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Transcript – Lecture 32

From early childhood, we can tell by touch whether an object is hot or whether it is cold.

If you want to heat an object, you bring it in contact with a hot object, for instance a flame.

If you want to cool an object, you bring it in contact with a cold object.

When objects are heated or when they're cooled, then--

and the temperature changes--

then some of their properties change, and those properties are called thermometric properties: ther-mo-metric properties.

One very characteristic thermometric property is that most substances when you heat them, they expand, and when you cool them, they shrink.

We'll talk more about it later.

If you take a gas in a closed volume and you heat it, the pressure goes up.

That's a thermometric property.

If you take an electric conductor and you heat it, in general the electric resistance will change.

If you heat an iron bar, it will expand.

And if you place it in contact with another iron bar which is cold, then the one that is hot will shrink and the one that is cold will heat up and will get longer, and this process will go on up to the point that the hot one will not get shorter and that the cold one will not get longer anymore.

And that is when the two objects, as we say, are in thermal equilibrium with each other, and that is when the temperature of the two objects are the same.

And so you can define a temperature scale by looking at the length of an object.

For instance, here is a bar, some material, I clamp it in here, has length L, and I increase the temperature by an amount delta T, and it gets longer by a certain amount delta L.

I could put the whole thing in melting ice...

melting ice...

and I could say, "Aha." The length then is L1.

Then I could put the whole thing in boiling water and I do that at one atmosphere pressure, and then I say, "Aha." I call that the length L2.

And those are my reference points for my temperature scale.

Celsius did just that.

The idea that he used melting ice, which is now called zero degrees centigrade, and he used boiling point of water, which was his 100 degrees centigrade.

He was a Swedish astronomer; in 1742 he introduced this temperature scale.

So you could make yourself a plot now of the temperature versus the length of that bar, and you could say, okay, 100 degrees centigrade...

if the length of the bar... L2, zero degrees centigrade if the length of the bar is L1.

And now you can draw a straight line--

you can always draw a straight line through two points, you have one point here, you have one point there--

and you can define temperature now by saying, if my bar has this length, L of T, then this will be the temperature.

So you can introduce a linear scale in this fashion, and the thing, in principle, could act like a thermometer.

I'll show you a demonstration of this shortly.

Centi in Greek means "one hundredth," and therefore we also call this scale often "centigrade." One degree centigrade is often called...

one degree Celsius is often called one centigrade, for the reason that it divides the scale from zero to one hundred in equal portions.

So we call them degrees centigrade, degrees Celsius.

Fahrenheit, a German scientist, invented the mercury thermometer.

We'll talk about the mercury thermometer a little later.

In 1714 he introduced a new scale.

He lived in Holland at the time, he lived there most of the time, and he used as his reference point body temperature, which he called 100 degrees Fahrenheit, and he used a mixture of salt and ice at zero degrees.

Now, neither one of these two are very reproducible.

If you pick one person, the temperature today may be a little higher than tomorrow.

A person may have fever.

In fact, the one that he picked probably did have a little bit of fever.

And so the Fahrenheit scale, in that sense, is not very reproducible, and it has been redefined now in such a way that zero degrees centigrade is 32 degrees Fahrenheit, and 100 degrees centigrade is 212 degrees Fahrenheit.

And so if you convert--

if you want to convert from Fahrenheit to centigrade or the other way around--

then the temperature in Fahrenheit is 9/5 times the temperature in Celsius plus 32.

If you take room temperature, the temperature is 20 degrees centigrade, what I was growing up with--

in Europe, everyone uses centigrade there--

then you can see that in terms of Fahrenheit, that becomes 68 degrees Fahrenheit.

9/5 times 20 gives you 36, and then you add 32.

Minus 40 degrees centigrade is the same as minus 40 degrees Fahrenheit.

Check that.

That's where the two scales cross over.

So almost the entire world uses the Celsius scale; it's part of our metric system.

United States is one of the very, very few countries who still, in a rather stubborn way, uses degrees Fahrenheit.

And it is really a pain in the neck, degrees Fahrenheit--

at least for me.

I have very little feeling for it.

I just happen to know that room temperature is 68, because that's the way I set my thermostat at my home, but that's about all.

I can't think in terms of degrees Fahrenheit.

There is no limit to high temperature, but there is a limit to the low temperatures.

There is an absolute zero.

This absolute zero below which you cannot go is about minus 273 degrees Celsius...

And if you take a system that cannot transfer energy to any other system that it is in thermal contact with, then it is at that lowest possible temperature.

