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PROFESSOR: Thermodynamics, all right, let's start. Thermodynamics is the science of the flow of heat. So, thermo is heat, and dynamics is the motion of heat. Thermodynamics was developed largely beginning in the 1800's, at the time of the Industrial Revolution.

So, taming of steel. The beginning of generating power by burning fossil fuels. The beginning of the problems with CO₂ and [NOISE OBSCURES] global warming. In fact, it's interesting to note that the first calculation on the impact of CO₂ on climate was done in the late 1800's by Arrhenius. Beginning of a generation of power moving heat from fossil fuels to generating energy, locomotives, etcetera. So, he calculated what would happen to this burning of fossil fuels, and he decided in his calculation, he basically got the calculation right, by the way, but he came out that in 2,000 years from the time that he did the calculations, humans would be in trouble.

Well, since his calculation, we've had an exponential growth in the amount of CO₂, and if you go through the calculations of -- people have done these calculations throughout times since Arrhenius, the time that we're in trouble, 2,000 years and the calculation, has gone like this, and so now we're really in trouble. That's for a different lecture.

So, anyway, thermodynamics dates from the same period as getting fossil fuels out of the ground. It's universal. It turns out everything around us moves energy around in one way or the other. If you're a biological system, you're burning calories, burning ATP. You're creating heat. If you're a warm-blooded animal. You need energy to move your arms around and move around -- mechanical systems, obviously, cars, boats, etcetera. And even in astrophysics, when you talk about stars, black holes, etcetera, you're moving energy around. You're moving heat around when you're changing matter through thermodynamics.

And the cause of some thermodynamics have even been applied to economics, systems out of equilibrium, like big companies like Enron, you know, completely out of equilibrium, crash and burn. You can apply non-equilibrium thermodynamics to economics.

It was developed before people knew about atoms and molecules. So it's a science that's based on macroscopic properties of matter. Since then, since we know about atoms and molecules now, we can rationalize the concepts of thermodynamics using microscopic properties, and if you are going to take 5.62, that's what you'd learn about. You'd learn about statistical mechanics, and how the atomistic concepts rationalize thermodynamics. It

doesn't prove it, but it helps to getting more intuition about the consequences of thermodynamics.

So it applies to macroscopic systems that are in equilibrium, and how to go from one equilibrium state to another equilibrium state, and it's entirely empirical in its foundation. People have done experiments through the ages, and they've accumulated the knowledge from these experiments, and they've synthesized these experiments into a few basic empirical rules, empirical laws, which are the laws of thermodynamics. And then they've taken these laws and added a structure of math upon it, to build this edifice, which is a very solid edifice of thermodynamics as a science of equilibrium systems.

So these empirical observations then are summarized into four laws. So, these laws are, they're really pillars. They're not proven, but they're not wrong. They're very unlikely to be wrong. Let's just go through these laws, OK, very quickly.

There's a zeroth law The zeroth law every one of these laws basically defines the quantity in thermodynamics and then defines the concept. The zeroth law defines temperature. That's a fairly common-sense idea, but it's important to define it, and I call that the common-sense law. So this is the common-sense law.

The first law ends up defining energy, which we're going to call u , and the concept of energy conservation, energy can't be lost or gained. And I'm going to call this the you can break even law; you can break even law. You don't lose energy, you can't gain energy. You break even.

The second law is going to define entropy, and is going to tell us about the direction of time, something that conceptually we, clearly, understand, but is going to put a mathematical foundation on which way does time go. Clearly, if I take a chalk like this one here, and I throw it on the ground, and it breaks in little pieces, if I run the movie backwards, that doesn't make sense, right? We have a concept of time going forward in a particular way. How does entropy play into that concept of time? And I'm going to call this the you can break even at zero degrees Kelvin law. You can only do it at zero degrees Kelvin.

The third law is going to give a numerical value to the entropy, and the third law is going to be the depressing one, and it's going to say, you can't get to zero degrees. These laws are universally valid. They cannot be circumvented.

