OK.

Let's get started.

How's everyone doing?

Wonderful.

Come on, let's do better than that.

How is everyone doing?

Wonderful!

Thank you.

Welcome to 3.091.

This is the first day.

And I'm really excited.

I hope you are too.

In this very first lecture, we're going to do a little bit of administration, tell you a little bit about the class and how it's set up.

And then we'll give a little mini-- we'll have time for a mini lecture in the second part of the lecture today.

So I thought I'd start by inducing me.

My name is Jeff Grossman.

I am in Course Three, that's the Department of Material Science and Engineering.

My background, I went to Hopkins, undergrad, moved my way towards the west coast, Illinois PhD.

And I did a post-doc at Berkeley.

And then I came here to MIT about nine years ago when I joined the faculty.

My own passion, my own interest in research is in materials for energy and water and chemical processes and separations.

So I thought I'd just give you a little example of what I mean by that.

So I get really excited about the ability to take the material and make it do something that it can't do now, but that it needs to do to solve a problem.

Maybe it needs to be cheaper.

Maybe it needs to be more efficient.

So one example is in this material.

This is a barrel of oil.

And what we do today with this barrel of oil is we mostly burn it.

A lot of what we do is burn it.

Now if you do that, and you think about it in terms of energy, that's 159 liters of this material.

And if you think about what you're carrying about as energy, you get 1.73 megawatt hours of energy out of that.

But see, I like to think about materials, again, and ask them what they can do differently for me, for these problems.

And so if you think about that and you say, well, OK, let's just take 1% of the carbon in that barrel of oil and do something with it.

Let's make thin film solar cells.

Well, if you do that and they're not very good, they're 5% efficient, they completely die in a year, you get 10,000 times as much energy over that year than burning it.

So it's an example of what you can do when you think about using elements differently.

That's what I get really excited about in my research.

And that's just one example.

You can take that same carbon and you can make a thermoelectric, that's on top.

Or you can make the world's thinnest filter.

That's a piece of graphene with a hole in it.

And that's still working with just one element, carbon.

All right?

So there are many, many things you can do once you understand what these elements are and how they combine together.

And that's what we're going to talk about in this class over the fall.

How many elements are in your phone?

Listen, we just talked about one element.

Anybody know how many elements are in your phone?

How many?

Take a guess.

Seven.

27.

OK, it depends.

It depends.

Do you have the Samsung?

If you've got the Samsung whatever, it might light on fire.

If you've got the newer one, it won't.

Do you have an iPhone?

Well you know what?

In the iPhone, there's 63.

63 elements.

So we have these lectures in Course Three, they're called the wolf lecture.

And I gave one a couple of years ago.

If you're interested in hearing a little bit more about what I do or what some other people do who think about materials in this way, you can use Google wolf lecture and you'll get to some of the videos.

And I'll mention it when they come around during the year.

OK, so that's a little intro to me.

What about the class?

So as I said, the class-- at the heart of the class is kind of what I just described.

But in order to do that, we need to know some very basic things.

We need to know how atoms are arranged, the atomic arrangement right there.

But we also need to know what atoms are there in the first place.

So if we know that, if we know those things, then we can build, then we can build.

We can get properties.

We can get structure.

We can get processing.

We can get performance.

And we can talk about how all of these things relate to each other.

They're all correlated.

If I change the processing of something, I change the properties.

How do you know how it changes when you've got to know these things?

And at the core of it all is really the thesis of this class, which is that the electronic structure-- Paul will be talking about this-- structure of the elements holds the key to understanding.

That really is what this class is about.

Holds the key.

The electronic structure of the elements holds the key.

That's what we're here to talk about.

And the first part of this class is really the basic foundations of chemistry.

Some of you may have seen some of this before.

We're going to build these elements.

We're going to talk about them.

We're going to learn about the electrons and the electronic structure.

But then we're going to make solids out of them and we're going to talk about what those do and how the chemistry relates to the solids and to the properties of those solids.

