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3.091SC Introduction to Solid State Chemistry, Fall 2010
Transcript – Exam B Problem 13

Hi. I'm Brian. We're going to be going over problem number 13 of the fall 2009 final exam. I like to think of the theme of this problem as polymers. So that's the overarching concept. But I'm going to give you some things I think are important to review and to know before actually meaningfully attempting this problem.

So there's three things that I that I sort of thought were very important. The first one is polymerization processes. So we learned in class and in the book as well that there's two ways that we've covered that you can create a polymer. And that is through either addition polymerization or condensation polymerization. And I'll talk about that more in a second.

The second thing you want to know is basically molecular weight and how it applies to polymers. And you want to know about elastomers for this problem. If you don't know about elastomers then you'll have trouble with the last part of the problem.

So that's kind of what I would review. And then once you've got that under your belt give the problem a try. So we're going to go and we're going to start the problem now.

We're given in the problem the 6-aminohexanoic acid, which I've drawn here. And we're also given at the beginning of the problem the structure of nylon 6. This is the actual reaction that's used to create nylon. So what I'm going to do is I'm going to show you-- or ask the question of how do we create nylon from 6-aminohexanoic acid. And that's actually going to answer part A and part B to this problem.

So to create a polymer-- in this case we're talking about the polymer nylon 6-- you actually have to add together many mers. So merge is the term we used to denote the single unit which is repeated n times to create the poly mer-- polymer. So in this case the mer, the individual unit of nylon 6, is 6-aminohexanoic acid. And that's this. That's the same thing right there. So we're going to add these together and we're going to start creating our long chain of nylon 6. Remember, nylon 6 a polymer is a really, really long chain. Think of it as spaghetti, very long spaghetti. It isn't just two molecules that react.

So let's just start somewhere. It's got to begin somewhere. You have to have two molecules at some point in the beginning reacting with each other. So let's look at our two molecules of 6-aminohexanoic acid-- I have to keep looking back at how to say that-- so let's take a look and we have to think about now our two possible processes or routes towards polymerization. There's addition and there's condensation.

Now addition, as you probably read and heard, requires there to be a double bond present between two carbon atoms. The reason for this is because usually have a free radical coming in, which will then initiate. That's why oftentimes the free radical molecule or free radical provider is called the initiator. You need an initiator to come in to break that double bond and then create another free radical. Which then lets the process continue along in a chain like that. If we look at our molecule here, we don't actually have any double bonds between two carbon atoms. We have a double bond with an oxygen but that's not sufficient for an addition-type reaction.

For a condensation reaction, what that basically implies is two mer units, or two things coming together to react and they give off a byproduct. So that's how I remember condensation, very often the byproduct is water. You can have other byproducts, like HCl or any other sort of small molecules can be given off. But most times what we'll see in 3.091 will be water given off in condensation, so it's sort of intuitive to call it condensation.

In this problem, if we look at this, we have a molecule that has the Hs on one side and has Os on the other side, we can actually almost see this immediately as being a condensation reaction. What's going to happen is we're going to have this O reacting with the positive end of this molecule, which has Hs. And we're going to have an H2O liberated and given off. We're going to have the new molecule formed. Let me draw the molecule for you. Let me write it out.

So we've just begun forming our polymer and this is a polymer which has an n of 2. It has 2 mer units building it. Notice I've kept the ends here. The positive and the negative here. In reality what's going to happen is we have a big vat of this 6-aminohexanoic acid and they're going to keep reacting. So we might have another one of these molecules float over and react with this O. Or conversely, we could have another one of these molecules come over and react with the H. So this thing is going to keep building. And the way these polymerization processes begin is the control of some parameter of the system. It could be temperature, pressure you can add something in to sort of initiate it. But that's how this is going to start.

So we've actually sort of answered part a and b. We've come to the conclusion that this is obviously a condensation reaction. Because we're going to give off-- I left that out there, see if you guys caught it-- H2O. So we're losing this O and two of these Hs and we're forming water. And that's the byproduct. And a byproduct immediately should tell you we've got condensation going on. So condensation polymerization, part A.

Part B, we've actually already done to sort of logic out the answer to part A. This is the answer to part B. Part B is just the reaction. I'll read it very specifically. Write the reaction that converts two molecules of 6-aminohexanoic acid into a dimer of nylon 6. So we have two molecules forming the dimer. You are going to have trimer, and it goes on and on. The most common mistake on this problem was to give us the full repeating units.

Let me just show you what that would look like. And then we'll move on with the problem. So the most common mistake on this problem was to not have these end units. And instead say, oh it's created this huge, long chain. So I'm going to write it as follows. And this is the symbol to imply that it repeats. Likewise over here. So people would give us this. And that's not correct. And the reason that's a problem is because not only do you lose points on this part, you also lose points on the next part.

