PROFESSOR: OK, OK. Settle down, settle down.

All right. Today is the last lecture. You think you're happy? I'm happy. So what I'm going to do, I'm going to teach for a little bit, wrap it up, and then I've got some comments about the final exam, and then some personal observations, reflections on the class.

So of course, the main announcement is the upcoming celebration of celebrations, a week from yesterday. The final exam will be Tuesday, 15 December, 9:00 to noon. I know 9:00 a.m. is kind of early for some of you. Use the buddy system. Get to that room on time. 9:00 to noon in the Johnson Athletic Center. I'll have office hours on Monday, 3:00 to 5:00, and Hilary will find a room. We'll post it, and you can swing by, if you want.

I guess the other thing I should say is just a reminder about the course evals. Please take a few minutes and fill out the course evals, if not for me and for your successors, but certainly for our TAs, so that I can write nice things about them when the time comes.

So last day we looked at binary phase diagrams. And we looked at two different types of binary phase diagrams. Type one, which is the lenticular, and type two, which is synclinal, and in both instances, we came upon two-phase regimes, and when p equals 2, that causes you to start thinking along the lines of phase separation. Phase separation then invokes a tie line. The tie line tells you the composition of the two phases present, and the lever rule tells you the relative quantities, the relative amounts, of the two phases present.

What I want to do today is talk about the last type of phase diagram that we'll speak about in 3091, and that's called type three. I came up with these very original, easy to remember labels. So type three. What characterizes type three phase diagrams? Well, we have partial solubility of A and B. We're doing all of this. A is one of the components, and B is the other component. So partial solubility of A and B, and change of state. And the result of this set of characteristics is freezing point depression of both components.

And that's different from the situation in type one. In type one, you see, if we have B on the right, then adding at A to B, if this is pure B over here, and this is pure A over here, adding A to B causes the freezing point of B to fall. But adding B to A causes the freezing point of A to rise. In this type three, we're going to have freezing point depression of both B and A. That's the difference between the type one and type three.

And actually, I'm going to approach this by a hybridization of sorts. So I'm going to consider type three a hybrid. It's a hybrid diagram of the lens and the syncline. I'm going to blend the lens and the syncline, and show you how to do that. So let me get one of those up here, so that we can look at it.

So what I'm going to do here, this is a great diagram to look at. It's gold nickel. And at the top, we have a type one, and at the bottom, we have a type two. And what I'm going to do, is I'm going to mix them. I'm going to hybridize them. I'm going to bring this bottom one up and have it touch the lens. And so we get is something that looks like this. We'll plot temperature versus composition. Left-- so here's temperature. Composition. On the left I have pure A and on the right I have pure B.

And we'll start here with the melting point of pure B. And when I add A to B, I'm going to get the depression that we see in the type one diagram. We want to start off like this, and use everything we've learned up until now. So up here, we have all liquid. This is all liquid. And over here, this is a solid solution. This is pure B, and this is B that has a little bit of A in it. So we're going to use the old metallurgical definition and call this beta. Beta meaning, beta is a solution of A and B, but it's very rich in B. It's almost pure B. So I'm going to call this a B-rich solid solution of A and B.

And we know from last day, you can't go from p equals 1, let's get those labels up here, you can't go from p equals 1 to another p equals 1 without going through a p equals 2. So this is single phase and this is single phase, and that means this one here must be two phrase. And what are the two phases? The two phases are the phases that are on either side. So this must be liquid plus beta in here. And that means-- phase rule-- p equals 2, tie line, lever rule. So that's what's going on in there.

And then the difference is, on this side, if this is t melting point of A we're going to start off with the same concept here. That we're going to get freezing point depression of A, as well. So we'll have the liquid. Over here we'll have an A-rich solution. So then I'm going to call that alpha. So alpha is an A-rich solid solution of A and B. And then that must mean that in between here, we have liquid plus alpha. And these keep going.

And in addition, down at the low end, I'm going to start with a syncline. I'm going to start with a syncline, coming up like so, and coming up like so. See what I'm doing? I'm taking the lens. I'm going to meet the syncline.

So what's here? This is alpha, this is beta. What's inside the syncline? This is miscibility gap, so this is alpha plus beta. So let's keep the phase labeling here. This is p equals 2. And look at how things have worked out so nicely. p equals 1, p equals 2, p equals 1, p equals 2, p equals 1, p equals 2. So nice.