Certainly people have tried to do that, and every year there's a newspaper story, Wall Street Journal, or New York Times about somebody that has invented the device that somehow goes around the second law and makes more energy than it creates, and this is going to be -- well, first of all, for the investors this is going to make them very, very rich, and for the rest of us, it's going to be wonderful. And they go through these arguments, and they find venture money to fund the company, and they get very famous people to endorse them, etcetera. But you guys

know, because you have MIT degrees, and you've, later, and you've taken 5.60, that can't be the case, and you're not going to get fooled into investing money into these companies. But it's amazing, that every year you find somebody coming up with a way of going around the second law and somehow convincing people who are very smart that this will work.

So, thermo is also a big tease, as you can see from my descriptions of these laws here. It makes you believe, initially, in the feasibility of perfect efficiency. The first law is very upbeat. It talks about the conservation of energy. Energy is conserved in all of its forms. You can take heat energy and convert it to work energy and vice versa, and it doesn't say anything about that you have to waste heat if you're going to transform heat into work. It just says it's energy. It's all the same thing, right? So, you could break even if you were very clever about it, and that's pretty neat.

So, in a sense, it says, you know, if you wanted to build a boat that took energy out of the warmth of the air, to sail around the world, you can do that. And then the second law comes in and says well, that's not quite right. The second law says, yes, energy is pretty much the same in all this form, but if you want to convert one form of energy into another, if you want to convert work, heat into work, with 100% efficiency, you've got to go down to zero degrees Kelvin, to absolute zero if you want to do that. Otherwise you're going to waste some of that heat somewhere along the way, some of that energy.

All right, so you can't get perfect efficiency, but at least if you were able to go to zero degrees Kelvin, then you'd be all set. You just got to find a good refrigerator on your boat, and then you can still go around the world.

And then the third law comes in, and that's the depressing part here. It says, well, it's true. If you could get to zero degrees Kelvin, you'd get perfect efficiency, but you can't get to zero degrees Kelvin, you can't. Even if you have an infinite amount of resources, you can't get there.

Any questions so far? So thermodynamics, based on these four laws now, requires an edifice, and it's a very mature science, and it requires that we define things carefully. So we're going to spend a little bit of time making sure we define our concepts and our words, and what you'll find that when you do problem sets, especially at the beginning, understanding the words and the conditions of the problem sets is most of the way into solving the problem.

So we're going to talk about things like systems. The system, it's that part of the universe that we're studying. These are going to be fairly common-sense definitions, but they're important, and when you get to a problem set, really nailing down what the system is, not more, nor less, in terms of the amount of stuff, that's part of the system, it's going to be often very crucial.

So you've got the system. For instance, it could be a person. I am the system. I could be a system. It could be a hot coffee in a thermos. So the coffee and the milk and whatever else you like in your coffee would be the system. It could be a glass of water with ice in it. That's a fine system. Volume of air in a part of a room. Take four liters on this corner of the room. That's my system.

Then, after you define what your system is, whatever is left over of the universe is the surroundings. So, if I'm the system, then everything else is the surroundings. You are my surroundings. Saturn is my surroundings. As far as you can go in the universe, that's part of the surroundings.

And then between the system and the surroundings is the boundary. And the boundary is a surface that's real, like the outsides of my skin, or the inner wall of the thermos that has the coffee in it, or it could be an imaginary boundary. For instance, I can imagine that there is a boundary that surrounds the four liters of air that's sitting in the corner there. It doesn't have to be a real container to contain it. It's just an imaginary boundary there. And where you place that boundary becomes important.

So, for instance, for the thermos with the coffee in it, if you place the boundary in the inside wall of the glass or the outside wall of the glass and the inside of the thermos, that makes a difference; different heat capacity, etcetera. So this becomes where defining the system and the boundaries, and everything becomes important. You've got to place the boundary at exactly the right place, otherwise you've got a bit too much in your system or a bit too little.