Now, I want you to know, again, this is the sort of administrative introduction.

You are not alone.

On this journey, you have many, many resources.

And we are here to help you, to help you learn this material and do the best you can.

So first you have me.

You have your TA.

We'll talk about them in a second.

You have Laura.

Oh, we're going to talk about Laura in a second.

You have the textbook and the internet.

I hear there's stuff on the internet.

And you have each other.

And I really want you to work together.

Thank you.

Who said --that was...

I was like, that hit made right here, right in the first 10 minutes of class.

So the textbook is Averill.

It's a really good textbook.

It's a really good textbook.

Please use it.

Please.

It's available here.

Notes, like I said, will be posted on the same day of each lecture.

I'll post whatever you see on this screen.

I will post.

All right, good.

The goody bag.

So the goody bag is another part of your homework.

And these will be given out nine weeks.

So sort of like the quizzes.

And in each goody bag, which I'm going to talk about in a second, there are things to do.

This is a hands on compliment to 309.1 lecturers and all the other materials.

Now, these goody bags are really important.

And one of the two quiz questions, every week that there's a quiz, there are two questions.

And one of them will be directly related to something that you're supposed to do in the goody bag.

And in fact, we will most times ask you to bring something into the quiz that is in the bag.

So don't throw it away and please do it.

Because one of the two quiz questions will be very related to the goody bag.

And the other will be related to problems, you know, lecture.

Everything's related to lecture.

But at least one will be related to what's in the bag.

So this, we really take this seriously.

This is a very important part of your homework.

And oh, there it is.

Some of which you need to bring to the quiz.

And we'll tell you what that is before the quiz.

I want to tell you a thing, though, because here's the thing, goody bags are-- it's a little bit of what's going on here?

This is a lecture class.

Why are we getting goody bags?

And it's because I believe in the soul of MIT.

I believe in the soul of MIT.

And that is that we learn best by thinking and doing, by thinking and doing.

And even though this is a lecture class, I still want you to do.

I want you to have stuff in your hands so that you can play with the chemistry that we're learning about.

Now, this goes back.

I said the soul of MIT.

What do I mean?

This goes back, all the way back to before MIT was born, 1850s.

You've got a group of really smart people.

They're getting together and they're meeting.

And they're saying, OK, we're going to start up a new university.

What should we do?

And they wrote out a plan.

They wrote out a plan.

And it's called the institute plan.

That makes sense, 1860.

It's a great read.

But I want to pull out one part that's really important, that what they wanted to do with this great new institution was to do something that would serve the interests of the commerce and the arts, as well as of general education, call for the most earnest cooperation of intelligent culture with industrial pursuits, intelligent culture, industrial pursuits.

That is Mens et Manus.

That is Mens et Manus.

Mind and Hand.

It's so important to MIT that we put it on our logo.

We put it on our logo.

That's how important it is.

We don't put some animal on our logo.

We put what matters, mens et manus.

We don't put the word truth.

Veritas, veritas, I mean, I'm not going to name names, Harvard.

But I mean, isn't that setting the bar kind of low?

You know, were they lying before?

I don't know.

I'm not-- look, honestly I don't know.

I don't know.

But what I know is that what we know is that, of course, the goal is truth.

The difference is, we know how to get it.

Mens et manus is how to get it.

Let me ask you a question.

Why are you here?

Not here in this classroom.

I know you're in the classroom because you signed up for it.

Why are you at MIT?

Why are you here at MIT?

I can tell you, you are here because you are some of the brightest, most gifted, most talented students on the planet.

Right?

Thank you, whoever said that.

Agreement.

That was like a like online.

But you are here because you want to use those talents to make the world a better place.

You are here because you know how to answer any question.

But you are also here because you are going to experience a transition.

You are going to experience a transition here.

You are going to make the transition from knowing how to answer any question to knowing which question to ask.

And that is the transition from student to scholar.

That is MIT.

That's mens et manus.

Now, it's not easy.

You don't come here-- nobody comes to MIT to phone it in.