And what happens when all this intersects? It intersects like so. Try to do this, stretch it a little bit. So these two lines connect. They cross at this point. They touch at this point, the don't cross. They just touch. And then this arc

comes up like so, this comes down like so, and now we have a line across here, and this comes down like so. OK? So the syncline stops at this value, which is the minimum temperature dictated by the two liquidus. We have a liquidus here and a liquidus here, and this gets you down to the lowest temperature.

And let's look at the phase mix going in this direction. p equals 1, p equals 2, p equals 1, p equals 2. What's happening at this point here? This point, we have three phases in equilibrium. We have liquid, alpha, and beta.

And this is the special point here. This is called the eutectic. This is the eutectic, which is the temperature at which we get liquid, all liquid, at the lowest value. So I'm going to call this here, I'm going to call this point e, and e is the eutectic. Lowest melting point on the diagram. Comes from the Greek, meaning easy melting. And at the eutectic, eutectic is special. Here we have p equals 3. It's a triple point. The eutectic is a triple point.

OK. So now let's take a look at some of the examples of such diagrams. All right? This is a good one now that winter is upon us. This is the antifreeze diagram. So on the left, I have pure water, and on the right, I have pure ethylene glycol. And as you can see, if you add glycol to water, you get freezing point depression. If you add water to glycol, you get freezing point depression with a eutectic here at roughly two-thirds. This is in volume percent, because that's practical unit. When you mix glycol with water, you do so by volume, not by mass, or certainly not by moles.

So if you mix two glycol with one part water, you'll end up with a eutectic of minus 69 degrees C, or minus 92 Fahrenheit. So that ought to take care of your driving needs. All right? Now practically speaking, we put an equal volume mix. So it's about a 50-50 glycol-water mix. And that gives you liquidus depression down to about not quite minus 40. It's about minus 35 Fahrenheit, which ought to take care of most peoples' driving needs.

Remember, what we're trying to do is to prevent the liquid in the engine block from freezing. because if it does freeze, you know that ice has a larger volume than water, and that energy is so great that you'll crack the engine block. So you have to prevent it from freezing, the water from freezing, and so you add the glycol.

If, by chance, the temperature dropped to minus 50, you'd still be OK, because you'd be in the slush zone, two-phase regime. You'd have some water ice forming, but you'd still have slush. And by the way, why does this not look like this? It turns out that the amount of solid solution behavior of a glycol in water is vanishingly small. So this point is slammed up over here. So that's why you don't see the right side of the lens. And likewise, on the other side, the amount of water that's soluble in glycol is vanishingly small. So according to this scale, you don't see the beta or the alpha phases here. It looks like it's pure, but it can't be, because of the phase rule here.

Now, you might say, well, why don't we run pure glycol? Because somebody might say, I'll just run pure glycol. Well, here's the problem with running pure glycol. First of all, if you get beyond two-thirds, the melting point rises.

But then you could say, well, but pure glycol, the solid glycol, has a smaller volume than liquid glycol, so it wouldn't freeze and crack the engine block.

But there's another problem here, and that is that the viscosity of water is 1 in these units, centipoise, and glycol is 21. So you'd probably burn out your water pump by running pure glycol, because it's so viscous, the water pump is going to be fatigued by running.

And here's the point. This is the 50-50, minus 37 degrees Celsius.

OK. And so what I've done, is I've superimposed the solid-liquid diagrams with the liquid vapor diagram. And this is one of the times when nature is kind. So when you add glycol to water, water is on the left here, as you add glycol to water, you get freezing point depression, and you get boiling point elevation. So adding glycol to water opens up the liquid range. You want to stave off boiling, because boiling will cause lousy cooling, and the engine will overheat, and you want to stave off freezing, which will cause the ice to form and crack the engine block, and you get both. Then you put the pressure cap, and then jump this up to about 265 degrees Fahrenheit.

So this is a very good example of management of the properties of the coolant through chemical change. And the binary phase diagram eutectic type is a critical piece here.

Again, apropos of the weather, if you get ice on the sidewalks, if this rain freezes, it's terrible here. Those of you who are in the Northeast for the first time, this is bad. Not with what you see now, but when this freezes, it's a skating rink, and you can't see it. It's black ice. You're walking along, next thing you're on your-- you're in the horizontal position, all right?