More definitions. The system can be an open system, or it can be a closed system, or it can be isolated. The definitions are also important here. An open system, as the name describes, allows mass and energy to freely flow through the boundary. Mass and energy flow through boundary. Mass and energy -- I'm an open system, right? Water vapor goes through my skin. I'm hot, compared to the air of the room, or cold if I'm somewhere that's warm. So energy can go back and forth. The thermos, with the lid on top, is not an open system. Hopefully, your coffee is going to stay warm or hot in the thermos. It's not going to get out. So the thermos is not an open system. In fact, the thermos is an isolated system. The isolated system is the opposite of the open system, no mass and no energy can flow through the boundary.

The closed system allows energy to transfer through the boundary but not mass. So a closed system would be, for instance, a glass of ice water with an ice cube in it, with the lid on top. The glass is not very insulating. Energy can flow across the glass, but I put a lid on top, and so the water can't get out. And that's the closed system. Energy goes through the boundaries but nothing else. Important definitions, even though they may sound really kind of dumb, but they are really important, because when you get the problem, figuring out whether you have an open, closed, or isolated system, what are the surroundings? What's the boundary? What is the system? That's the first thing to make sure that is clear. If it's not clear, the problem is going to be impossible to solve.

And that's also how people find ways to break the second law, because somehow they've messed up on what their system is. And they've included too much or too little in the system, and it looks to them that the second law is broken and they've created more energy than is being brought in. That's usually the case. Questions?

Let's keep going. So, now that we've got a system, we've got to describe it. So, let's describe the system now. It turns out that when you're talking about macroscopic properties of matter, you don't need very many variables to describe the system completely thermodynamically. You just need a few macroscopic variables that are very familiar to you, like the pressure, the temperature, the volume, the number of moles of each component, the mass of the system. You've got a magnetic field, maybe even magnetic susceptibility, the electric field. We're not going to worry about these magnetic fields or electric fields in this class.

So, pretty much we're going to focus on this set of variables here. You're going to have to know when you describe the system, if your system is homogeneous, like your coffee with milk in it, or heterogeneous, like water with an ice cube in it. So heterogeneous means that you've got different phases in your system. I'm the heterogeneous system, soft stuff, hard stuff, liquid stuff. Coffee is homogeneous, even though it's made up of many components. Many different kinds of molecules make up your coffee. There are the water molecules, the flavor molecules, the milk proteins, etcetera. But it's all mixed up together in a homogeneous, macroscopic fashion. If you drill down at the level of molecules you see that it's not homogeneous.

But thermodynamics takes a bird's eye view. It looks pretty, beautiful. So, that's a homogeneous system, one phase. You have to know if your system is an equilibrium system or not. If it's an equilibrium system, then thermodynamics can describe it. If it's not, then you're going to have trouble describing it using thermodynamic properties. Thermodynamics talks about equilibrium systems and how to go from one state of equilibrium to another state of equilibrium.

What does equilibrium mean? It means that the properties of the system, the properties that describe the system, don't change in time or in space. If I've got a gas in a container, the pressure of the gas has to be the same everywhere in the container, otherwise it's not equilibrium. If I place my container of gas on the table here, and I come back an hour later, the pressure needs to be the same when I come back. Otherwise it's not equilibrium. So it only talks about equilibrium systems.

What else do you need to know? So, you need to know the variables. You need to know it's heterogeneous or homogeneous. You need to know if it's an equilibrium, and you also need to know how many components you have in your system. So, a glass of ice water with an ice cube in it, which is a heterogeneous system, has only one component, which is water, H₂O. Two phases, but one component. Latte, which is a homogeneous system, has a very, very large number of components to it. All the components that make up the milk. All the components that

make up the coffee, and all the impurities, etcetera. cadmium, heavy metals, arsenic, whatever is in your coffee.

OK, any questions?

All right, so we've described the system with these properties. Now these properties come in two flavors. You have extensive properties and intensive properties.

