

## CHAPTER 1

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# Heat

Let's say you put a 1 kg aluminum pan that is 80° C into 3 liters of water that is 20° C. Energy, in the form of heat, will be transferred from the pan to the water until they are at the same temperature. (We call this "thermal equilibrium.")

What will the temperature of the water be?

### 1.1 Specific Heat Capacity

If you are heating something, the amount of energy you need to transfer to it depends on three things: the mass of the thing you are heating, the amount of temperature change you want, and the *specific heat capacity* of that substance.

#### Energy in Heat Transfer

The energy moved in a heat transfer is given by

$$E = mc\Delta_T$$

where  $m$  is the mass,  $\Delta_T$  is the change in temperature, and  $c$  is the specific heat capacity of the substance.

(Note that this assumes no phase change. For example, this formula works nicely on warming liquid water, but it gets more complicated if you warm the water past its boiling point.)

Can we guess the specific heat capacity of a substance? It is very, very difficult to guess the specific heat of a substance, so we determine it by experimentation.

For example, someone determined that it took about 0.9 joules to raise the temperature of solid aluminum one degree Celsius. So we say "The specific heat capacity of aluminum is 0.9 J/g °C."

The specific heat capacity of liquid water is about 4.2 J/g °C.

To answer the question, then, the amount of energy given off by the pan must equal the amount of energy absorbed by the water. And they need to be the same temperature at

the end. Let  $T$  be the final temperature of both.

Watch Khan Academy's discussion of heat capacity at <https://www.khanacademy.org/science/ap-chemistry-beta/x2eef969c74e0d802:thermodynamics/x2eef969c74e0d802:heat-capacity-and-calorimetry/v/heat-capacity>

Three liters of water weighs 3,000 grams, so the change in energy in the water will be:

$$E_W = mc\Delta_T = (3000)(4.2)(T - 20) = 12600T - 252000 \text{ joules}$$

The pan weighs 1000 grams, so the change in energy in the pan will be:

$$E_P = mc\Delta_T = (1000)(0.9)(T - 80) = 900T - 72000 \text{ joules}$$

Total energy stays the same so  $E_W + E_P = 0$ . So you need to solve

$$(12600T - 252000) + (900T - 72000) = 0$$

And find that the temperature at equilibrium will be

$$T = 24^\circ\text{C}$$

## Exercise 1 Thermal Equilibrium

Working Space

Just as you put the aluminium pan in the water as described above, someone also puts a 1.2 kg block of copper cooled to  $10^\circ\text{C}$ . The specific heat of solid copper is about  $0.4 \text{ J/g } ^\circ\text{C}$ .

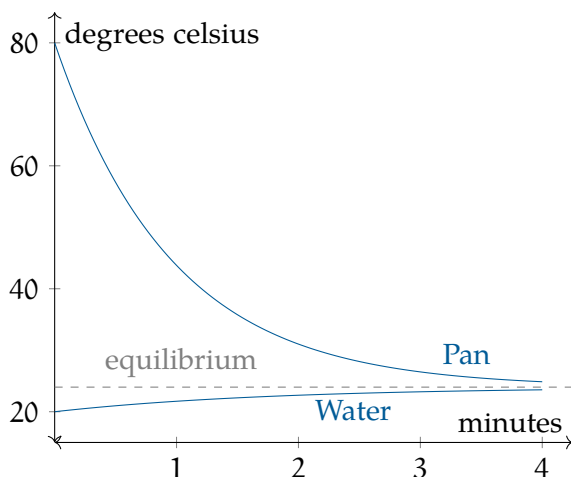
What is the new temperature at equilibrium?

Answer on Page 5

## 1.2 Getting to Equilibrium

When two objects with different temperatures are touching, the speed at which they exchange heat is proportional to the differences in their temperatures. Thus, as their temperatures get closer together, the heat exchange slows down.

In our example, the pan and the water will get close to equilibrium quickly, but they may never actually reach equilibrium.



### Exercise 2 Cooling Your Coffee

*Working Space*

You have been given a ridiculously hot cup of coffee and a small pitcher of chilled milk.

You need to start chugging your coffee in three minutes, and you want it as cool as possible at that time. When should you add the milk to the coffee?

*Answer on Page 5*

### 1.3 Specific Heat Capacity Details

For any given substance, the specific heat capacity often changes a lot when the substance changes state. For example, ice is  $2.1 \text{ J/g } ^\circ\text{C}$ , whereas liquid water is  $4.2 \text{ J/g } ^\circ\text{C}$ .

Watch Khan Academy's discussion of the specific heat of water: <https://www.khanacademy.org/science/biology/water-acids-and-bases/water-as-a-solid-liquid-and-gas/v/specific-heat-of-water>

Even within a given state, the specific heat capacity varies a bit based on the temperature and pressure. If you are trying to do these sorts of calculations with great accuracy, you will want to find the specific heat capacity that matches your situation. For example, I might look for the specific heat capacity for water at  $22^\circ\text{C}$  at 1 atmosphere of pressure(atm).

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*This is a draft chapter from the Kontinua Project. Please see our website (<https://kontinua.org/>) for more details.*

# Answers to Exercises

## Answer to Exercise 1 (on page 2)

$$E_C = (1200)(0.4)(T - 10) = 480T - 4800$$

Total energy stays constant:

$$0 = (12600T - 252000) + (900T - 72000) + (480T - 4800)$$

Solving for T gets you  $T = 23.52^\circ \text{ C}$ .

## Answer to Exercise 2 (on page 3)

During the 3 minutes, you want the coffee to give off as much of its heat as possible, so you want to maximize the difference between the temperature of the coffee and the temperature of the room around it.

You wait until the last moment to put the milk in.





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