Learning Objectives

- Define heat capacity and specific heat capacity and differentiate between the two terms
- Deduce which substance will have greatest temperature changed based on specific heat capacities
- Calculate unknown variables based on known variables using the specific heat equation

Heat Capacitance

The heat capacity of a substance describes how its temperature changes as it absorbs or releases heat, it is the capacity of a substance to contain heat. This equation relates the heat absorbed (or lost) to the temperature change

\[
\Delta q = q_{\text{transferred}} = q = C\Delta T
\]

Please note this heat q is the amount of heat transferred to or from an object as its temperature is changed, and we call it q, not (\Delta q). It is not the total heat energy of the object.

Rearranging the above eq gives the definition of the heat capacitance of an object

\[
C = \frac{q (J)}{\Delta T (K)}
\]

This is an important equation because it relates the heat lost or gained by an object to its temperature change. A substance with a small heat capacitance cannot hold a lot of heat energy and so warms up quickly. We should note that the rate of heat transfer (how fast something heats up or cools down), is a function of the temperature difference. So as heat transfers from the hot object (which cools) to the cold object (which warms) the temperature difference reduces, and the rate of heat transfer slows down and finally stops when they reach the same temperature. The heat capacitance of a substance depends both on the material it is made of, and the mass of the substance.

Note: You can determine the above equation from the units of Capacity (energy/temperature). That is if a constant has units, the variables must fit together in an equation that results in the same units. So C equals something with energy in the numerator and temperature in the denominator. Now, you need to use some common sense here, as we are adding heat, not work, and adding heat changes the temperature, it does not make the temperature. So the right side is a \(\Delta T\), and not a \(T\).
Exercise \(\PageIndex{1}\)

The Heat Capacitance of a 10.0 g silver ring is 2.36J/°C.

a. Convert this value to units of J/K.

b. Convert this value to units of cal/°C.

Answer a

2.36J/K, these are the same value because the denominator is \((\Delta T)\) not T.

Answer b

0.564cal/°C.

Specific Heat Capacitance

The specific heat capacitance is the heat capacitance per gram of a substance. This value depends on the nature of the chemical bonds in the substance, and its phase.

\[q = mc\Delta T\] \(\text{or}\) \[c = \frac{q(J)}{m(g)\Delta T(K)}\]

Note: Capital “C” is the Heat Capacity of an object, lower case “c” is the specific heat capacity of a substance. The heat capacity of an object made of a pure substance is:

\[C = mc\] If the material of an object is made of uniform in composition you can use the specific heat capacity for that material to calculate the heat capacitance of the object. So doubling the mass of an object doubles its heat capacity, but does not change its specific heat capacitance.

Exercise \(\PageIndex{2}\)

In exercise \(\PageIndex{1}\) we saw that a 10.0 g silver ring has a heat capacitance of 2.36J/°C, what is the specific heat capacity of silver?

Answer

Assuming the ring is pure silver, the specific heat capacity of silver is 0.236J/g°C.
Tip: Using Units of a Constant to Identify the Equation

It should be noted that just as for heat capacity, the units of specific heat capacity must align with the units of the equation, and so you can calculate the equation from the units, as long as you realize J is a unit of energy (we are talking heat, not work), g is a unit of mass, and °C is a unit of temperature, although here, it stand for temperature change (ΔT). Video \(\PageIndex{1}\) shows how we can use the units of a constant to determine the equation.

Video \(\PageIndex{1}\): 5'32" YouTube on using constants to determine equations related to heat capacity and phase changes (https://youtu.be/mWj9pHQQylc). NOTE: in this video the values of \(\Delta H_v\) are for water, and so we use the molar mass of water to relate these. Some of these values are tabulated in table 5.3.1.

Is specific heat capacitance an extensive or intensive property?