If universities were restaurants, this wouldn't be that fancy one where you go in and you order, and then somebody cooks and brings you your food.

This would be the one where we all go back into the kitchen and together we make the best meal we've ever had.

That's the MIT way.

That's the MIT way.

And it's not about-- you don't roam the halls here and bask in this reputation and think of it as some privilege to be here, because you are MIT's reputation.

Freshmen, raise your hand.

Yeah.

Starting-- There's a few of you.

Starting today, you are MIT's reputation.

Starting today.

It's on you.

So we don't walk around these great halls and feel privilege.

We feel responsibility.

That's what it means to be here.

OK?

All right.

Good.

Well, now that we've got that all straightened out, let's move on.

That's the end of my administrative stuff.

And with the last 20, 25 minutes, I want to do a little bit of an introduction to chemistry.

And I'm not going to ever test you on history.

But I want to just kind of get ourselves in the mood by going back.

So I'll give you a little bit of history here in a few slides.

So we are interested in solid state chemistry because chemistry is that essential ingredient to understanding the natural world.

And the solid state is the link between that and materials, and engineering.

That is the link.

And so we'll talk a lot about this all the time.

Oh oh.

Come on out, Jerome.

But where did chemistry begin?

OK, now hold on.

I've got a pen.

Oh no, I got a-- OK, that's better.

I thought it was a pen.

Where did it begin?

Where did it begin?

Well, people were mixing stuff a long time ago.

But really, and there's some debate about this, you know, the word chem itself, you know, it may have come from chem, the land of chem, which means sort of the rich soil in Egypt.

Or maybe it came from chemea in Greek, which meant sort of mixing and pouring together.

But the point is that what they were doing was they were taking stuff and making other stuff out of it.

That dagger there is from ancient Egypt.

It's from around 3,000 BC.

And the way they made that was by taking stuff from a meteor.

It was iron and some nickel and some other things.

But from a meteor.

And they were able to make a really, really strong weapon out of it.

They called those daggers from heaven.

But the point is that what chemistry is about is it's about how you mix these things and what are you mixing in the first place.

What was it that you took out of the meteor?

And why did it make that instead of that?

How did I get that dagger?

That's really what this is about.

And so if we go back to sort of the first people who really started discussing this, we start with Plato and Aristotle.

And Plato had this idea, probably some of you may have heard it, so what is stuff made of?

What is like the essence of things?

They really thought about this and they debated it.

And you know, Plato-- well, Plato said there's four things.

And some of you may have heard this.

There's earth.

There's fire.

There's air.

And there's water.

And everything is made out of that.

Now, you can see that's a little limiting.

Aristotle came along and said, wait a second.

Hold on.

If I look out into the stars, they don't seem to change much.

So there must be something else that's not quote, "earthly and corruptible." And he called that ether.

But anyway, the point is, it's hard to kind of explain everything with this.

How are you going to build a world out of-- We can't even explain the Boston weather with just these four words.

So it was limiting.

But then along came these guys, Democritus and Leucippus, who was his teacher.

And Democritus said, OK look, there's something fundamental.

So Democritus, he said, look I believe there's something more than these four things.

Democritus.

And he said there are these things called atoms.

So he was an atomist.

And atom is indivisible.

Indivisible, that's the meaning.

Atomist in Greek, it meant indivisible, atom.

And they fought about this.

They fought about this a lot.

And Plato, it's said, was so upset about Democritus that he wanted all of his books burned.

That's a-- back in the day, that was a serious diss.

It would be like if I blocked somebody on Instagram.

Can I do that?

Is that a thing?

No, Snapchat.

What?

I don't know.

I was right.

See!

That's how-- I'm blocking you.

Burn your books.

Seriously dissing each other.

Democritus.

Now, it really happened quickly from there.

A mere 2,000 years later we get to modern chemistry.

Why did it take 2,000 years?

It took 2,000 years because we were missing something.

So we had a lot of alchemy.

