We know that there is geminal splitting. I'll label this middle peak here in red. How did I determine that that peak corresponded to that particular hydrogen? It has geminal splitting, but a coupling constant of 17.5 [Hz] means that we have trans; that red hydrogen is trans to the hydrogen that is on the other carbon. It's split by the two remaining hydrogens, which I'll color in magenta and green. Which of the remaining two hydrogens is which? There's only one other peak that does have geminal splitting. That one has a cis relationship, which matches the 8.7 coupling constant. We have one hydrogen left that has both a cis and a trans relationship, which means it must correspond to the first peak. Notice that all three of these are doublets of doublets, which, if you pick any one hydrogen, there's two other hydrogens that would be nearby that could split. This is an unusual case because we do have one carbon where the two hydrogens split each other. It's not the only situation we could have that; technically, if we have a diastereotopic proton, we could also have splitting within the same carbon.

Look again at the leftmost of these hydrogens, the one that corresponds to the top peak. We have a doublet of doublets of nothing else. That again means we end up in a situation where the neighbor cannot have splitting. How many carbons have we used up so far? Four. How many hydrogens have we used up? Eight; there are only eight hydrogens. So, we have a carbon, and we have an oxygen, which means we have what? A carbonyl.

This is the answer: pen-1-en-3-one. If we have a carbon here with two hydrogens, this one would be a doublet of doublet of triplets; you'd have triple splitting, meaning three different kinds of neighbors.

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C<sub>6</sub>H<sub>12</sub> – delta 5.45, dt, 1H, J = 15 Hz; 5.42, dq, 1H, J = 15 Hz; 1.95, dt, 2H; 1.643, d, 3H; 1.360, tq, 2H; 0.885, t, 3H

Because D.O.U. = 1 and delta > 5 → alkene → [J = 15] trans  
∴ no ring (only one D.O.U.)

C<sub>5</sub>H<sub>8</sub>O – delta 6.342, d, 1H, J = 6.2 Hz; 4.664, dt, 1H, J = 6.2 Hz; 3.957, t, 2H; 1.984, dt, 2H; 1.846, tt, 2H  
D.O.U. = 2 : C≡C, C=C & C=C, C=C & ring, C=O & ring, C=C & C=O, ring & ring

Given D.O.U. = 2 and delta > 5 [and J], likely to have an alkene.

C<sub>5</sub>H<sub>8</sub>O – delta 6.34, dd, 1H, J<sub>1</sub> = 8.7 Hz, J<sub>2</sub> = 17.5 Hz; 6.23, dd, 1H, J<sub>1</sub> = 3.3 Hz, J<sub>2</sub> = 17.5 Hz; 5.811, dd, 1H, J<sub>1</sub> = 3.3 Hz, J<sub>2</sub> = 8.7 Hz; 2.616, q, 2H; 1.112, t, 3H

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Structures – Identical to those from lab 14B (03/20/12)