The extensive properties are the ones that scale with the size of the system. If you double the system, they double in their numerical number. For instance, the volume. If you double the volume, the v doubles. I mean that's obvious. The mass, if you double the amount of stuff the mass will double.

Intensive properties don't care about the scale of your system. If you double everything in the system, the temperature is not going to change, it's not going to double. The temperature stays the same. So the temperature is intensive, and you can make intensive properties out of the extensive properties by dividing by the number of moles in the system. So I can make a quantity that I'll call V bar, which is the molar volume, the volume of one mole of a component in my system, and that becomes an intensive quantity. A volume which is an intensive volume. The volumes per mole of that stuff.

So, as I mentioned, thermodynamics is the science of equilibrium systems, and it also describes the evolution of one equilibrium to another equilibrium. How do you go from one to the other? And so the set of properties that describes the system -- the equilibrium doesn't change. So, these on-changing properties that describe the state of the equilibrium state of the system are called state variables. So the state variables describe the equilibrium's state, and they don't care about how this state got to where it is. They don't care about the history of the state. They just know that's if you have water at zero degrees Celsius with ice in, that you can define it as a heterogeneous system with a certain density for the water or certain density for the ice, etcetera, etcetera. It doesn't care how you got there.

We're going to find other properties that do care about the history of the system, like work, that you put in the system, or heat that you put in the system, or some other variables. But you can't use those to define the equilibrium state. You can only use the state variables, independent of history. And it turns out that for a one component system, one component meaning one kind of molecule in the system, all that you need to know to describe the system is the number of moles for a one component system, and to describe one phase in that system, one component, homogeneous system, you need n and two variables. For instance, the pressure and the temperature, or the volume and the pressure. If you have the number of moles and two intensive variables, then you know everything there is to know about the system. About the equilibrium state of that system.

There are hundreds of quantities that you can calculate and measure that are interesting and important properties, and all you need is just a few variables to get everything out, and that's really the power of

thermodynamics, is that it takes so little information to get so much information out. So little data to get a lot of predictive information out.

As we're going on with our definitions, we can summarize a lot of these definitions into a notation, a chemical notation that that will be very important. So, for instance, if I'm talking about three moles of hydrogen, at one bar 100 degrees Celsius. I'm not going to write, given three moles of hydrogen at one bar and three degrees, blah, blah, blah. I'm going to write it in a compact notation. I'm going to write it like this: three moles of hydrogen which is a gas, one bar 100 degrees Celsius. This notation gives you everything you need to know about the system. It tells you the number of moles. It tells you the phase. It tells you what kind of molecule it is, and gives you two variables that are state variables. You could have the volume and the temperature. You could have the volume and the pressure. But this tells you everything. I don't need to write it down in words.

And then if I want to tell you about a change of state, or let's first start with a mixture. Suppose that I give to a mixture like, this is a homogeneous system with two components, like five moles of H₂O, which is a liquid, at one bar 25 degrees Celsius, plus five moles of CH₃, CH₂, OH, which is a liquid, and one bar at 25 degrees Celsius. This describes roughly something that is fairly commonplace, it's 100-proof vodka 1/2 water, 1/2 ethanol -- that describes that macroscopic system. You're missing all the impurities, all the little the flavor molecules that go into it, but basically, that's the homogeneous system we were describing, two component homogeneous systems. Then you can do all sorts of predictive stuff with that system.

All right, that's the equilibrium system. Now we want to show a notation, how do we go from one equilibrium state like this describes to another equilibrium state?

So, we take our two equilibrium states, and you just put an equal sign between them, and the equal sign means go from one to the other. So, if we took our three moles of hydrogen, which is a gas at five bar and 100 degrees Celsius, and, which is a nice equilibrium state here, and we say now we're going to change the equilibrium state to something new, we're going to do an expansion, let's say. We're going to drop the pressure, the volume is going to go up. I don't need to tell you the volume here, because you've got enough information to calculate the volume. The number of moles stays the same, a closed systems, gas doesn't come out. Stays a gas, but now the pressure is less, the temperature is less.