So part C is now asking us to calculate the molecular weight of a molecule given a certain n. n is the degree of polymerization. So in this case, n equals 2, we've got a dimer. In part C, we have n equals-- surprisingly-- 3,091 You'll see that's a recurring theme in this class. So we have n equals 3,091 And the question is, how do we approach the molecular weight problem? Well we're told that we have 3,091 one of these mer units making up this polymer chain. So let me just write this down. We're going to form an equation. If we take the mass of the full chain and divide it by the mass of a single mer unit we should be able to extract the number of units in the chain. So let me write that out for you. So the total molecular weight of the molecule, divided by the weight of a particular mer unit. OK so we're going to put that as mer. And so this is easy. Let's first identify what our mer unit is. And this is why it was easy get tripped up on this problem. Because if you made a mistake on the part B, you have trouble on part C.

What is our mer unit? So in our mer unit, what we're talking about is a chain which has 3,091 of these linked pieces here. So let's look at this. What do we have? Here's our mer unit. Let me circle it. We have 6 carbons. We have 11 hydrogens, 1 nitrogen and 1 oxygen in this mer unit. We're not going to take the full, complete end unit. We're not counting this O. We're not counting those 2 Hs. We're dropping off 18 grams per reaction into water.

So this is our mere unit. Let's calculate the mass of our mer unit. So it's going to be-- let me write this here-- we're looking for molecular weight. We're going to divide that by the mass of the mer unit. Let me just write out the full line of what it would be. Approximately 6 times 12 plus 11 times 1. So this is 6 carbons, times the mass of carbon. 11 hydrogens times the mass of hydrogen. We're going to have 1 oxygen times the mass of oxygen. And we're going to have the nitrogen as well. So let me add that down here. 1 nitrogen times the mass of nitrogen. I rounded. That's OK. As long as you get the idea right.

So now we can easily just solve for the molecular weight. And we'll find that molecular weight in this problem will be equal to 3.5 times 10 to the fifth grams per mole.

There's another way to do this problem, actually. And what you can do is you can calculate n times the number of this-- this particular molecule-- and you can subtract off 3,090 orders. 18 grams. 3,090 times eighteen. You subtract that off. Think about a little bit why it's 3,090 and not 3,091. So that's just maybe a brain teaser for you. That is the answer to part C.

And now part D asks us if we're able to convert this into an elastomer. So this is where it's really required that you understand what an elastomer is and what that implies and what the structure looks like. So an elastomer-- and I sort of paraphrased this from the book and added my own thing to it-- is basically a randomly oriented amorphous polymer with some cross-linking such that you have the ability to move the chains but not slide them completely over each other. So in order to have an elastomer you must have cross-linking. In order to have cross-linking, what must you have? Well from lecture and from the book we know that to cross-link you must have double bonds in your carbons. So you must have 2 carbons-- going back over here-- which are double-bonded together. And why is that? Because what happens is those double bonds will be broken by some initiator element-- many times we'll have sulfur-- will come in, break the double bond and then you'll have links forming between things.

So let me actually give you real-life example of this so you can see what I'm talking about. We're going to show disulfide bridges bounding and creating cross-links in a molecule. Something we're very familiar with is rubber. And we're also very familiar with car tires. The big difference between those two things is that rubber has vulcanized Which means we're actually putting sulphur into it to create a different type of polymer. We're looking at a cross-linked, much stronger rubber which we use on our car tires.

So polyisoprene looks something like this. You should be familiar with this notation by now. We have this denotes it repeats. We have our double bonds, we have our carbons and hydrogens. This is polyisoprene. And this is what we're going to add sulphur to vulcanize rubber. We're going to create vulcanized rubber. sulphur generally actually looks, it's a ring of 8 sulphur atoms. We'll then add it to rubber, maybe heat it up mixed. And you'll make what you're used to on car tires. So what's actually happening here is that you can see we have this double bond between carbons. The sulphur's going to come in, it's going to react with this double bond, and is actually going to pull it off. And it might form a chain like that. And then this sulfur will then connect to another one of these polyisoprene molecules that was originally double bonded. And I'm not going to draw the rest of it out. And it's going to react, kill this double bond, and it's going to connect it.

So basically what's happened in this process of forming sulfide bridges is you've got this polymer, polyisoprene, connecting to this polymer, polyisoprene, and you have cross-linking going on. And that's what we would need to have in our case for the nylon 6 in order to get an elastomer, And because nylon 6, because our mer unit, 6-aminohexanoic acid doesn't have double bonds, we can't break them. We can't network. We can't cross-link. And therefore we can't make an elastomer. So the answer to this problem-- in a very long-winded manner-- is no. You cannot create an elastomer given that mer unit.