This is the way we define it.

It's about minus 460 degrees Fahrenheit.

And so we now have a third scale, which was introduced by Lord Kelvin, was a British scientist.

He did a lot of research on heat, and he introduced the absolute scale whereby he uses the lowest possible temperature as zero degrees Kelvin.

But the increments in terms of increase of one degree, he uses the same as the Celsius scale.

So an increase of two or three degrees Kelvin is the same as an increase of two or three degrees centigrade.

So if we now compare the three scales--

Celsius, Fahrenheit and Kelvin--

then 20 degrees centigrade would be 68 Fahrenheit, and that would be 273.15 plus 20.

Let's round it off and make it 293, and if we take zero Kelvin, then we would have minus 273.15, but let's leave that off for now, and it is approximately minus 460.

We will almost always work with degrees Kelvin in physics and we'll discuss that in more detail Friday.

Most substances expand when you heat them, and if we start with an object which has length L and I heat it up delta T degrees, it gets longer by an amount delta L.

And that delta L can be expressed in a very simple way.

It is alpha times L times delta T, and alpha is called the linear expansion coefficient.

And the units are one over degrees centigrade, or one over degree Kelvin, which is the same, because it's the increments that matter.

The various values for alpha differ a great deal.

Give you some values for alpha.

I'll give you copper, I'll give you brass, I'll give you Pyrex, I'll give you Invar and I'll give you steel, and they are in units of ten to the minus six per degree centigrade, and we will use some of them today.

Brass is about 19.

Copper is 17.

Pyrex 3.3; Invar 0.9; and steel is roughly 12, but there are many different kinds of steel.

Invar was a great invention.

Notice it has a very low expansion coefficient.

It was very important in the 19th century, even today, to make instruments very precise, like clocks.

Clocks are affected by the expansion of the gears.

And so the invention of Invar, which is a mixture of 64% iron and 36% nickel, was invented by a physicist Guillaume in 1898, and for this discovery, he received the Nobel Prize in 1920.

It tells you something how important it was to get an alloy that has a very low expansion coefficient.

If we use these numbers, let us look at the expansion of, for instance, a railroad.

We take a railroad, and we take a piece, a stretch of rail which is, say, a thousand meters.

We take steel, iron--

so this is the expansion coefficient, roughly--

and we compare a cold day, not extremely cold, but a cold day with a hot summer day.

A cold winter day, minus 15 degrees centigrade, and a hot summer day, plus 35 degrees centigrade.

So delta T would be about 50 degrees centigrade.

So what is delta L? Well, that would be 12 times ten to the minus six times ten to the third, times 50, and that is about 0.6 meters, which is about 60 centimeters.

So what are you going to do with that now? How is that solved? If the rail wants to get longer and can't get longer, it will start to bulge either in this way, or sideways, whichever is the easiest.

But the way this is solved is actually quite simple.

When you look at rails, there are openings between them.

They're very distinct.

They're about five centimeters.

If you walk along the rail, you can see the openings.

And if you make these openings, say, five centimeters, then you would need 12 of them in thousand meters, so every 80 meters you would need a gap.

And you can hear these gaps when the train goes over these gaps.

It's a very typical sound.

Because imagine when the wheel goes over it, you hear a certain click.

You can see them and you can hear them, and that's the way they correct for this expansion and contraction.

Bridges can be many kilometers long, and they have, of course, the same problem of expansion, and the way that that is dealt with, also very clever, is as follows.

This is a picture that I copied actually from your book.

It's called an expansion joint, and there are many of them in bridges, and so what it allows the bridge is to do this--

to breathe, so to speak, adjust to the temperature.

There is a bizarre picture whereby the claim is made that this railroad became so warped because of an extremely hot day.

I trust it, although it's hard to believe that it could be so bad.

It must have been extraordinarily hot.

As I mentioned, if a rail cannot expand, then all it can do is either bulge in this way or this way, whichever way is easiest for it, and apparently here, the easiest way is to go sideways, so you see a remarkable destruction, actually, due to an unexpected high temperature.

I have here a brass bar which is about 36 centimeters long, and I'm going to heat that brass bar.

You'll see it there, too.

The brass bar is right here, and we have a way of showing you the extension, even though it is extremely small--

only a fraction of a millimeter.

We can show that to you very easily.

The way we do that is we have some kind of an amplifier.

If this is the rod, and I would put here a hand, and pivot that hand here, then it's easy to see that if you push against it here, that this hand will go like this.