I've done some sort of expansion on this. I've gone from 1 equilibrium state to another equilibrium state, and the equal sign means you go from this state to that state. It's not a chemical reaction. That's why we don't have an arrow here, because we could go back, this way too. We can go back and forth between these two equilibrium states. They're connected. This means they're connected. And when I put this, I have to tell you how they are connected. I have to tell you the path, if you're going to solve a problem. For instance, you want to know how

much energy you're going to get out from doing this expansion. How much energy are you going to get out, and how far are you going to be able to drive a car with this expansion, let's say, so that's the problem. So, I need to tell you how you're doing the expansion, because that's going to tell you how much energy you're wasting during that expansion. It goes back to the second law. Nothing is efficient. You're always wasting energy into heat somewhere when you do a change that involves a mechanical change.

All right, so I need to tell you the path, when I go from one state to the other. And the path is going to be the sequence, intermediate states going from the initial state the final state. So, for instance, if I draw a graph of pressure on one axis and temperature on the other axis, my initial state is at a temperature of 100 degrees Celsius and five bar. My final stage is 50 degrees Celsius and one bar. So, I could have two steps in my path. I could decide first of all to keep the pressure constant and lower the pressure. When I get to 50 degrees Celsius, I could choose to keep the temperature constant and lower the pressure. I'm sorry, my first step would be to keep the pressure constant and lower the temperature, then I lower the pressure, keeping the temperature constant. So there's my intermediate state there.

This is one of many paths. There's an infinite number of paths you could take. You could take a continuous path, where you have an infinite number of equilibrium points in between the two, a smooth path, where you drop the pressure and the temperature simultaneously in little increments. All right, so when you do a problem, the path is going to turn out to be extremely important. How do you get from the initial state to the final state? Define the initial state. Define the final state. Define the path. Get all of these really clear, and you've basically solved the problem. You've got to spend the time to make sure that everything is well defined before you start trying to work out these problem.

More about the path. There are a couple ways you could go through that path. If I look at this smooth path here. I could have that path be very slow and steady, so that at every point along the way, my gas is an equilibrium. So I've got, this piston here is compressed, and I slowly, slowly increase the volume, drop the temperature. Then I can go back, the gas is included at every point of the way. That's a reversible path. That can reverse the process. I expand it, and reverse it, no problem. So, I could have a reversible path, or I take my gas, and instead of slowly, slowly raising it, dropping the pressure, I go from five bar to one bar extremely fast. What happens to my gas inside? Well, my gas inside is going to be very unhappy. It's not going stay in equilibrium.

Parts of the system are going to be at five bar. Parts of it at one bar. Parts of it may be even at zero bar, if I go really fast. I'm going to create a vacuum. So the system will not be described by a single state variable during the path. If I look at different points in my container during that path, I'm going to have to use a different value of pressure or different value of temperature at different points of the container.

That's not an equilibrium state, and that process turns out then to be in irreversible process. Do it very quickly. Now to reverse it and get back to the initial point is going to require some input from outside, like heat or extra work or extra heat or something, because you've done an irreversible process. You've wasted a lot of energy in doing that process.

I have to tell you whether the path is reversible or irreversible, and the irreversible path also defines the direction of time. You can only have an irreversible path go one way in time, not the other way. Chalk breaks irreversibly and you can't put it back together so easily. You've got to pretty much take that chalk, and make a slurry out of it, put water, and dry it back up, put in a mold, and then you can have the chalk again, but you can't just glue it back together. That would not be the same state as what you started out with.

And then there are a bunch of words that describe these paths. Words like adiabatic, which we'll be very familiar with. Adiabatic means that there's no heat transferred between the system and the surrounding. The boundary is impervious to transfer of heat, like a thermos. Anything that happens inside of the thermos is an adiabatic change because the thermos has no connection in terms of energy to the outside world. There's no heat that can go through the walls of the thermos. Whereas, like isobaric means constant pressure. So, this path right here from this top red path is an isobaric process. Constant temperature means isothermal, so this part means an isothermal process. So then, going from the initial to final states with a red path, you start with an isobaric process and then you end with an isothermal process. And these are words that are very meaningful when you read the text of a problem or of a process.

