Specific Heat Capacity & Calorimetry

Unit: Thermochemistry (Heat)

MA Curriculum Frameworks (2016): HS-PS2-6, HS-PS3-1

Mastery Objective(s): (Students will be able to…)

- Calculate the heat transferred when an object with a known specific heat capacity is heated.
- Perform calculations related to calorimetry.
- Describe what is happening at the molecular level when a system is in thermal equilibrium.

Success Criteria:

- Variables are correctly identified and substituted correctly into the correct equations.
- Algebra is correct and rounding to appropriate number of significant figures is reasonable.

Tier 2 Vocabulary: heat, specific heat capacity, coffee cup calorimeter

Language Objectives:

- Explain what the specific heat capacity of a substance measures.
- Explain how heat is transferred between one substance and another.

Labs, Activities & Demonstrations:

- Calorimetry lab.

Notes:

Different objects have different abilities to hold heat. For example, if you enjoy pizza, you may have noticed that the sauce holds much more heat (and burns your mouth much more readily) than the cheese or the crust.

The amount of heat that a given mass of a substance can hold is based on its specific heat capacity.

Use this space for summary and/or additional notes:

specific heat capacity (C): a measure of the amount of heat required per gram of a substance to produce a specific temperature change in the substance.

C_p: specific heat capacity, measured at constant pressure. For gases, this means the measurement was taken allowing the gas to expand as it was heated.

C_v: specific heat capacity, measured at constant volume. For gases, this means the measurement was made in a sealed container, allowing the pressure to rise as the gas was heated.

For solids and liquids, $C_p \approx C_v$ because the pressure and volume change very little as they are heated. For gases, $C_p > C_v$ (always). For ideal gases, $C_p - C_v = R$, where R is a constant known as "the gas constant."

When there is a choice, C_p is more commonly used than C_v because it is easier to measure. When dealing with solids and liquids, most physicists just use C for specific heat capacity and don't worry about the distinction.

Calculating Heat from a Temperature Change

The amount of heat gained or lost when an object changes temperature is given by the equation:

$$Q = mC\Delta T$$

where:

Q = heat (J or kJ)

m = mass (g or kg)

C = specific heat capacity ($\frac{\text{J}}{\text{g}\cdot{}^\circ\text{C}}$)

ΔT = temperature change (K or °C)

Note that $1\frac{\text{J}}{\text{g}\cdot{}^\circ\text{C}} \equiv 1\frac{\text{kJ}}{\text{kg}\cdot{}^\circ\text{C}} \equiv 1\frac{\text{J}}{\text{g}\cdot{}^\circ\text{C}}$.

You need to be careful with the units. If the mass is given in kilograms (kg), your specific heat capacity will have units of $\frac{\text{kJ}}{\text{kg}\cdot{}^\circ\text{C}}$ and the heat energy will come out in kilojoules (kJ). If mass is given in grams, you will use units of $\frac{\text{J}}{\text{g}\cdot{}^\circ\text{C}}$ and the heat energy will come out in joules (J).

Use this space for summary and/or additional notes:

Specific Heat Capacities of Some Substances

Substance	Specific Heat Capacity $\left(\frac{J}{g\cdot{}^\circ C}\right)$	Substance	Specific Heat Capacity $\left(\frac{J}{g\cdot{}^\circ C}\right)$
water at 20 °C	4.181	aluminum	0.897
ethylene glycol (anti-freeze)	2.460	glass	0.84
		iron	0.450
ice at −10 °C	2.080	copper	0.385
steam at 100 °C	2.11	brass	0.380
steam at 130 °C	1.99	silver	0.233
vegetable oil	2.00	lead	0.160
air	1.012	gold	0.129

Calorimetry

calorimetry: the measurement of heat flow

In a calorimetry experiment, heat flow is calculated by measuring the mass and temperature change of an object and applying the specific heat capacity equation.

calorimeter: an insulated container for performing calorimetry experiments.

coffee cup calorimeter: a calorimeter that is only an insulated container—it does not include a thermal mass (such as a mass of water). It is usually made of styrofoam, and is often nothing more than a styrofoam coffee cup.

bomb calorimeter: a calorimeter for measuring the heat produced by a chemical reaction. A bomb calorimeter is a double-wall metal container with water between the layers of metal. The heat from the chemical reaction makes the temperature of the water increase. Because the mass and specific heat of the calorimeter (water and metal) are known, the heat produced by the reaction can be calculated from the increase in temperature of the water.

It has a great name, but a bomb calorimeter doesn't involve actually blowing anything up. ☺

Use this space for summary and/or additional notes:

Solving Coffee Cup Calorimetry Problems

Most coffee cup calorimetry problems involve placing a hot object in contact with a colder one. Many of them involve placing a hot piece of metal into cold water.

To solve the problems, assume that both objects end up at the same temperature.

If we decide that heat gained (going into a substance) by each object that is getting hotter is positive, and heat lost (coming out of a substance) by every substance that is getting colder is negative, then the basic equation is:

$$\text{Heat Lost} + \text{Heat Gained} = \text{Change in Thermal Energy}$$
$$\sum Q_{lost} + \sum Q_{gained} = \Delta Q$$

If the calorimeter is insulated, then no heat is gained or lost by the entire system (which means $\Delta Q = 0$).