The thing about alchemy, there are actually some really interesting discoveries in alchemy but they always tied it to something very non-rigorous, like oh, this works because of the phases of the moon or the tides.

And so it really needed some rigorous way to study what things were made of, what things were made of.

And that came, oh, inevitable that that might happen.

Here we go.

That came with the scientific method in the 1600s and Sir Francis Bacon.

And I think a lot of you have seen the scientific method.

But it was pivotal for chemistry.

It was pivotal.

Because it allowed people to think about this question of what stuff is made of but using a rigorous approach.

Making observation, form a hypothesis, do an experiment, record.

And that's what people started doing.

That is what, for example, Robert Boyle did, one of the earlier ones to think about things and talk about the element.

They were all going back to thinking about these same issues, what are things made of?

An element can't be broken down into two or more simpler substances by chemical means.

So he was at that.

He was going for that core.

What is at the core?

Oh, and then you had Priestly.

Priestly discovered oxygen and he did it by burning things.

He did it by burning things.

Just mentioning that word makes me want to put those on.

And so he really studied combustion.

He studied these reactions that were happening with oxygen and carbon containing matter.

It was combustion.

So he burned stuff.

He burned this.

He burned that.

He burned that.

And he said, what happens when I do that?

That was another way.

Priestly-- sorry, Boyle played with pressure and volume.

Pressure and volume relationships for gases, that was his way to try to get at what things are made of.

Priestley wanted to blow stuff up.

Oh, and he also worked with beer.

He actually worked with beer.

And he discovered that the same gas that comes out of fermenting beer is the gas that comes out of combusting.

So you got a guy who's working on lighting stuff on fire and beer.

And you can imagine maybe that wasn't going to be a good day at some point.

And what happened is, actually, his experiments did-- this is true, they slowed down when he fell into a vat of beer during one of his experiments.

Now, the thing is, though, that he studied combustion.

And that makes me think about combustion.

And I feel like oh oh, I feel like this is a good time for my goody bag, which is to illustrate a point.

Oh, thank you, Jerome.

That's going to some feed somewhere.

OK, now the thing is that when you go to a restaurant and they have real candles, I get really happy about it.

We'll tell candle stories later in the term as well.

And this is what you're doing.

You are lighting a candle on fire.

Now, when you do that, you see, here's the thing.

You're actually-- I don't want you to think about it as lighting a candle.

I want you to now from now on think about it as lighting C25H52.

And in fact, if you go to a restaurant and you want to ask them if they have real candles, I don't care if you're out with friends or maybe you're on a date, raise your hand.

Ask the waiter and say, do you have any C25H52?

And see if they know, see if they've taken some chemistry.

What you're doing is you're doing that.

You're combusting that fuel.

See, the whole world runs by lighting things on fire.

You could light propane on fire.

Or you could light hydrogen on fire.

That's where we said, yo, hands on is a good way to learn.

So let's see what that's like.

There's the candle, which is tilting.

I'm watching it.

Really?

Oh, OK.

Or you could light hydrogen on fire.

And if you do that, this is what happens.

So, OK, let's do that again.

These bubbles aren't-- oh, I should have kept this on.

There we go.

That's really, really fun.

But I'm going to stop.

Oh, I'm not going to stop because you just turned it on again.

Now you're coaxing me to do more.

Well, these are bigger bubbles.

These are bigger boulders.

Let's see if this gets a nice flame.

Oh, thank you.

There we go.

OK, now that's my goody bag for today.

We run our world by doing this, I mean, not by lighting hydrogen bubbles on fire, but when you put your phone in to charge it, you are lighting a fire.

Think about that.

You might not feel it.

You are.

No, I'm-- I love that reaction.

I love that reaction.

You are lighting a fire.

It may not be you, but somebody else's down the street at a power plant.

This is how we run our world, we burn things.

And so this study of combustion was extremely important.

And it's going to be our first reaction.

So what's happening?

When you light C25H52 on fire, what's happening is that you're reacting.

