Here's a pan on a stove top. The pan's body and handle are made out of the same material. The burner has been turned on for a little while, and the pan body is hot enough to cook this egg. But what about the handle? Is it too hot to touch? Or is it cool enough to hold? Let's find out. This video is part of the Equilibrium video series. It is often important to determine whether or not a system is at equilibrium, to do this we must understand how a system's equilibrium state is constrained by its boundary and surroundings. Hi, my name is John Lienhard, and I am a professor of Mechanical Engineering at MIT. Today, I am going to talk to you about Equilibrium and Steady State. It's a common misconception that Equilibrium and Steady State are the same. In this video, we'll take a closer look at these concepts and see how they differ. In order to understand this video, you should be familiar with the First and Second Laws of Thermodynamics, the meaning of thermal equilibrium, and the concept of heat flow rate, which is heat transfer per unit time. After watching this video, you will be able to identify whether a system is at equilibrium or at steady state, and to describe the difference between Thermal Equilibrium and Steady State. This metal bar has been sitting in a large room for a long period of time. In this example, we can assume that the room, which acts as the surroundings, is very large, much larger than the bar, which acts as our system. Heat transfer from the bar to the room acts as energy transfer across the system boundary. We'll assume that the volume of the bar and pressure of the room are constant. In other words, no mechanical work is done. The temperature of the bar is 25Â°C and the temperature of the room is also 25Â°C. Even though the molecules in the air are colliding with the atoms on the surface of the bar, there is no net transfer of energy between the room and the bar. The temperature of both the bar and the room remain constant at 25Â°C. In thermodynamic terms, we say that the bar and the room are in thermal equilibrium. Because there is no difference in temperature, there is no heat transfer between the bar and the room. What if we wanted the temperature of the bar to be larger than that of the room, and we wanted it to remain that way? Pause the video and think about how we might do this. Of course, if we simply place a bar at 45Â°C in the room, the small bar will lose energy to the large room until both the bar and room are once again at thermal equilibrium at a temperature approximately equal to but ever so slightly higher than 25Â°C. You might have suggested connecting some sort of heating element to the bar. Let's try this and see what happens. Here's the bar after it has been left on a heater for a long time. As you might have expected, the bar is hottest where it's touching the heater, and coolest at the opposite end. There is a temperature gradient between these two points, but this gradient doesn't change over time. In this case, would you say the bar is at thermal equilibrium with the room? Why or why not? Pause the video here and discuss this with a partner. We know that energy is being continuously transferred from the heater to the metal bar. And we also know that the temperature profile of the bar is not changing; in other words, it's not getting any hotter or cooler. That means the bar must be transferring the energy it's gaining from the heater to the air in the room. And that means it cannot be in thermal equilibrium with the room. Now, in order for the temperature profile to be constant in time, the heat flow rate from the heater into the bar must be constant and equal to the heat flow rate from the bar to the room. We could use a new term to describe these conditions -- we could say that the bar is at steady state. A quantity is at Steady State when it is constant with respect to time. In other words, the partial derivative of the quantity with respect to time is zero. The metal bar is at steady state because the time derivative of its temperature at any point is zero. This happens when the heat flow rate into the bar and out of the bar are equal and constant. Let's go back to the heated pan which was left on the stove for a long time. Do you think the pan handle will be too hot to touch, or cool enough to hold? Use the concepts of thermal equilibrium and steady state temperature to think of circumstances in which the handle might be too hot, or cool enough, to hold. You might consider how the handle is attached to the pan, or how well the handle transfers heat to the room. Pause the video here and discuss. How many scenarios did you come up with? There are many, but let's start with two extreme cases. What would happen if the handle and pan were in perfect thermal contact, and both were completely isolated from the room? Eventually, the handle would reach the same temperature as the pan. This is what that would look like: the temperature of the pan and handle are identical and constant. So, the handle is in thermal equilibrium with the pan. What can you say about the transfer of heat from the pan to the handle once the pan and handle are in this situation? Pause the video and discuss. The rate of heat transfer must be zero -- if it wasn't, the handle would keep getting hotter, which is impossible, assuming that the temperature of the pan is constant. The heat flow rate from the handle to the room is also zero, because we assumed the handle is isolated from the room. So, the heat flow rates into and out of the handle are exactly the same - zero and constant. And steady state occurs when the flow rate in equals the flow rate out, even if they're both zero. So this scenario, which we've been describing as "equilibrium," is really just a limiting case of steady state. And that's true for all systems at thermal equilibrium: they are all at steady state with respect to temperature. But the opposite is not true: not all systems at steady state are in thermal equilibrium. In this case, the handle will obviously be too hot to hold, since it's the same temperature as the pan. Now let's consider the opposite case. What would happen if the handle were completely insulated from the