Let's do a couple of standard physics problems using this equation so we can see what it adds to physics.

- How many joules are required to raise the temperature of 200 kg of steel from 28 °C to 1370 °C (steel's melting point)?
  - $Q = mc\Delta T$, and we are solving for "Q." We know m—200 kg—and we know Δt—1342 °C (the temperature changes from 28 °C to 1370 °C, so the change in temperature is 1370 – 28 = 1342 °C). We need to convert the mass from kg to g because the specific heat constant (c) we are using is in grams (200 kg = 200,000 g). So, here is what we know so far:

$$Q = 200{,}000g \cdot c \cdot 1342^{\circ}C$$

Ok, we have two variables in that equation—Q and c. What now? The specific heat value of almost every substance is known, so you can always obtain that value from somewhere. For now, look to **Figure 4.7.1** to get "c" for steel—0.45 J/g · °C (make sure to use the joule value and not the calorie value since the question asks for the value in joules)—and we'll put that value into the equation:

$$Q = 200{,}000g \cdot 0.45\,\frac{J}{g \cdot {}^{\circ}C} \cdot 1342^{\circ}C$$

Let's do the math first and then deal with the units. The numbers multiply out to 120,7800,000:

$$Q = 120{,}780{,}000\,\frac{g\,J\,{}^{\circ}C}{g \cdot {}^{\circ}C}$$

So, it is 120,780,000 somethings. Let's cancel the units:

$$Q = 120{,}780{,}000\,\frac{\cancel{g}\,J\,{}^{\circ}\cancel{C}}{\cancel{g} \cdot {}^{\circ}\cancel{C}}$$

It takes 120,780,000 J to heat 200 kg of steel from 28 °C to 1370 °C. If we put the number into scientific notation, it is 1.2078×10^{8} J. Steel has a very low specific heat capacity, which means that it doesn't require very much heat to heat it up compared to other substances.

Let's look at another example, using water, to see how much of a difference the high specific heat value of water makes. We'll use the same amount of water—200 kg—as we did the steel (note that 1 l of water weighs 1 kg).

- What quantity of heat is required to bring 200 l (200 kg) of water from 0 °C to 100 °C? $Q=m \cdot c \cdot \Delta T$ and we know m (200,000 g), c (4.186 J/g °C, from the Table above) and ΔT (100 – 0 = 100 °C), so let's plug in our numbers:

$$Q = 200{,}000g \cdot 4.186\frac{J}{g\,{}^{\circ}C} \cdot 100^{\circ}C$$

The numbers multiply to 83,720,000, or 8.372×10^{7}. The unit cancellation looks like this:

$$Q = 83{,}720{,}000\frac{\cancel{g}\,J\,{}^{\circ}\cancel{C}}{\cancel{g} \cdot {}^{\circ}\cancel{C}}$$

So, to raise 200 kg of water 100 °C, it takes 83,720,000 J of heat. In the steel example, we used the same amount of steel—200 kg—and raised its temperature 13 *times* higher than we did the water's, and it only took 1.4 times more heat to do it. This reflects how much heat water can absorb without its temperature changing very much. Its high specific heat capacity makes it warm and cool slowly. The lower the specific heat capacity, the faster a substance heats and cools.

For those who haven't had much algebra, yet, this next part might be a little confusing, but I think if you stick with me, it will make sense. Since using the Q = mcΔT equation is all about understanding the concept that heat put into a system is related to the mass of the system (or object being heated or cooled), its specific heat value, the temperature change and then plugging in the numbers, it is also possible to use the equation to determine any variable in it.

For example, let's say you had performed a thermodynamic experiment several weeks ago in which you heated some silver to measure various aspects of its response. You know that it took 1,237.7 cal (we'll use calories for this example) to heat the silver from 20.1 °C to 135.5 °C, but neither you nor your lab assistant can find how much silver you heated. You need to know how much silver you had for a scientific paper you are writing, but the silver has now been used for other experiments, so you are unable to measure its mass. Is there any way to know how much silver you had, or is all lost?