Any questions before we got to the zeroth law? We're pretty much done with our definitions here. Yes.

STUDENT: Was adiabatic reversible?

PROFESSOR: Adiabatic can be either reversible or not, and we're going to do that probably next time or two times. Any other questions? Yes.

STUDENT: Is there a boundary between reversible and irreversible?

PROFESSOR: A boundary between reversible and irreversible? Like something is almost reversible and almost irreversible. No, pretty much things are either reversible or irreversible. Now, in practice, it depends on how good your measurement is. And probably also in practice, nothing is truly reversible. So, it depends on your error bar in a sense. It depends on what what you define, exactly what you define in your system. It becomes a gray area, but it should be pretty clear if you can treat something is reversible are irreversible. Other questions, It's a good question.

So the zeroth law we're going to go through the laws now. The zeroth law talks about defining temperature and it's

the common-sense law. You all know how. When something hot, it's got a higher temperature than when something is cold. But it's important to define that, and define something that's a thermometer.

So what do you know? What's the empirical information that everybody knows? Everybody knows that if you take something which is hot and something which is cold, and you bring them together, make them touch, that heat is going to flow from the hot to the cold, and make them touch, and heat flows from hot to cold. That's common sense. This is part of your DNA, And then their final product is an object, a b which ends up at a temperature or a warmth which is in between the hot and the cold. So, this turns out to be warm. You get your new equilibrium state, which is in between what this was, and what a and b were.

Then how do you know that it's changed temperature, or that heat has flowed from a to b? Practically speaking, you need some sort of property that's changing as heat is flowing. For instance, if a were metallic, you could measure the conductivity of a or resistivity, and as heat flows out of a into b, the resistivity of a would change. Or you could have something that's color metric that changes color when it's colder, so you could see the heat flowing as a changes color or b changes color as heat flows into b. So, you need some sort of property, something you can see, something you can measure, that tells you that heat has flowed.

Now, if you have three objects, if you have a, b, and c, and you bring them together, and a is the hottest, b is the medium one, and c is the coldest, so from hottest to coldest a, b, c, -- if you bring them together and make them touch, you know, intuitively, that heat will not flow like this. You know that's not going to happen. You know that what will happen is that heat will flow from a to b from b to c and from a to c. That's common-sense. You know that. And the other way in the circle will never happen. That would that would give rise to a perpetual motion machine, breaking of the second law. It can't happen. But that's an empirical observation, that heat flows in this direction. And that's the zeroth law thermodynamic. It's pretty simple. The zeroth law says that if a and b -- it doesn't exactly say that, but it implies this. It says that if a and b are in thermal equilibrium, if these two are in thermal equilibrium, meaning that there's no heat flows between them, so that's the definition of thermal equilibrium, that no heat flows between them, and these two are in thermal equilibrium, and these two are in thermal equilibrium, then a and c will be also be in thermal equilibrium. But if there's no heat flowing between these two, and no heat flowing between these two, then you can't have heat flowing between these two. So if I get rid of these arrows, there's no heat flowing because they're in thermal equilibrium, then I can't have an arrow here.

That's what the zeroth law says. They're all the same temperature. That's what it says. If two object are in the same temperature, and two other object are in the same temperature, then all three must have the same temperature.

It sounds pretty silly, but it's really important because it allows you to define a thermometer and temperature. Because now you can say, all right, well, now b can be my thermometer. I have two objects, I have an object which is in Madagascar and an object which is in Boston, and I want to know, are they the same temperature? So I come out with a third object, b, I go to Madagascar, and put b in contact with a. Then I insulate everything, you know, take it away and see if there's any heat flow. Let's say there's no heat flow. Then I insulate it, get back on the plane to Boston, and go back and touch b with c. If there's no heat flow between the b and c, then I can say all right, a and c were the same temperature. B is my thermometer that tells me that a and c are in the same temperature. And there's a certain property associated with heat flow with b, and it didn't change. And that property could be color. It could be resistivity. It could be a lot of different things. It could be volume. And the temperature then is associated with that property. And if it had changed, then the temperature between those two would have changed in a very particular way. So, zeroth law, then, allows you to define the concept of temperature and the measurement of temperature through a thermometer.

