Today we will be melting ice using our microwave ovens. The purpose of this is to examine how energy affects matter. If we were in Weniger we would transfer our energy using a power supply and resistor, and you would be able to use a couple of multimeters to measure voltage and current and quantitatively determine how much energy was being dissipated per second. Instead we will use a microwave oven, and assume that its power is constant so we can treat time as a measure of the energy transfered.

In Math Bits, you have learned that the way amount internal energy changes relates to the work done:

$$dU = F_L dx_L + F_R dx_R \tag{1}$$

You made small changes in dx_L and dx_R and determined from that how much the energy changed.

Today we are gong to examine energy transfer in a backwards manner. When we transfer energy to something by heating, it's hard to measure the "thing we changed," which was entropy. It is, however, possible in some cases to measure the amount of energy transfered by heating, and from that we can work backwards to find out how much the entropy changed.

The amount of energy transfered into a system by heating is generally written as Q.[1] An infinitesimal amount of energy transfered by heating is called $đQ$. Recall that $đ$ indicates an inexact differential, which you can think of as a "small chunk" that is not the change of something. $đQ$ is **not** *a small change in the amount of energy transfered by heating*, but rather is a small amount of energy transfered by heating.

Heat here is analogous to left work $F_L dx_L$, which is also an amount of energy transfered to a system. So you might wonder what the "thing changing" is, which is analogous to dx_L. A natural guess might be temperature, since you know that has something to do with heat, but we can see that temperature can't be the "thing that changes" when you heat something, because you can transfer energy by heating without changing the temperature.

1 Latent heat

A phase transition is when a material changes state of matter, as in melting or boiling. At most phase transitions (technically, *abrupt* phase transitions as you will learnin the Capstone), the temperature remains constant while the material is changing from one state to the other. So you know that as long as you have ice and water coexisting in equilibrium at one atmosphere of pressure, the temperature must be 0°C. Similarly, as long as water is boiling at one atmosphere of pressure, the temperature must be 100°C. In both of these cases, you can transfer energy to the system (as we will) by heating *without changing the temperature*! This relates to why I keep awkwardly saying "transfer energy to a system by heating" rather than just "heating a system" which means the same thing. We have deeply ingrained the idea that "heating" is synonymous with "raising the temperature," which does not align with the physics meaning.

So now let me define the latent heat. The **latent heat** is the amount of energy that must be transfered to a material by heating in order to change it from one phase to another. The **latent heat of fusion** is the amount of energy required to melt a solid, and the **latent heat of vaporization** is the amount of energy required to turn a liquid into a gas. We will be measuring both of these for water.

A question you may ask is whether the latent heat is extensive or intensive. Technically the latent heat is *extensive*, since if you have more material then more energy is required to melt/boil it. However, when you hear latent heat quoted, it is almost always the specific latent heat, which is the energy transfer by heating required per unit of mass. It can be confusing that people use the same words to refer to both quantities. Fortunately, dimensional checking can always give you a way to verify which is being referred to. If L is an energy per mass, then it must be the specific latent heat, while if it is an energy, then it must be the latent heat.

2 Heat capacity and specific heat

The **heat capacity** is the amount of energy transfer required per temperature to raise the temperature of a system. If we hold the pressure fixed (as in our experiment) we can write this as:

$$đQ = C_p dT \tag{2}$$

[1] Q is often called "the heat", but I try to avoid this language, because there is a historical misconception built deeply into our language that heat is a property of a material, that is a state property. This is caloric theory. You don't need to know any of this history.

where C_p is the heat capacity at fixed pressure. You might think to rewrite this expression as a derivative, but we can't do that since the energy transfered by heating is not a state function.

Note that the heat capacity, like the latent heat, is an extensive quantity. The **specific heat** is the the heat capacity per unit mass, which is an intensive quantity that we can consider a property of a material independently of the quantity of that material.

I'll just mention as an aside that the term "heat capacity" is another one of those unfortunate phrases that reflect the inaccurate idea that heat is a property of a system.

3 Entropy

Finally, we can get to entropy. Entropy is the "thing that changes" when you transfer energy by heating. I'll just give this away:

$$đQ = TdS \tag{3}$$

where this equation is only true if you make the change quasistatically (see another lecture). This allows us to find the change in entropy if we know how much energy was transfered by heating, and the temperature in the process.

$$\Delta S = \int \frac{1}{T} đQ \tag{4}$$

where again, we need to know the temperature as we add heat.