So we can add sodium chloride to water, and when we do, we cause this, a eutectic type diagram, which can give you freezing point depression and prevent ice formation, and if you get enough sodium chloride in, you can get the temperature down to minus 21 degrees Celsius.

And I've color coded all of these. This is the liquidus, this is the solidus, and then this line here, I can't remember if we gave it a name last day, this is called solvus. This is the solvus. This is, we know, liquidus. This is liquidus, and this one here is solidus. Yeah. OK.

So this is all color coded. And notice that minus 21 Celsius is not too different from 0 degrees Fahrenheit. Turns out, that's how the Fahrenheit scale was born. Daniel Fahrenheit was a glassblower in Leyden who also made exquisitely accurate mercury thermometers. And he used ammonium chloride, not sodium chloride. And the lowest temperature he could get for all liquid with ammonium chloride, he pegged as 0 on his scale.

And it's roughly this. It's a little bit different, but you can see the similarity.

Now, you need two points to define a scale. So he took this mercury in bulb thermometer, put it in the eutectic mixture of ammonium chloride and water, said, that's zero, calls in his wife, tucks the mercury in bulb thermometer under her armpit, and says, that's 96. And that's the birth of the Fahrenheit scale. And that's why we have water freezes at 32, and it boils at 212, and all the other nonsense. You know, it's 98.6, but here it's a little bit colder. Now, why he chose 96 and 100 instead of 100 or something, you know, you could read in the history. Maybe he wanted something that was a power of two. I don't know what the reason for it was, but that's why we have the Fahrenheit scale. OK.

Now, maybe you're a little bit hypertensive, so you don't want to throw sodium chloride on your walk, so you can put potassium chloride. But you won't get much of a freezing point depression, And point of fact, we usually salt our roads with calcium chloride, which gives you two advantages. Number one, very, very low eutectic. Number two, it's a lot cheaper than anything else. So it's the cheapest one to use, and that's why we use it.

Christmas is coming, and I told you that phase diagrams would save the day. We saw that the cubic zirconia was stable in pure zirconia only at temperatures above 2000 centigrade, which is useless for a ring, or other such pieces of jewelry. But by the addition of calcium oxide, we stabilize the cubic form of zirconia all the way down to room temperature. And now we've got the high index of refraction, clear, colorless gemstone that passes for diamond. Poor man's diamond. Cubic zirconia. And you can see in this regime here.

And notice that cubic zirconia-- here's a eutectic. Why I'm showing you this is that the zirconia- calcia system ultimately becomes eutectic. And the eutectic is at about 2300 degrees C. But over here is the solid solution. Notice, if it's a solid solution, that means it's p equals 1. Single phase. As it must be. If it were two phase, the gemstone would be frosty, right? You'd have all those internal surfaces, and they'd be reflecting. So this is clear and colorless.

And what's it bounded by, this region? Cubic zirconia plus calcium zirconate. So p equals 1, single-phase field, p equals 2, dual-phase field. And what's on the other side? Over here it's tetragonal solid solution, single phase. Here's tetragonal solid solution with cubic zirconia, two phase. Here's cubic zirconia, one phase. Here's cubic zirconia with calcium zirconate. Two phase. Same concept here. p equals 1, p equals 2. p equals 1, p equals 2.

OK. So now you know. When you go in jewelry store, ask the guy, is it single phase? He'll say, get out of here.

Actually, you know how they test? The index of refraction is so high with zirconia. It's a little bit less than diamond. Diamond's up around three. Cubic zirconia is over two. One of the ways they test is, diamond has a very high band gap, about 5.5 electron volts. But it's got the remarkable property, even though it's an electronic insulator, it's a very good thermal conductor. Most materials that are poor conductors of electricity are poor conductors of

heat. But diamond, for reasons I can't explain with just the utility of a 3091 education, has a good phonon transmission properties.

And the way they tell cubic zirconia from diamond, is they actually put a couple of tips on either side of the stone, and they heat one tip, and measure the time lag for the thermal wave to get to the other tip. And if it's cubic zirconia, it takes a long time, because cubic zirconia is an insulator. If it's diamond, it's almost like metallic conduction. And that's how they can tell a fake diamond from a real diamond.