So very little extension here will give you a large extension there.

We do it twice, so we have two levels.

And that is this arm.

I have here a set screw, and I can make... I can move the bar in this direction.

I'm not making it longer, but I can move it, and you will see what effect it has.

If I move the bar one way, it goes up.

Move the bar back, it goes down.

You can think of this as a thermometer.

It will be 70 degrees, as it is now, and if I heat it up, then it will get longer and you will see this end go up.

We could try that.

[blowtorch hissing]

There it goes.

Doesn't take very much.

So we have brass.

And L is 36 centimeters.

Delta L would be about one millimeter for a temperature increase of only 150 degrees centigrade, which of course is trivial for us with that blowtorch.

It's still hot.

I could cool it.

I could force it to cool it, and then I could even go below this point.

This was our 70 degrees, remember? It was the room temperature.

I can cool it with some liquid and see whether I can get it down quickly, and even past this point, which would indicate that it is shorter than it was when the lecture started.

[air whooshing]

You see, it's now shorter.

Now, what you're looking at is only something like maybe a millimeter or even a little less.

But we amplify it and we show that in a quite convincing way, then.

A very important implication--

an application of the expansion of metals--

is what we call bimetals.

They're all around you.

A bimetal is the following.

Say I have a strip here, length L, of Invar.

And I have another strip here which is attached to it so that they cannot slip relative to each other, and let this be copper.

And suppose I make, just as a working example, I make the thickness of each one of them two millimeters.

And I'm going to heat it.

I'm going to heat it, increase in temperature delta T.

I'm not interested really in knowing how long the copper gets and how long the Invar gets, but I'm very interested in knowing the difference in the length between the two.

Because what's going to happen when one gets longer than the other, something got to give.

What do you think will happen? And they're stuck together, they can't slip relative to each other.

What will they do? They will bend.

And since the Invar is not going to expand very much, but the copper will, if you heat it up, it will go like this.

And we'll see that there are many applications of that.

So what I'm interested in is really the delta L of the copper minus the delta L of the Invar.

That's what I'm after.

And that is the alpha of copper minus alpha of Invar times L times delta T.

So it is the difference that matters.

So the difference is 17 minus one, so that is 16 times ten to the minus six times L times delta T.

And if I take a length of ten centimeters and I increase the temperature by 100 degrees centigrade, then this difference, which you can easily calculate, is .16 millimeters--

0.16 millimeter.

Very little.

And yet, this one will curve substantially.

For those of you who are mathematically oriented, I would advise you to make an attempt to calculate that.

So you have, you assume that it is a perfect circle--

that's a reasonable approximation--

and so you have an outer circle which is longer by .16 millimeters than the inner one, and you try to solve and find what that D is.

And I went through that exercise, and you want to do that, too, perhaps, and I found that it's four millimeters for these dimensions.

Four millimeters--

that's substantial.

So this thing is being used for thermostats.

Um... you break and make a contact in a heating system, which could, for instance, be as follows.

Here would be your bimetal, very schematically.

You plug it in the wall here, your 110 volts.

Here is your heater.

And you let it sit like that, and when it's cold, this is down.

It's not curled, and the heater works.

And when the room temperature goes up, this starts to curl, it breaks, and that's a thermostat.

That is the basic idea behind a thermostat.

And you have them in your cars, you have them at home.

Your central heating system, air conditioner and your heaters--

they're all over the place.

They're also being used for safety devices.

If you have a gas hot water heater, in the pilot light, in the flame of the pilot light, is a bimetal.

And when that bimetal is hot, your gas valve is open.

But when that bimetal gets cold, it shuts off the gas valve, which is a safety device.

In fact, in Europe, all gas stoves are protected that way by law.

Strangely enough, not in the United States, which is very surprising.

If I open my gas valves at home of my stove, the gas will just come out, just like that.

There's no prevention of that happening.

In Europe, that's not possible.

There is always a pilot light somewhere with a bimetal that senses that there is a flame nearby to ignite the gas.

And if that flame is out, the gas valve will be closed.

So bimetals can also be used very effectively for safety devices.

I have here a bimetal.

One side I believe, we believe, is aluminum, and the other side we believe is iron.

And when I heat that, you will see that it starts to bend.

[blowtorch hissing]

Here we go.

I think you get the idea.

You could use that as a thermometer--

very crude one, but this is the idea of the thermometer, of course.

Mark Bessette, who is the person who is preparing always these demonstrations in a fabulous way, told me he had at home a coffee maker.

