

LATENT HEAT

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In most cases, adding heat to a substance causes its temperature to rise, by an amount governed by its heat capacity. At a phase transition (melting or boiling), however, heat is required just to convert the substance from one phase to another without changing its temperature. [I can still remember the first time I discovered this, in a high school chemistry lab. We were given a test tube filled with wax in which was embedded a thermometer and had to record the temperature as we heated the test tube over a bunsen burner. At first, as you'd expect, the temperature of the (still solid) wax increased, but then it levelled off as the wax started to melt. It was one of those experiments that left a lasting impression on me some 45 years later.]

The amount of heat per unit mass required to effect a phase transition is called *latent heat*:

$$L \equiv \frac{Q}{m} \quad (1)$$

Every substance has its own latent heats at its melting and boiling points, and these latent heats can be quite large compared with the specific heat capacity. For water, the latent heat for melting ice is $333 \text{ J g}^{-1} = 80 \text{ cal g}^{-1}$ and for boiling water it is $2260 \text{ J g}^{-1} = 540 \text{ cal g}^{-1}$. (Recall that the specific heat capacity of liquid water is $1 \text{ cal g}^{-1}\text{K}^{-1}$, so heating liquid water from its melting point to its boiling point takes 100 cal g^{-1} .)

Example 1. We have a 200 gram cup of tea at boiling point and wish to cool it down to 65°C before we drink it, by putting a mass m of ice (initially at -15°C) into the tea. Given that the specific heat capacity of ice is $0.5 \text{ cal g}^{-1}\text{K}^{-1}$, how much ice do we need?

The tea (assumed to have the same heat capacity as pure water) must decrease by 35 K , so it must give up an amount of heat

$$Q = 200 \times 35 = 7000 \text{ cal} \quad (2)$$

This heat goes into, first, heating the ice by 15 degrees to its melting point, then melting it, then heating the resulting water to 65°C . The heat required for each of these steps is

$$Q = \begin{cases} 15 \times 0.5m & \text{to heat the ice to } 0^\circ \\ 80m & \text{to melt the ice} \\ 65m & \text{to heat the water to } 65^\circ \text{ C} \end{cases} \quad (3)$$

The sum of these three heats is equal to the heat lost by the tea, so

$$(7.5 + 80 + 65)m = 7000 \quad (4)$$

$$m = 45.9 \text{ g} \quad (5)$$

Example 2. Estimating how long it takes the snow pack to melt with the spring thaw. Suppose the snow is composed of 50% ice and 50% air, and that it's 2 metres deep. The sun provides around 1000 watts m^{-2} of energy, but around 90% of this is reflected by the snow, so the snow absorbs only about 100 watts m^{-2} . The density of ice at its melting point is 0.9167 g cm^3 so in a block of snow with 1 m^2 surface area and a depth of 2 m, there is a mass m of ice:

$$m = 1 \times 2 \times 0.9167 \times \frac{1}{2} \times 10^6 = 9.167 \times 10^5 \text{ g} \quad (6)$$

The amount of heat required to melt the ice is

$$Q = 80 \times 9.167 \times 10^5 = 7.33 \times 10^7 \text{ cal} \quad (7)$$

The heat is provided by the sun at the rate of

$$P = \frac{100}{4.186} = 23.89 \text{ cal s}^{-1} \quad (8)$$

so it takes

$$t = \frac{7.33 \times 10^7}{23.89} = 3.07 \times 10^6 \text{ s} \approx 5 \text{ weeks} \quad (9)$$

to melt the snow. Of course, the sun is shining only during the daytime, so we'd expect about double this time would actually be needed. [This is actually not that bad an estimate. I remember when I used to go hiking in the mountains north of Vancouver that even in July there was still a lot of snow. We usually had to wait until August before it was gone.]

PINGBACKS

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