Here's, you know, I've been drinking from these cans all semester. And this is the alloy system, aluminum magnesium. So we put about 1% magnesium into the aluminum. So here's pure aluminum over here. It goes down to eutectic. This is pure magnesium over here. They both melt at roughly the same temperature. And by putting about 1% magnesium in here, it changes the metallurgical properties favorably. Notice we don't want to put 4% or 5% magnesium in here. Otherwise, as we get down to room temperature, we'll enter a two-phase regime, and that means we won't be able to process.

Because this can is made from a single sheet of aluminum. The body of the can. There's two pieces, the top and the body. There's no third bottom here. Start with a flat sheet of aluminum and it's punched deep, drawn down, up, down, and it gives you the whole shape. And you have to have, you know, this is FCC. You have to have the glide. Dislocations are gliding, the slip systems are operative, and the magnesium gives you just a little bit of strength.

But if you get into the two-phase regime, the punch, instead of making deep drawing metal, will end up punching holes. So what's the difference between drawing and punching holes? It's all in the metallurgy. So you can see, this is where we are. OK.

Ah! Microelectronic devices. How do we hold all those wires together? With solder. And this is the phase diagram for solder. It's made of lead and tin. And we use eutectic. The eutectic here is about 62 weight percent tin at 183 degrees Celsius.

I took a class in high school called Industrial Arts. It was shop. We had it drilled into us, the eutectic point of soft solder is 374 degrees Fahrenheit. I will know that on my deathbed. Plus the wavelength of copper K-alpha radiation. 1.5418 angstroms. Yeah.

So what's the magic here? The magic here is, the solder must be low-melting enough that when you're-- remember, you've got your microelectronic device. You've already got your chip, and you're putting wires. You want to put enough heat in to solder the wires, but you don't want to have to raise the temperature so much that you can damage the rest of the device.

So you say, well, why don't you get something that's lower melting? Well, if it's lower melting, you know from running your laptops and charging your cell phones, they get warm. So it's a Goldilocks problem. If the melting point of the solder is too low, you might encounter that temperature in service, and pop all of the joints. If the melting point of the solder is too high, then you have to use so much energy to make the joints that you damage some of the microelectronic componentry. So this has to be in the right temperature range.

The problem with this excellent, excellent solder is that it contains lead. No one's going to get lead poisoning from using a device. But the disposal of the device ends up introducing the lead into the landfill, and then if it soaks in an aqueous solution, you could get leeching, et cetera. So there's a lot of research right now on trying to find other solders that operate. And there are other solders, but they're very expensive. So that, how do you find something that's functional the way this is, nontoxic, and cheap? They can give you any two of those, but to get all three of them to line up? Requires research. You see the alpha phase, beta phase, everything there. All right.

And here's the lead tin system. And let's just take this one that happens to be 40%, and let's see what happens. We'll go through in time. So we start here, all liquid regime. And so this bubble shows what you might see on a microscope slide. So it's all white here, meaning that it's homogeneous single phase. And then you drop into the two-phase regime, just below the liquidus, and you start seeing these blobs.

Those little blobs are the primary alpha. That's the solid solution, right? Because we're in the two-phase regime, so we've got a tie line here. We get down to a lower temperature, there's more of this stuff. There's more of this stuff forming , because it's forming in time. It takes you time to traverse this. This isn't parking and waiting. This is just cooling something. Imagine you're soldering, so you took the temperature up to here, now you're going to let it cool.

Once you cross the eutectic temperature, now it's alpha plus beta. So now you get this lamellar structure. Stripes of alpha, stripes of beta. But the previous blobs that formed the primary alpha, they don't disappear. The only way they can disappear is by solid state diffusion. That's going to take a long time. So I can look at the microstructure here, and I can predict-- not predict-- I can go back and calculate what the cooling rate must have been. If I cool very slowly, I will have nearly the equilibrium structure.

And so that's why, when I told you about, say, analyzing the records from the World Trade Center, I can look at the metal, and look at the phase distribution, and tell you what the thermal history was. And so for example, there was some cock-eyed theory saying that the steel was burning. Somebody said that the steel melted, and so on. You can look and you say, that did not happen. Temperatures went fairly high, crossed into some different solid phases, went from BCC to FCC and then back. But didn't melt. Because if it melted, we would have seen this kind of structure. So this is-- every time a plane crashes, this is the metallurgical investigation that is taking place. The

history is written in the microstructure.