If we have two substances (#1 and #2), one of which is getting hotter and the other of which is getting colder, then our equation becomes:

$$\text{Heat Lost} + \text{Heat Gained} = \text{Change in Thermal Energy}$$
$$\sum Q_{lost} + \sum Q_{gained} = \Delta Q = 0$$
$$m_1 C_1 \Delta T_1 + m_2 C_2 \Delta T_2 = 0$$

In this example, ΔT_1 would be negative and ΔT_2 would be positive.

To solve a calorimetry problem, there are six quantities that you need: the two masses, the two specific heat capacities, and the two temperature changes. (You might be given initial and final temperatures for either or both, in which case you'll need to subtract. Remember that if the temperature increases, ΔT is positive, and if the temperature decreases, ΔT is negative.) The problem will usually give you all but one of these and you will need to find the missing one.

If you need to find the final temperature, use $\Delta T = T_f - T_i$ on each side. You will have both T_i numbers, so the only variable left will be T_f. (The algebra is straightforward, but ugly.)

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Sample Problems:

Q: An 0.050 kg block of aluminum is heated and placed in a calorimeter containing 0.100 kg of water at 20. °C. If the final temperature of the water was 30. °C, to what temperature was the aluminum heated?

A: To solve the problem, we need to look up the specific heat capacities for aluminum and water in the table on page 439. The specific heat capacity of aluminum is $0.898\,\frac{\text{J}}{\text{g}\cdot{}^\circ\text{C}}$, and the specific heat capacity for water is $4.181\,\frac{\text{J}}{\text{g}\cdot{}^\circ\text{C}}$.

We also need to realize that we are looking for the initial temperature of the aluminum. Δ*T* is always ***final – initial***, which means $\Delta T_{\text{Al}} = 30 - T_{i,\text{Al}}$. (Because the aluminum starts out at a higher temperature, this will give us a negative number, which is what we want.)

$$\begin{aligned}
m_{\text{Al}}C_{\text{Al}}\Delta T_{\text{Al}} \quad + \quad m_{\text{w}}C_{\text{w}}\Delta T_{\text{w}} &= 0\\
(0.050)(0.897)(30-T_i)+(0.100)(4.181)(30-20) &= 0\\
0.0449(30-T_i) + \quad 4.181 &= 0\\
1.3455-0.0449T_i + \quad 4.181 &= 0\\
5.5265 &= 0.0449T_i\\
T_i = \frac{5.5265}{0.0449} &= 123.2\,^\circ\text{C}
\end{aligned}$$

Q: An 0.025 kg block of copper at 95°C is dropped into a calorimeter containing 0.075 kg of water at 25°C. What is the final temperature?

A: We solve this problem the same way. The specific heat capacity for copper is $0.385\,\frac{\text{J}}{\text{g}\cdot{}^\circ\text{C}}$, and $\Delta T_{\text{Cu}} = T_f - 95$ and $\Delta T_{\text{w}} = T_f - 25$. This means T_f will appear in two places. The algebra will be even uglier, but it's still a straightforward Algebra 1 problem:

$$\begin{aligned}
m_{\text{Cu}}C_{\text{Cu}}\Delta T_{\text{Cu}} \quad + \quad m_{\text{w}}C_{\text{w}}\Delta T_{\text{w}} &= 0\\
(0.025)(0.385)(T_f-95_i) + (0.075)(4.181)(T_f-25) &= 0\\
0.009625(T_f-95) \quad + \quad 0.3138(T_f-25) &= 0\\
0.009625\,T_f-(0.009625)(95)+0.3136\,T_f-(0.3138)(25) &= 0\\
0.009625\,T_f-0.9144+0.3138\,T_f-7.845 &= 0\\
0.3234\,T_f &= 8.759\\
T_f = \frac{8.759}{0.3234} &= 27\,^\circ\text{C}
\end{aligned}$$

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Homework Problems

You will need to look up specific heat capacities in Table Z. Selected Properties of the Elements, starting on page 516.

1. 375 kJ of heat is added to a 25.0 kg granite rock. If the temperature increases by 19.0 °C, what is the specific heat capacity of granite?

   Answer: $0.790\,\frac{\text{J}}{\text{g}\cdot{}^{\circ}\text{C}}$

2. A 0.040 kg block of copper at 95 °C is placed in 0.105 kg of water at an unknown temperature. After equilibrium is reached, the final temperature is 24 °C. What was the initial temperature of the water?

   Answer: 21.5 °C

3. A sample of metal with a specific heat capacity of $0.50\,\frac{\text{J}}{\text{g}\cdot{}^{\circ}\text{C}}$ is heated to 98 °C and then placed in an 0.055 kg sample of water at 22 °C. When equilibrium is reached, the final temperature is 35 °C. What was the mass of the metal?

   Answer: 0.0948 kg

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4. A 0.280 kg sample of a metal with a specific heat capacity of $0.430\,\frac{J}{g\cdot{}^{\circ}C}$ is heated to 97.5 °C then placed in an 0.0452 kg sample of water at 31.2 °C. What is the final temperature of the metal and the water?

Answer: 57 °C

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