There is a way, using the Q = mcΔT equation. You know Q—1,237.7 cal—and ΔT—115.4 °C (135.5 – 20.1 = 115.4). Also, checking **Figure 4.7.1**, you find that c for silver is 0.0558 cal/g °C. Therefore, the only piece missing is what you're searching for: the mass of the silver, and you can figure this out by filling the known values into the equation:

$$1{,}237.7\text{cal} = m \cdot 0.0558\,\frac{\text{cal}}{\text{g}\cdot{}^\circ\text{C}} \cdot 115.4^\circ\text{C}$$

Next, we need to solve it for "m," which is the mass of the silver that we need to know. To solve for "m," we divide both sides of the equation by 0.0558 and its units, and 115.4 and its units:

New graphic

This equals 1 (again, if you haven't had much algebra, yet, this may not make a lot of sense, but this is just how to solve equations like this)

$$\frac{1237.7\ \text{cal}}{0.0558\,\frac{\text{cal}}{\text{g}\cdot{}^\circ\text{C}} \cdot 115.4^\circ\text{C}} = m \cdot \boxed{\frac{0.0558\,\frac{\text{cal}}{\text{g}\cdot{}^\circ\text{C}} \cdot 115.4^\circ\text{C}}{0.0558\,\frac{\text{cal}}{\text{g}\cdot{}^\circ\text{C}} \cdot 115.4^\circ\text{C}}}$$

$$1{,}237.7\text{cal} = m \cdot 0.0558\,\frac{\text{cal}}{\text{g}\cdot{}^\circ\text{C}} \cdot 115.4^\circ\text{C}$$

That big mass of numbers and units in the red box all equals 1, so we are left with this:

$$\frac{1237.7\ \text{cal}}{0.0558\,\frac{\text{cal}}{\text{g}\cdot{}^\circ\text{C}} \cdot 115.4^\circ\text{C}} = m$$

Next, we'll take care of the units. When you have a fraction in the denominator, the numerator of the fraction (in our case, the "cal") stays in the denominator and the denominator of the fraction (here the "g °C") gets moved into the numerator:

$$\frac{1237.7\ \text{cal}\cdot\text{g}\cdot{}^\circ\text{C}}{0.0558\ \text{cal} \cdot 115.4^\circ\text{C}} = m$$

Finally, we will do the math, cross out the units that cancel each other and we will have the answer:

$$\frac{1237.7\ \cancel{cal}\cdot g\cdot \cancel{^\circ C}}{0.0558\ \cancel{cal}\cdot 115.4\cancel{^\circ C}} = m$$

$$192.2\ g = m$$

So, in your experiment of several weeks ago, you heated 192.2 g of silver!

4.8 PEOPLE OF SCIENCE

James Prescott Joule (1818–1889) James Joule is one of the greatest physicists who ever lived and is often overlooked for such honor. He was born in England into a wealthy family of brewers (and is one of many scientists of the 19th century to be homeschooled). Due to his father's illness, James was required to help run the family's brewery, so he received no formal university science training. However, he was taught science by the likes of the great John Dalton and was destined to become a great scientist in his own right. In his career, he discovered basic principles of electrical current flow through wires (a formula which bears his name). His discovery of the formula for quantity of work that needed to be performed to produce an equivalent amount of heat led to the formation of an entirely new area of study in physics known as thermodynamics. Not only was he an underrated theoretical physicist, he was a gifted, clever experimenter, which fostered relationships with men like William Thomson (Lord Kelvin), Michael Faraday and James Clerk Maxwell, some of the greatest scientists of his time. Joule was one of many scientists who understood that his investigations were made possible by his belief that he was studying the world that an orderly God created. One of many things Joule wrote on the subject stated this very clearly:

> **'[T]he phenomena of nature, whether mechanical, chemical, or vital, consist almost entirely in a continual conversion … into one another. Thus it is that order is maintained in the universe—nothing is deranged, nothing ever lost, but the entire machinery, complicated as it is, works smoothly and harmoniously… the whole being governed by the sovereign will of God.'**

Along with scientific luminaries like Lord Kelvin, Joule was one of the 86 Fellows of the Royal Society who, in 1864, signed a manifesto titled "The Declaration of Students of the Natural and Physical Sciences," which was a statement against the Darwinian evolutionary movement and proclaimed the sufficiency of Scripture.

4.9 KEY CHAPTER POINTS

- Energy is the ability to do work. There are two general forms of energy—kinetic and potential.
  - Kinetic energy is the energy of motion.
  - Potential energy is stored energy.