So this is a micrograph that's actually taken from some solder. This is 50 weight percent. The slide was 40, but this happened to be 50. It's the one I could find easily. So 50 tin, 50 lead, and these dark zones are the primary lead-rich alpha. And it's all metal.

So how do I get the dark and the light? First we polish, because it's an optical microscope, which has a really crummy depth of field. So you've got to make it flat, and you polish it, and now you've got a mirror, and you look, and all you see is your eyeball. So what you do then, is you etch it with some acid. And the lead will etch at a different rate from the tin. And the contrast, then, is what you see here.

So this is all the blobs of primary alpha. Then you go below the eutectic, and, you know, this cute little schematic of stripes-- this is the textbook version of it, but this is the real version of it. And you see, it's a distorted lamellar structure. Alternating stripes. Because you're trying to make alpha and beta. And so you're making alpha and beta, and the system's trying to make both of it. So it makes it in striped form called lamellar microstructure.

So I can look at that and I can say, wow. That must have been cooled at a fairly rapid rate, because you've got a large amounts of primary alpha. If it were cooled at a very slow rate, the thing should be all lamellar structure, right? If you're down here, there should be no alpha. This is not the equilibrium phase. So this alpha is trapped there. It's a victim of its history.

So there it is. That's cute. That's a nice, it's a beautiful graphic. See? There it is. All right.

So I'm going to show you some phase diagrams from hell. This is, you're going to be on airplanes. The airplane alloy is aluminum copper. It's about 4% copper and aluminum. Now remember, I just told you about 1% magnesium and aluminum to give you single phase. In the case of the airplane, we want to make the wings strong. So what we do, is we come down into here, which is a two-phase regime. And if we're clever about it, we can control the particle size of that second phase. And by controlling the particle size, we can cause grain boundaries, which can arrest the dislocations and make sure the wings don't fall off.

This is aluminum manganese. This is the one that Danny Schechtman worked with to get the quasicrystals. Look at all the phases. He's running out of Greek letters by the time you get across this diagram. Look at it. But one thing holds. The two-phase regimes are always bounded by single-phase regimes. Look. Here's liquid, here's a two phases, there's a single phase, two phase, single phase, two phase. Beautiful. All makes sense.

Now, what happens if you try to take a metal and mix it with a nonmetal? They don't want to mix. Look at the big miscibility gap here. Molten iron doesn't want to mix with molten sulfur. This is a liquid-liquid miscibility gap. Over here, you can add some sulfur to iron, you get a eutectic, get a line compound. And then over here, no dice. Does

not want to mix. And look at all the solid phases. Why do we have all these solid phases? Different crystal structures.

OK. So now what we're going to do, is I'm going to talk about application of phase diagrams to the making of champagne. Because champagne relies on phase diagrams. And then I'm going to make some general comments.

But I'm going to actually show you some champagne. So before I get into my commentary, I'm going to get some champagne chilling. So first I have to show you how to chill champagne. First I will show you how not to chill champagne. This is how not to chill champagne. And it's not because, OK, we can put it in there. Why? Because, as I showed you last day, with respect to the cooling of the engine coolant by the radiator, if you have-- if this a bottle here, here's the contents, the precious contents. And I have this with blocks of ice. The contact between the ice and the bottle is sporadic, and I've got air in between, so the quality of the cooling is very poor.

So instead, what I do is I rely on the phase diagram. So what do I do? What do I know about the phase diagram? if I pour water in here, I will thermostat the entire system, liquid plus solid, at 0 degrees. Because the ice is probably, I don't know, minus 3, minus 4 Celsius? But the air is 20, and it gets in there, and it's very few atoms. It's crummy heat transfer. Instead, if I flood this with water, the whole thing is thermostatted at 0 degrees C.

So now I've got a good delta t, because I started here at about 22 degrees C. I've got a delta t, and it's a fixed law, right? It's going to be what? It's going to be the flux. The heat flux is going to be minus thermal conductivity, dt by dx. It's Fickian type motion of the thing.

So let's do it. This is how you properly chill-- I'm told it also works for sodas and fruit juices. This technique, I mean. But I do know that it works with champagne. Now that's working beautifully. I can just feel the heat being extracted.

OK. So now let's talk about champagne. All right. So we're going to talk about champagne and a great inventor, and the inventor is the Widow Clicquot. This is the Veuve Clicquot champagne. And veuve is the French for widow.