pan? The handle would be at thermal equilibrium with the room, and would stay that way no matter how hot the pan got. The temperature of the handle would be exactly the same as that of the air. Just as in our first case, both the heat flow rate from the pan to the handle and from the handle to the air are zero and constant. Thus, this case of "thermal equilibrium" is really just another limiting case of steady-state temperature, except, of course, the handle will be cool enough to hold. Both of these cases are great thought experiments. But they could never happen in real life, because it's impossible to completely isolate one component of a system from another. In case 1, it would be impossible to isolate the pan and handle from the room; and in case 2, it would be impossible to isolate the handle from the pan. So are we any closer to figuring out whether we can pick up this pan or not? Let's keep going... Let's go back to our first case and refine our thinking. We originally assumed that the pan and handle were in perfect thermal contact, and that the pan and handle were totally isolated from the room. Let's keep the first assumption, but change the second assumption. In other words, we will allow for some flow of heat from the handle to the room. Now what happens as we heat up the pan? We can assume that the heat flow rate from the pan to the handle is initially larger than the heat flow rate from the handle to the room. This is reasonable because the pan is initially much hotter than the handle. So the handle will definitely heat up, just like our metal bar from before. As long as the flow of heat from the pan to the handle is greater than the flow of heat from the handle to the room, the handle will get hotter. And also just like our metal bar, it will be hottest closest to the pan, and coolest far away from it. As the temperature of the handle rises, the heat flow rate from the handle to the room will also rise. And eventually, it will equal the heat flow rate from the pan to the handle. In other words, after some length of time the handle will be losing energy to the room at exactly the same rate as it's gaining energy from the pan. When this happens, the temperature gradient along the handle will stop changing, and the system will be at steady state with respect to temperature. But, remember: it will not be in thermal equilibrium. So, can we say whether the handle is too hot to hold? No! That depends on the exact temperature distribution when the system reaches steady state. Take a moment to sketch a temperature profile that describes a steady-state situation wherein all or part of the handle is too hot to touch. What values of the heat flow rate from the pan to the handle could result in a handle that is too hot to touch. What characteristics of the pan, handle and/or room could produce this profile? Pause the video and discuss this with a partner. Okay, we're at our final scenario. Let's review the previous cases. In case 1, we assumed the pan and handle were in perfect thermal contact and that the system was completely isolated from the room. In case 2, the handle was completely isolated from the pan. In both case 1 and case 2, the handle was in thermal equilibrium -- there was no transfer of heat into or out of the system. The handle was also at steady state with respect to temperature. Make sure that you can explain why this is true. In case 3, we went back to our assumption of perfect thermal contact between the pan and the handle, but we allowed for some heat transfer from the handle to the room. For this final case, let's pick and choose the most reasonable assumptions from our previous cases and build from there. We'll assume that the handle can exchange heat with the room. We'll also assume that the pan and handle are insulated from each other. This is reasonable, because if you're a pan designer, you don't want your customers burning their hands! But of course, there is no such thing as perfect insulation, so we have to allow for at least some heat transfer between the pan and handle. If the rate of heat flow from the pan to the handle is extremely small, what can you say about the temperature profile across the handle once the system reaches steady state? Pause the video and sketch a possible steady state temperature profile in the handle. Here's one. If the rate of heat flow from the pan to the handle is very low, the system will reach a steady state temperature well before the majority of the handle gets hot. There will be a very small region near the pan where the handle is hotter than the room, but most of the handle will be close to the temperature of the room. So let's answer our original question. Will the pan handle be too hot to hold or will it be comfortable to touch? Let's look at a thermal image of the pan after it has been left on the stove for 30 minutes. It looks like we predicted in case 4! A very small portion of the handle is warmer than the room, but most of the handle is at room temperature. Remember, this does not mean that the handle is in thermal equilibrium with the room. There is a constant but small rate of heat flow from the pan to the handle, and an equal rate of heat flow from the handle to the room. The handle was designed to reach a steady-state temperature that is comfortable to hold without a glove. This is a well-designed pan! You now have the tools to understand that Thermal Equilibrium and Steady State temperature are different. We saw that if the temperatures of all parts of a system do not change with time, the system can either be at steady state or at thermal equilibrium. If the net heat flow is constant and nonzero as for our metal bar on the heater, the system will have a steady temperature profile. If it is constant and zero, as for our metal bar at room temperature, the system is at thermal equilibrium. So, equilibrium is just a special case of steady state. We were able to apply our understanding of thermal equilibrium and steady state temperature to describe the temperature profile of a pan left on the stove for a long time and to understand the design elements that led to that profile. I hope you enjoyed this video. Good luck in your studies.