You're doing-- remember, Priestley discovered H52 plus oxygen. He discovered oxygen.

And he also, remember, this comes off of beer too.

He also discovered these other gases coming out.

Right?

And that's the chemical reaction.

Is it the chemical reaction?

It's not done yet.

It's not balanced.

It's not balanced.

Mass is being lost left and right.

Not OK.

Not OK.

So we must, when we write down things that happen in chemistry like a reaction, we must find balance.

It's also important in life.

But it's very important in chemistry.

And so if you balance this, you're going to put a 2.

Because here's the deal and I'll talk about this more in a sec, $C_{25}H_{52}$ plus-- anybody know how many O_2s?

38, whoever said that, 38 is going to go to $25CO_2$ plus $26H_2O$.

These are the kinds of things that are perfect, perfect to keep doing exercises on though your problems, through your goody bags, in your recitation.

These are exactly the-- how did you do that?

If you don't know, you will soon.

You'll get help, practice.

I know, I know.

I wrote this down.

I'm just testing you.

I made a mistake.

Because the 2 was supposed to go to the propane one because I wanted to write that one and I got excited.

And I went to that instead.

And that would be $13O_2$.

And that would be $8CO_2$, and so on, $10H_2O$.

These are balanced.

These are balanced.

And balancing reactions is important.

Why?

Because it balances the mass and it tells us something else.

Once we count atoms, you'll see.

We're going to count atoms on Friday.

But it's telling us that you can't just lose stuff.

You can't just lose stuff.

You've got to have the-- Oh, and that, by the way, is what-- Lavoisier, Lavoisier.

Where is Jerome?

Oh, yeah.

No.

Shoot.

Isn't that butane, not propane?

Butane not propane.

It very well might have been.

C4 H10, yes.

I believe that is butane.

Thank you.

Oh, Jerome, come back.

Jerome helps the class and he helps my French.

Lavoisier?

No.

OK, say it.

Lavoisier.

OK, I tried.

But now he said, look, you've got to conserve mass.

You can't lose-- you can't create or destroy matter when you do chemistry.

When you do this, when you do this you cannot create or destroy matter.

Conservation of mass, Lavoisier.

It means that if I-- you know, you get a little more than that, see this is balancing.

But you also can think about whether you have anything-- I probably should blow that out.

Whether you have anything-- did you have too much, too little?

Did I mix it just right?

So like if you take-- let's take another reaction just as an example.

If I mix iron and oxygen to make ferric oxide, oh, not balanced.

Two, three, four.

And I tell you, for example, that I've got 10 grams of iron reacts with, let's see-- OK, I'm going to give it to you a different way.

I'm going to say that it gives you, reacts with O2 to give 18.2 grams of FE203.

This is an example from the textbook.

Then I know because of conservation of mass from Lavoisier that 8.2 grams-- if this reacts fully, right, if iron reacts fully, it all goes away.

There's none left.

Then I must have, if I got 18.2 grams of ferric acid, I must have reacted 8.2 grams of oxygen.

That's conservation of mass.

But there's another thing you can do with this.

So I must have reacted 8.2 grams of oxygen.

But there's another thing because if I started, you know, if I started now with 10 grams of O2 and 10 grams of iron, aha, I'm going to have excess.

I know that.

I know that now.

I'm going to have excess.

And the thing is that there's something that's limiting here.

What's in excess?

The oxygen because I started with the same amount of iron.

There is more-- but that means that we've got another term, which is that iron is the limiting reagent.

You see that?

Because now I'm limited, meaning this reaction goes and goes and goes and something runs out first.

That is the limiting reagent.

And this was just by thinking about Lavoisier's conservation of mass.

I can't create or destroy atoms in a reaction, not in this class.

You can take nuclear somewhere else.

But not here.

Here we don't destroy or create matter.

Limiting reagent, balancing reactions, very, very fundamental first chemical concepts.

Now, these guys were playing around with stuff and really trying to figure out, again, they're going back to Democritus.