So Veuve Clicquot, her real name was Nicole-Barbe Ponsardin. And in 1798, she married Francois Clicquot. This is a big French winemaking family. And he died and left her a widow at the age of 27. She was very unusual for a French woman in the 18th century, because they were not involved in society. They were certainly not involved in business. This woman was different. She decided to get under the hood, and she took control of the winery. And I've written here, bold, imaginative management. There's a fantastic book about her. It's actually a very good book portraying late 18th century, early 19th century France.

And these are among her accomplishments. Marketed champagne to all the great courts of Europe. Champagne was a regional beverage, drunk only in the Champagne region. And she created the myth, propagated the myth of champagne. You use it for festive occasions, bought land in the best vineyards, quality control. It's about the chemistry. Fought fiercely against counterfeiting. As she started getting champagne more recognition, people started making sparkling wine and labeling it as champagne. She used the court system to take them down. Established strict quality control procedures. That's all about defending the brand, and what's the quality control? It's the chemistry. Produced the first rose champagne. The Pinot Noir grape has a black skin. Depress, and then take the juice, and away you go. What she did, is she let the skin sit with the juice for long enough to give a just a rose tinge.

And then oversaw the invention of new technology. Remouillage. And that's where the phase diagrams come into play. Phase diagrams give us champagne we enjoy today.

So what's the problem? Champagne is cloudy. Why is it cloudy? Well, here's the chemistry. Here's how you make, this is how you make all wine. It's one-stop shopping. You take the grape. The grape has sugar in the grape juice. And yeast that attacks the sugar is in the skin. So the yeast attacks the sugar to make alcohol and CO_2. So ethyl alcohol and CO_2, plus some insolubles.

There are some insoluble products of that reaction. And there's two types of insolubles. Those that will settle, they're called sedimentary, and those that won't settle. They're called suspended. And how do you get rid of the sedimentary stuff? By mechanical separation. You let the juice sit, this reaction is taking place, and the sedimentary stuff is turning into gunk, and it sits at the bottom. And then periodically you siphon. You siphon the juice off, and you leave all the crud at the bottom of the barrel, and then you go for a few more months, and then you siphon again.

Well, that works for the sedimentary stuff, but it won't work for champagne, because as you're siphoning, you're letting out all the gas. You see, you're trapping this gas. The champagne has CO_2 that's naturally occurring. It's not carbonated. It's carbonated naturally. Not carbonated, man-made carbonation. It's natural carbonation.

So how do you separate the juice from the crud without losing the gas? That's the problem. And by the way, the other stuff that's suspended, they use tricks. You know, here's the free body diagram. Remember, I showed you this for milk. So what they do, is they add things like eggshell, and the eggshell acts as a coagulant, so the tiny particles that will float agglomerate to become big enough that then they'll settle. Tiny particles of a given density will float, large particles of the same density will sink. So you need to coagulate, and do that without spoiling the taste. Fantastic chemistry.

So she comes along with the answer. By the way, the early champagne glasses were all cut crystal. Why were they cut crystal? Because the champagne was cloudy. It tasted fantastic, but who wanted-- it looked like swill! So how to make it clear? So what they did, is they made champagne bottles with the deep ruts, and they still do to this day. They have a deep rut here, because the idea was, if you opened it carefully, you wouldn't disturb so much of the crud. But it gets churned up by the gas.

So what she reasoned was, let's turn him upside down, and let's have the crud settle on the underside of the cork. And furthermore, 45 degrees is the optimal angle. You know this from your Newtonian mechanics. And then you turn them, so you spiral the bottle. Turn them, and have all the crud collect on the underside of the cork.

I know what you're thinking. How are you going to get the cork out? Now you take the cork out, you're going to lose not just the gas. You're going to lose the liquid, too. Ah, that's where the phase diagrams come in.

So here's a phase diagram of ethanol water. And it's eutectic. Look at, way down here. In fact, ethanol makes a really good antifreeze. Look! A little bit of-- go way down here.

Now, most wines are somewhere between 10% and 15% alcohol, that gives you very modest freezing point depression. Maybe about minus 5 Celsius. Which is why if you forget, you put a wine bottle in the freezer and you forget about it, and you've got your freezer really cranked to, say, minus 5 Fahrenheit, you'll freeze the wine, and it'll expand, because it's 90% water, and push the cork out, make a mess.