And the coffee maker is designed in such a way that there is a bimetal at the bottom of the water reservoir.

You heat up the water reservoir, and when the water heats to a certain temperature, the bimetal opens and the water comes out and it goes through the coffee.

I'd like to show that to you--

it's really cute.

Here is that coffee machine.

It's not working anymore, it's a very old one, but I want to show you at least that bimetal.

This is that bimetal strip.

Water goes in here, you heat it, and when it's hot enough, the bimetal lifts up and you can see there is a hole there.

This is the hole.

And the water comes out, and when the bimetal is closed, then it closes off that hole.

So it's an amazing, simple idea.

The criterion for letting the water go through the coffee is simply when the water reaches that temperature close to boiling and you have your bimetal control it.

So bimetals in many ways control matters.

Thermostats, in this case they act like... like a valve.

Bimetals can be used as thermometers.

In fact, the one that you see right here is driven exclusively by a bimetal.

If you look in the back of this thermometer--

and I will show that to you shortly because I broke one open for you--

then it looks like this.

There's a coil.

This end of the coil is attached to the plastic casing.

And here is the red hand.

It's a pivot here--

the red hand.

But this is fixed, this cannot move.

I heat it up.

What will happen when I heat it up? This is already a bimetal, it's already curved.

But when I heat it up, it will tighten even more, it will curl up even more.

And when this one curls up even more, it will go into this direction.

So this is when the temperature increases.

And when it, of course, gets colder, it will uncurl, and so here is cold.

And that's what the whole thermometer is based upon.

And in the back is this coil.

And so I broke one open for you in order to make you see that coil.

Now, I have that here.

This is the part that is in the back, and this is that bimetal--

the bimetal coil.

This is the bottom part, this is the top, and this is just the hand that is attached to it.

And then it goes into this case.

Let's make sure that the pivot goes in there--

yeah.

If I increase the temperature, try to see that.

You see the coil tightens up.

See, the coil gets tighter.

And when I make the temperature go down artificially now by uncurling the coil, it goes in this direction.

Now, what we can do is we can actually heat it up.

We have to set the temperature at whatever we think it is now.

It's about 70 degrees in the room.

Is that what it is? Well, that's close enough.

This is Fahrenheit--

oh, what a terrible scale.

Yeah, by the way, you also see some civilized scale there.

You see centigrade in addition to the Fahrenheit.

So it's close enough, it's a little bit over 70, and I can now make sure that this is stuck to it, to the case.

I can heat it.

[motor purring]

The bimetal tightens up more.

So when I heat it, the bimetal tightens up more, and when I blow air over it, I can actually make it cool a little faster than it will otherwise.

[blowing]

So as simple as that.

Very simple device with...

the bimetals have many, many applications.

Your thermostats in your dormitories of your heating systems, and also perhaps of the air-conditioning systems, almost all have a coil like this in there.

It was an extremely ingenious device.

It has a coil, and at the end of the coil is a little glass tube, only one centimeter large, and there is mercury inside.

So the coil is like this.

Bimetal.

And at the end here is a glass container and there is some mercury, and the mercury is here on this side, because notice the way I have tilted it a little.

The mercury rolls to the left.

And there are here two wires, electric wires, one here and one here, which go to the heating system.

And so when the mercury is here, which has a good conductivity, the heater is on.

Now, the room gets warmer and warmer and warmer and the bimetal will tighten up, will curl even more.

And so there comes a time that this glass thing will go like this and the mercury rolls out.

And when the mercury rolls out--

here is the mercury--

these contacts here are open, and the heater will stop.

And that's in almost every room.

Very ingenious device.

Now I want to move from linear expansion coefficients to cubic expansion coefficients.

I will leave these numbers there, because I will need them later on.

But now I take a block of some material and want to discuss the volume increase--

not just the length, but the volume increase.

So here I have a solid material.

Let's make it simple, all sides L.

And I increase it by an amount of temperature delta T.

Well, the old volume is L cubed, and then I'm going to increase the temperature by delta T, so all these sides will get longer by amount delta L, and so the new volume will be L plus delta L to the power 3.

This can also be written as L to the third times one plus delta L over L to the power 3.

Same thing, right? Now, perhaps you remember, or at least you should remember, that one plus x to the power n, in case that x is much, much smaller than one, is approximately one plus nx.

We've used that before when we discussed the Doppler shift--

light from receding stars.

This is called the binomial series, binomial expansion.

It's really the first order terms of the Taylor expansion.