Let's very briefly go through stuff that you've learned before. So, now you have this object which is going to tell you whether other things are in thermal equilibrium now. What do you need for that object? You need that object to be a substance, to be something. So, the active part of the thermometer could be water. It could be alcohol, mercury, it could be a piece of metal. You need a substance, and then that substance has to have a property that changes depending on the heat flow, i.e., depending on whether it's sensing that it's the same temperature or different temperature than something else. And that property could be the volume, like if you have a mercury thermometer, the volume of the mercury. It could be temperature. It could be resistivity, if you have a thermocouple. It could be the pressure.

All right, so now you have an object. You've got a property that changes, depending on the heat flow. It's going to tell you about the temperature. Now you need to define the temperature scales. So, you need some reference points to be able to tell you, OK, this temperature is 550 degrees Smith, whatever.

So, you assign values to very specific states of matter and call those the reference points for your temperature. For instance, freezing of water or boiling of water, the standard ones. And then an interpolation scheme. You need a functional form that connects the value at one state of matter, the freezing point of water, to another phase change, the boiling point of water. You can choose a linear interpolation or quadratic, but you've got to choose it.

And it turns out not to be so easy. And if you go back into the 1800's when thermodynamics was starting, there were a zillion different temperatures scales. Everybody had their own favorite temperature scales.

The one that we're most familiar with is the centigrade or Celsius scale where mercury was the substance, and the volume of mercury is the property. The reference points are water, freezing or boiling, and the interpolation is

linear, and then that morphed into the Kelvin scale, as we're going to see later.

The Fahrenheit scale is an interesting scale. It turns out the U.S. and Jamaica are the only two places on Earth now that use the Fahrenheit scale. Mr. Fahrenheit, Daniel Gabriel Fahrenheit was a German instrument maker. The way he came up with his scale was actually he borrowed the Romer scale, which came beforehand. The Romer scale was, Romer was a Dane, and he defined freezing of water at 7.5 degrees Roemer, and 22.5 degrees Romer as blood-warm. That was his definition. Two substances, blood and water. Two reference points, freezing and blood-warm, you know, the human body. A linear interpolation between the two, and then some numbers associated with them, $7\frac{1}{2}$ and $22\frac{1}{2}$. Why does he choose $7\frac{1}{2}$ as the freezing point of water? Because he thought that would be big enough that in Denmark, the temperature wouldn't go below zero. That's how he picked $7\frac{1}{2}$. Why not? He didn't want to use negative numbers to measure temperature in Denmark outside.

Well, Fahrenheit came along and thought, well, you know, $7\frac{1}{2}$, that's kind of silly; $22\frac{1}{2}$ that's, kind of silly. So let's multiply everything by four. I think it becomes 30 degrees for the freezing of water and 22.5×4 , which I don't know what it is, 100 or something -- no, it's 90 I think. And then for some reason, that nobody understands, he decided to multiply again by $\frac{16}{15}$, and that's how we get 32 for freezing of water and 96 in his words for the temperature in the mouth or underneath the armpit of a living man in good health. What a great temperature scale. It turns out that 96 wasn't quite right. Then he interpolated and found out water boils at 212. But, you know, his experiment wasn't so great, and, you know, maybe had a fever when he did the reference point with 96, whatever. It turns out that it's not 96 to be in good health, it's 98.6 -- whatever. That's how we got to the Fahrenheit scale.

All right, next time we're going to talk about a much better scale, which is the ideal gas thermometer and how we get to the Kelvin scale.