But remember, you only get down to about minus 5. Remember, I showed you this one? It gets down to minus 21. So what she reasoned was, what if you took the bottle upside down? You've got all the crud on the underside of the cork. What if you took the bottle and put it into not water, but what if I put sodium chloride in here? I still have my ice cubes, only the temperature is now minus 21. And that's below the freezing point of the alcohol, and now I've frozen an ice plug in the neck. So now there's an ice plug between the crud and the cork. So now I can turn the bottle like this, just melt ever so slightly, and the pressure in the bottle will blow the ice plug, take with it the crud out, and then I quickly put the cork on top. And that's how every bottle of champagne is made.

And it all comes from these phase diagrams. See? So you put it in brine. Minus 21. But this thing is frozen already. That red is frozen. And now I've turned it right side up, out it goes, takes the crud with it, put the cork back on. So it's a combination of this phase diagram, this phase diagram. Both eutectic phase diagrams would give us clear champagne. Positively brilliant.

So there it is. The invention and-- oh, by the way. They call this-- the English word remouillage is riddling. So they have people that actually go, and they, these wooden racks with the slots in them at 45 degree angles, and all these bottles are pointed downward, 45 degree angle. Guys come in every day, quarter turn, quarter turn, quarter

turn.

French are very traditional. Few champagne wineries have motorized, so they have this thing called giropalette. Gyrating pallet. The California champagne wineries call it VLM. Very Large Machine. I kid you not. I didn't make that up. In California, the giropalette is called VLM, which is Very Large Machine, dude. I guess. That's what they say. California.

All right. So let's have a few words now about the final exam. So you know, it's going to be Tuesday, 9:00 to noon, Johnson Athletic. Three hours. You have three full hours, not three times 50 minutes. Three full hours. But I'm not going to give you three times the work. It's sort of a hybrid between intensive coverage since T3, so sort of like a T4 and a redemptory part. It'll go back, extensive coverage of everything.

One aid sheet. One aid sheet. I'm saying it three times. One aid sheet. Do not come in there with a bunch of aid sheets. Well, I didn't know! I thought we could have-- no! One aid sheet. That's all you need. And the TAs are smart. You know, every year somebody tries to bring the origami and all that stuff. And they get caught, and then-- you know.

Bring your periodic table, table of contents, calculator, a pen. No headphones, no audio. Please. Because people are writing, they're trying to concentrate. I don't want to get into a dispute over whether your music is too loud for your neighbor. So let's just, out of courtesy, no audio. You can go three hours without your music. All right?

What else. This is going to be comparable difficulty to the monthly tests. Of course, read the entire exam. You've got plenty of time. Most people are leaving 11:15, 11:30. It's not a race against the clock. And make sure you show your work, justify your conclusions, solve algebraically. Stay confident. Do your own work, academic honesty, all that applies.

Now, your overall grade is going to be based on many factors, including the trend. So we're going to look at how you performed throughout the semester. You started off really strong, and you crash and burn on the final, or you've done the math and you say, I only need a 37 on the final, and you go in there, shooting for a 37, and you miss and you get a 35, and your total average is 49.5? You go down. Because you've got a 49.5 and you wrote a 35 on the final. I'm just telling you.

Claim, you can have your exam papers back. But don't come and see us before Christmas. You can have them back starting IAP. So starting January 4, you can have your exams back, if you want them. And there's no time limit for appeal, so you don't have to be bursting into your TA's office on January 4 if you see that we've misgraded something. You can come and see us.

There will be some security measures in place. It has not escaped my notice that some people have attempted to

erase answers that were written in pencil, and then bring in this newly brilliantly solved problem for regrading. And that's, of course, qualifies as academic dishonesty, and I'll take you to the committee on discipline if you try it. But just to inspire honesty on a random basis, we'll photocopy about 5% of the exams. So if you want to try this, the question you've got to ask yourself is do you feel lucky? Do you?

All right. So now it's time for some personal observations. So I wrote them down.

OK. So first thing is, you've come a long way. Syllabus is full. You think about where we were on day 1, you know, this is equations, stoichiometry, all that baby stuff. And you know, look. So be proud of what you've learned.

Number two. I wish you much success on the final. Remember, no grade that I assign to you, or any of my colleagues assigns to you has any relevance to your value as a human being. It's just a grade in a subject. That's all it is.