If you, as an example, if you take x equals 0.05 and you calculate the exact value with your calculator, you would find 1.158.

If you do it this way, you will find 1.15, which is very close.

Approximation is better than one percent.

So I will use the same approximation here, and so we're going to get L to the third times one plus three delta L divided by L.

So that is L to the third plus three delta L, L squared.

So the difference in terms of delta V, the old volume was this.

And this volume is V plus delta V, so delta V is the difference between the two, is three delta L, L squared.

But I know that delta L equals alpha times L times delta T.

And so I can substitute that in here, and so I find that delta V equals three alpha times L squared times L--

that is L cubed--

times delta T.

But L cubed was the old volume, and so I now find that delta V equals three alpha times the old volume times delta T, and this one is often called beta.

Beta is the cubical expansion coefficient, as opposed to the linear one.

So you will say, well, big deal.

I mean, why are you talking about beta? Because if we have the values for alpha, all we have to do if we go to a volume, to make that beta three alpha, and we are in business.

Well, when you have liquids, in general, you don't find in the tables values for alpha.

So when you deal with liquids, for instance, mercury, which is the one that I want to use today, then you find that the cubic expansion coefficient is 18 times ten to the minus five per degree centigrade.

If I compare that with Pyrex, you have to take three times this value, so that's very roughly ten to the minus five per degree centigrade.

And so now you begin to smell the idea of a mercury thermometer.

I put some mercury in Pyrex glass, and the Pyrex glass is not going to expand very much, but the mercury will.

And then the mercury, which is in an enclosed environment, will have to expand, and it expands into my thermometer and that's the way that we read the temperature.

So here is a glass tube which is very, very narrow.

All this is closed here.

And let's say the radius here is only 0.1 millimeter.

And here is a reservoir, mercury, just a working example, and suppose we take one cubic centimeter--

just simple numbers.

Just want to show you the basic idea behind the thermometer.

I'm going to increase the temperature of this mercury, say by ten degrees, so delta T, ten degrees centigrade.

So by how much will this volume expand? Well, delta V equals beta 18 times ten to the minus fifths times the volume, which is one cubic centimeter--

let me just put the volume in there; you may want to do it in cubic meters--

I leave it up to you--

times the delta T.

And you will find that the expansion in terms of cubic centimeters is 0.0018 cubic centimeters.

See, if you leave V in cubic centimeters, which you can do, then you get your answer also in cubic centimeters, of course.

You do not always work...
have to work mks.

So this is an extraordinarily small increase in terms of its volume.

However, the Pyrex is not expanding at all.

You can just forget that for now.

If you want to calculate how much it is, it's fine, but it is 18 times less, so the fact that the vessel gets a little larger of course is important, but I will just ignore that for now.

And so I will just assume that all this mercury will be driven up here.

And so if the mercury, then, changes its height by an amount delta h, and if this is a tube with a radius .1 millimeters, then this amount of mercury must be the same as pi r squared times delta h, which is the volume of the new column--

the increase in the column.

And so you take your .1 millimeters and you'll find that delta h for this example that I chose is 5.7 centimeters.

That's huge.

That's very easy to see.

For ten degrees increase in temperature, it's 5.7 centimeters.

So for one degree centigrade, you would get six millimeters.

It's very easy to see, and so that's the idea behind a mercury thermometer.

I have a mercury thermometer here, but they're very hard to read.

But I have one here.

It's a medical one.

It says "oral," not to be confused.

And I can stick it in my mouth and measure my temperature using this scale.

It's easier for me to show you the one that I have in my office, which also works on liquid.

[mumbling]: This one.

So this one, you see the red liquid? Let me be sure that we have the right light setting.

This should go off.

Okay.

So you see the red liquid.

There it is.

And also notice that it is degrees Fahrenheit, which is unfortunate.

But it's helping.

When the temperature is here, at least you know that you're going to get ice.

[a few chuckles]

Well, that's somewhere near 32... 32 Fahrenheit.

That must be here.

Snow.

And this makes you feel good--

sun.

Yeah.

You know, just in case you don't remember.

I could heat it up.

[blow-dryer humming]

You always should be careful when you heat it up that you don't go too far, because the top of the thermometer is closed.

In the case of a mercury thermometer, there is vacuum in here, and so if you--

when I was a kid, I loved to do this--

to take the medical thermometer of my parents and heat it up with a hair dryer and then it would just burst through it, it would just break the glass, because the expansion is huge, the force, and it would just pop off.