The specific heat capacity is intensive, and does not depend on the quantity, but the heat capacity is extensive, so two grams of liquid water have twice the heat capacitance of 1 gram, but the specific heat capacity, the heat capacity per gram, is the same, 4,184 (J/g·K). So a table of specific heat capacitance based on the type of material can be used to allow us to calculate the heat capacitance of an object. Note the heat capacity depends on the phase of the substance.
<table>
<thead>
<tr>
<th>Substance</th>
<th>Symbol (State)</th>
<th>Specific Heat (J/g °C)</th>
<th>Substance</th>
<th>Symbol (State)</th>
<th>Specific Heat (J/g °C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>helium</td>
<td>He(g)</td>
<td>5.193</td>
<td>aluminum</td>
<td>Al(s)</td>
<td>0.897</td>
</tr>
<tr>
<td>water</td>
<td>H₂O(l)</td>
<td>4.184</td>
<td>carbon dioxide</td>
<td>CO₂(g)</td>
<td>0.853</td>
</tr>
<tr>
<td>ethanol</td>
<td>C₂H₆O(l)</td>
<td>2.376</td>
<td>silicon</td>
<td>Si(s)</td>
<td>0.712</td>
</tr>
<tr>
<td>ice</td>
<td>H₂O(s)</td>
<td>2.093 (at -10 °C)</td>
<td>argon</td>
<td>Ar(g)</td>
<td>0.552</td>
</tr>
<tr>
<td>water vapor</td>
<td>H₂O(g)</td>
<td>1.864</td>
<td>iron</td>
<td>Fe(s)</td>
<td>0.449</td>
</tr>
<tr>
<td>nitrogen</td>
<td>N₂(g)</td>
<td>1.040</td>
<td>copper</td>
<td>Cu(s)</td>
<td>0.385</td>
</tr>
<tr>
<td>air mixture</td>
<td>mixture</td>
<td>1.007</td>
<td>gold</td>
<td>Au(s)</td>
<td>0.129</td>
</tr>
<tr>
<td>oxygen</td>
<td>O₂(g)</td>
<td>0.918</td>
<td>lead</td>
<td>Pb(s)</td>
<td>0.128</td>
</tr>
</tbody>
</table>

Table\(\PageIndex{1}\): Specific Heat Capacities for common substances.

Note: Metals have low heat capacities and thus undergo rapid temperature rises when heat is applied.

Exercise \(\PageIndex{3}\)

If you add the same amount of heat to an equal mass of liquid water, solid gold, and solid iron, which would end up having the highest temperature?

**Answer**

Solid Gold. They all have the same mass and are exposed to the same amount of heat. So, the one with the lowest
specific heat would have the highest temperature. It has the lowest resistance to temperature change when exposed to heat. If you ever reached into an oven to grab your food with a gold bracelet on, you may have experienced the low specific heat capacity of gold. Metals have low heat capacities and thus undergo rapid temperature rises when heat is applied.

Example $\PageIndex{1}$

What is the final temperature if 100.0 J is added to 10.0 g of Aluminum at 25°C? $c_{AI} = 0.902 \text{J/(g} \cdot \text{C)}$. For extra help watch video $\PageIndex{2}$, which solves this problem.

Solution

$T_f = T_i + \frac{q}{mc} = 25^\circ \text{C} + \frac{100.0 \text{J}}{10.0 \text{g} \left( \frac{0.902 \text{J}}{\text{g} \cdot ^\circ \text{C}} \right)} = 36.1^\circ \text{C}$

Video $\PageIndex{2}$: 1'18'' YouTube solving example $\PageIndex{2}$ (https://youtu.be/4hKfm4B-C6o).
Specific heat capacity can be used to identify an unknown substance.

The specific heat capacity is a physical property of the material a substance is composed of and can be used to help identify the substance the way density can help identify an incompressible substance like a solid or liquid. It should be noted that two substances can have the same specific heat capacity just as two substances can have the same density, but for example, if the heat capacity of a clear liquid is not 1 cal/g°C, the substance can not be pure water.

Example \(\PageIndex{2}\)

You have an unknown metal that is either Al, Cu, Ag or Fe and want to identify it. Upon adding 51.26J to 10.0G of the metal its temperature is raised by 22°C

**Solution**

Calculate the specific heat capacity and relate to those on table \(\PageIndex{1}\). The metal is silver and this problem is solved in Video \(\PageIndex{3}\)
Video \(\PageIndex{3}\): 1'12" YouTube using specific heat capacity calculations to help identify a metal
(https://youtu.be/duAzx66-0Tl)

Exercise \(\PageIndex{4}\)

Can you use the specific heat capacity to tell the difference between lead and gold?

**Answer**

No, gold had a specific heat capacity of 0.129J/g°C and lead of 0.128J/g°C. The thousandths position is uncertain and so to three significant digits, you can not differentiate between these two samples (you report all certain and the first uncertain, so if you have a measurement of 0.128, you are not really sure of the 0.008 value.

Contributors

Robert E. Belford (University of Arkansas Little Rock; Department of Chemistry). The breadth, depth and veracity of this work is the responsibility of Robert E. Belford, rebelford@ualr.edu. You should contact him if you have any concerns. This material ahs both original contributions, and content built upon prior contributions of the LibreTexts Community and
other resources, including but not limited to:

- Ronia Kattoum & Emily Choate (UALR)