What's the worst thing that can happen? Suppose you get all Fs, and you're required to withdraw from the Institute. So what? So what? You know? You're all smart people. I know you're smart. I used to chair the Admissions Committee. I know how smart you are. If you're getting all F's, this is not the right place, it's not the right time for you to be here. Look, I have no degrees from this place. I feel great.

I've been teaching here at MIT for 32 years, and I've never enjoyed teaching as much as I have this semester. This has been really a blast to teach, really. I can't believe I said that with a straight face. So of course it's not true.

I want to think my staff. My TAs, sitting here. The tutors who helped out. Professor Demkowicz, who subbed for me that time, when I had the visit of President Obama. Administrators, the audiovisual techs. Dave Broderick, who's done a great job of making sure that we have sound and light. And the academic media production services people, who have recorded the lectures so that on the rare occasion that you didn't make it the class, you're able to catch up.

And the last thing is that, I've got here, there's one more chemistry lesson. You know, we've learned about the four different types of primary bonding. Covalent, ionic, metallic, and in some instances, van der Waals. But there's a fifth type of bond. The fifth type of bond that I haven't talked about yet. And it's the type of bond that's been forming in this room over the last 14 weeks.

Yeah, I know. It's kind of sappy. I didn't come up with this. It came from a student.

So the fifth type of bond is-- it's not this one.

[MUSIC PLAYBACK]

No, it's not this one. It's a bond that's formed between people, and this bond has a very special property. It can never be broken. I know! It came from a student. It's very sappy. I'll tell you the story. I'll tell you the story how it happened.

I used to teach 321, which is a core graduate class in kinetics. And I'd been teaching it for, I don't know, five, seven years. And I was at a conference, and there's these two people standing there talking. And I know both them. One was from industry, and one of them was an alum. So I go up, and the fellow in industry, says, hi, how are you doing, do you know so and so? And I said, yeah. He was at MIT. I was his kinetics professor

And the student, the alum, he says, excuse me, Professor Sadoway. It's true that I was at MIT, but please do not say that you were my kinetics professor. You will always be my kinetics professor. I went, oh, man. This is really something.

So now the tables are turned. And, and, you know, I know you're going to go go on and do something remarkable in your life, and I hope it's remarkably wonderful and not remarkably stupid. But you know, at some point, somebody may say to you, where did you learn your chemistry? And you'll have to say, Sadoway at MIT. So whether you like it or not, I will always be your chemistry professor.

So now, let's see. I think it's time to open up the champagne. So first thing, we have to teach you how to open champagne. So there's the foil here. So we'll take the foil off. Take the foil off, very carefully. And then there's the wire basket that keeps the cork on. How many turns on the wire basket? Everyone in 3091 knows. Six turns. One, two, three, four, five, six. Six turns.

And so now, I don't want to point that at anybody, because the only thing between me and six atmospheres of pressure is that cork. And Dave, if we can cut to the document camera. The cover, the metal cover on this, has the image of the Widow Clicquot. This is Veuve Clicquot, and this is the image of the Veuve, and she's on every bottle. She was the one that gave us clarified champagne, so you thank her very much.

All right. So now what we're going to do, is we're going to open this thing. To open it, we point it 45 degrees and turn it ever so slightly. Never point it at people. No, really, point it away. You'll put an eye out with this thing. You turn it very slightly. Actually, my hands are wet now, so I'm going to use a towel here. Oh yeah. Go like this. You like the suspense, huh?

See that? No pfff! That's for football locker rooms. It's very declasse. OK.

Now we have to have a glass. So since we have clarified champagne, we're not going to use cut crystal. We're going to use Baccarat, French crystal that's not cut. Because we've got nothing to hide, right? So now we're going

to pour this. And the rut now has some value. The rut has value, because now what you can do is to pour it like so.

I've been waiting fourteen weeks for this.

All right. So the surface tension, you see the carbon dioxide outgassing, because it's supersaturated. Six atmospheres, not one atmosphere. The bubbles are nucleating on the defects in the glass. It's all about chemistry. So there we go.

OK. So I'm going to propose a toast to the class, to the 3091 class of Fall 2009, to wish you much success in your academic pursues, and much happiness in your personal lives. And with that, I'm going to find out what's going on inside.

Look at those bubbles! You know, the legend is, the blind monk, Dom Perignon, when he first drank champagne, said, I feel as though I'm drinking stars. He's right. Drinking stars.

OK. This is to you.