And then I'd put it back and say nothing.

And that can happen with this, too.

So it doesn't have an opening.

It is not open, it's a closed thing, so you've got to be quite careful.

There is a technique which is called "shrink fitting," and shrink fitting is the following.

You have a piece of metal--

let's take just a solid cylinder as a working example--

and you have a ring.

The ring could be itself a cylinder.

Well, this one, this opening is smaller than this--

just a little smaller--

purposely made that way.

Just a little smaller.

You heat this one.

Expands.

And you put it over here, it will fit.

And then you let it sit.

It cools, and it tightens itself up.

That's called shrink fitting, a technique which is often used.

I have something to show you here which is the opposite of shrink fitting.

I have a ring--

I'll show you shortly on the screen there--

and that's made of brass, and I have a ball which goes through there.

Just barely, but it goes through there.

And then I will heat up this ball, and then it won't go through there, so it's the reverse, but at least you get the idea.

And then if you wait and it cools, when you bring them in contact with each other, this one will cool and this one will get warmer.

So you catch two birds with one stone.

This one will shrink, and at the same time, this one will become a little larger, and so then clearly it will fall through, and that's the idea.

And let's try that.

Get the best lighting that we can under the circumstances, and we'll change to...
is that it? Yeah, this is the ring.

And here is that brass ball.

It goes through there quite easily.

I'll put it horizontal now.

And then I will start heating up this ball.

[flame whooshing]

Here's the ball.

It can't be too close to the ring, because then the ring will also be heated, and then of course if the two have the same temperature, then the ball will still go through.

[flame whooshing]

Let's see.

Now it doesn't want to go through.

So we'll leave it like that, and we'll see what happens.

So the ring will now expand a little because it gets hotter, and the ball will shrink a little because it gets colder and it shouldn't take too long for the ball to be able to get through.

If I heat them both with the torch, then of course they will always be able to go through each other.

And there it goes.

So if I heat them both...

[flame whooshing]

...so they both expand, since it's both brass, there is no differential expansion like with bimetals, then no matter what you do, it will always be able to go through.

It's only when I...

...heat the ball and not the ring that you get the effect that it won't get through.

It may actually get through now, still get through.

Yeah.

What I've left out of my discussion with you is water.

Why have I not mentioned to you what is the expansion coefficient, the cubical expansion coefficient of water? Water is so important in our lives.

Well, there is a reason why I left it out, because there is something very special with water.

If you take 20-degree centigrade water and you cool it, it shrinks.

Normal behavior.

Beta has a positive value.

But when you reach four degrees centigrade and you go all the way down to zero, then it doesn't shrink--

it expands.

So in that range, from zero degrees centigrade to four degrees centigrade, water has a negative value for beta.

When you heat it, it shrinks, and when you cool it, it expands.

And that makes water extremely unusual.

But it's great for fish, because it means that water of four degrees centigrade has the highest possible density.

It's higher density than at 20 degrees, and a higher density than at zero degrees.

And so when in the winter the ponds freeze, the highest density water goes to the bottom, and that's why the way... that's the way that fish can survive.

Rather than becoming deep-freeze fish right there, they can swim.

So most of the pond in the winter, the bottom layers are four degrees centigrade, which is safely from the freezing point.

Now, when you melt a solid and it becomes liquid, in almost all cases the liquid expands.

Sort of natural.

And so the solids sink in the liquids.

If you take crystals, they sink in their own liquid.

But not water.

Water and ice are very anomalous.

If you take water at zero degrees and you freeze it and it becomes ice crystals, it expands.

And the expansion is enormous, because the density of ice is eight percent lower than the density of water.

The density of ice is 0.92 grams per cubic centimeter, and water per definition is one.

This is why pipes can burst in the winter when they freeze.

The pipes freeze, people have water pipes near the outside walls.

They cool, they freeze, the pipes burst, because the ice expands.

They're not aware of that, and in the spring when the water melts, when the ice melts, all of a sudden--

they have a flood because the pipe burst.

This is why the Titanic sank.

Because ice floats on water.

Ice has a lower density.

Without ice floating, no icebergs.

This is why you can skate on ponds, because ice has a lower density than water, so ice floats on water.

The best way that I can demonstrate to you that ice floats is to treat myself and give myself a glass of something.

Today it will be apple cider.

And I have here some ice cubes.

And I put some ice cubes in here, and they float.

And if you don't believe it, come and take a look.

Okay, enjoy your weekend.

Oh, no, we still have a lecture on Friday.

See you then.