What are these indivisible elements, atoms, what are they?

And all these guys were starting to mess with that.

Once they had the scientific method, they were willing to go very far.

Here's Lavoisier's list, 33 elements.

And he tried to organize them.

And in some cases, he succeeded fairly well.

Look at this.

This is a, OK, where is Jerome?

This is a Tableau des Substances...

No, not even close.

But look, "Simples..."

Simple, fundamental atoms.

What are those things that we're mixing together that we've been mixing together for thousands of years?

What is that thing I'm pulling out of this oar and making stuff out of?

And he was trying to classify them using these experiments.

And some of these are actually really good discoveries.

I want you to experience this.

I want you to go back to this time.

And that is what the first goody bag is about.

So what I have given you in this goody bag is the most accurate measuring device ever created and branded 309.1.

It's a ruler.

I've given you five metal strips.

And I want you to pretend that you don't know what these are.

How do you find out?

You do nothing with fire, nothing.

But I gave you vinegar.

And you do lots with vinegar.

Pour it on them.

Measure it, weigh it.

Look at it.

Shiny, not shiny.

Different color, densities.

Think about what the differences are.

And I want to put you back in that time.

And I want to make a point here, goody bags are not just about the questions I ask.

I hope that you think even beyond the Goody bag.

So if you use that vinegar and one of those things reacts, let's just suppose, with the vinegar, think about what that is and maybe vinegar is a test.

Maybe it's a test and you can react-- you can pour vinegar and make reactions with other things.

Maybe you should be thinking about where that thing is in the Infinite Corridor and the whole Infinite Corridor should smell like vinegar.

But we won't tell President Reif about that.

But that's what I mean, maybe not the Infinite-- but explore.

These are meant to be-- I want you to really use these as an adventure.

You know, think outside the box.

So you've got this most accurate measuring device.

You've got these strips of pipette.

And you've got some gloves.

And that is your first goody bag.

OK, now though the last thing that I'm going to tell you about is why this matters.

And just like the goody bags, when I started teaching class three years ago, I wanted to also protect a certain fundamental part of each lecture.

And I call it my why this matters moment.

Sometimes it goes on for more than a moment.

But I really, really want every lecture to connect what we just learned to a big picture.

Most of the time, it's some application or some global challenge.

Right I want you to see those connections, that what you're learning is directly relevant to some big thing.

So my why this matters moment is really related to these discoveries themselves.

Please give me till 11:55.

I will always let you go on time, 11:55.

But please don't start putting stuff away because it's distracting to everybody.

So two and a half minutes.

We name the age we live in often by the element, by the atom, by the material, by the material that was most useful at the time.

The Stone Age, the Bronze Age, the Iron Age.

I would say we've moved through the industrial age, the age of plastics, the age of silicon.

As a material scientist and engineer, I love this.

I love that you name the age you live in by the material that mattered.

But I also love that we will never do that again, ever.

And the reason is that we live in a truly unique age now, a different age, one in which we can put atoms, we can realize Feynman's dream and put atoms anywhere we want.

The question is not, can we make it as much any more as it is, what should we make?

We live in the age of atomic design.

And that is really important.

And I mentioned the phone and the 63 elements.

You know, look, this is called a revolution.

This is called a revolution.

You went in 50 years from $1 per transistor, eight orders of magnitude cheaper.

In 2012, it became cheaper to print a transistor on a chip than a character in a newspaper.

That's a revolution but that revolution, it started as a processing revolution with one really important element, silicon.

And now it's a materials revolution, with 63.

It's a chemistry revolution.

And the reason this matters so much, what are these things, is because so many of the problems that we face in this world today, so many of the global challenges, will rely on new chemistry and on new materials.

Those are the bottlenecks.

Those are the bottlenecks in costs, in efficiency, in processing, in properties.

And those are the kinds of things that we're going to be talking about all throughout the fall.

And that is our construction set.

And we will build this on Friday.

So see you guys all on Friday.

[INTERPOSING VOICES]