Specific Heat and Phase Change

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CONCEPT 1 Specific Heat and Phase Change

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Key Equations

$Q = mc\Delta T$; the heat gained or lost is equal to the mass of the object multiplied by its specific heat multiplied by the change of its temperature.

$Q = mL$; the heat lost or gained by a substance due to a change in phase is equal to the mass of the substance multiplied by the latent heat of vaporization/fusion (L refers to the latent heat)

1 cal = 4.184 Joules ; your food calorie is actually a kilocalorie (Cal) and equal to 4184 J.

TABLE 1.1: Table of Specific Heat Values

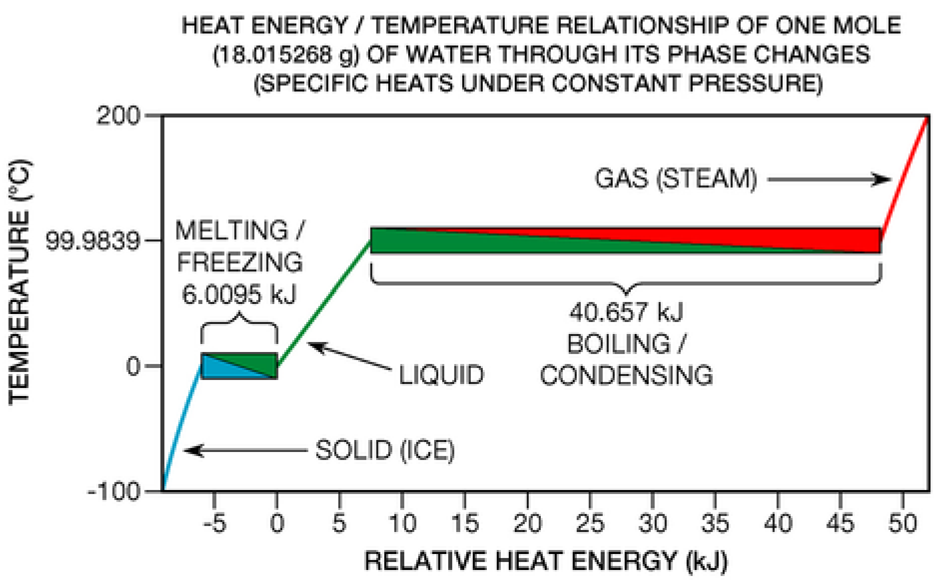
Substance	Specific Heat, c $(cal/g°C)$
Air	6.96
Water	1.00
Alcohol	0.580
Steam	0.497
Ice $(-10°C)$	0.490
Aluminum	0.215
Zinc	0.0925
Brass	0.0907
Silver	0.0558
Lead	0.0306
Gold $\sim$ Lead	0.0301

TABLE 1.2: Table of Heat of Vapourization

Substance	Fusion, $L_f(cal/g)$	Vaporization, $L_v(cal/g)$
Water	80.0	540
Alcohol	26	210
Silver	25	556
Zinc	24	423
Gold	15	407
Helium	-	5.0

Guidance

- The amount of heat capacitance (and thus its specific heat value) is related to something called 'degrees of freedom,' which basically says how free is the object to move in different ways (and thus how much kinetic energy can it store inside itself without breaking apart). For example, solids have a more fixed structure, so they cannot rotate and jostle as much, so they can't store as much internal energy so they have lower heat capacitance then liquids.
- **Specific heat** is similar to heat capacitance, but is a specific number. The specific heat tells you how much energy one must put in per unit mass in order to raise the temperature $1°C$.
- **Phase changes**: it takes energy to changes phases from a solid to a liquid and from a liquid to a gas. The substance releases energy when changing phase from gas to liquid or from liquid to solid. How much energy per unit mass depends on the substance in question. When you get out of the shower you often feel cold. This is because the water on you is evaporating, and heat is flowing from you to the water droplets in order for them to change phase from water to gas. You are losing heat and thus feel cold.
- A calorie is a unit of energy. The food Calorie, with a capital C, is actually 1,000 calories (a kcal). Thus, for example, a snicker bar labeled with 200 Cal is actually 200,000 cal.
- Food calories are determined by burning the food and measuring the heat released.
- During a phase change, the number of degrees of freedom changes, and so does the specific heat capacity. Heat capacity can also depend on temperature within a given phase, but many substances, under constant pressure, exhibit a constant specific heat over a wide range of temperatures. For instance, here is a graph of temperature vs heat input for a **mole** (6.0221415×10^{23} molecules) of water. Note that the x-axis of the graph is called 'relative heat energy' because it takes a mole of water at 0 degrees Celcius as the reference point.



The sloped segments on the graph represent increases in temperature. The flat segments represent phase transitions, governed by equation for latent heat. Notice that the sloped segments have constant, though different, slopes. According to this equation, the heat capacity at any particular phase would be the slope of the segment that corresponds to that phase on the graph. The fact that the slopes are constant means that, within a particular phase, the heat capacity does not change significantly as a function of temperature. **Heat capacity** is the amount of internal energy that the substance can store. A large heat capacitance means the substance can store a lot of internal energy and thus the temperature changes slowly. Aluminum foil has a small heat capacitance and water has a large one.

Example 1

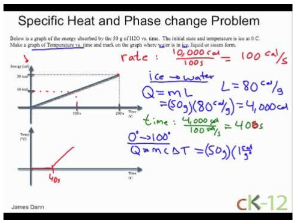
A 500 g piece of aluminum metal of unknown temperature is thrown into a cup containing 500 g of water which had an initial temperature of $20°C$. If the final temperature of both the aluminum and the water was $25°C$, what was the starting temperature of the metal? Use the table above to find the specific heat of water and aluminum.

Solution

The key to this problem is connecting it with conservation of energy. The energy that went into heating up the water must have come from heat stored in the metal. Therefore, we know that the change in energy of the water is equal to however much energy the aluminum lost when it was put into the water. When solving this problem, we'll call the energy of the aluminum Q_A and the energy of the water Q_w.

$$
\begin{aligned}
-\Delta Q_A &= \Delta Q_w && \text{start with conservation of energy}\\
-m_A c_A \Delta T_A &= m_w c_w \Delta T_w && \text{substitute in the values for each energy term based on the equation gi}\\
\Delta T_A &= -\frac{m_w c_w \Delta T_w}{m_A c_A} && \text{solve for } \Delta T_a\\
T_f - T_i &= -\frac{m_w c_w \Delta T_w}{m_A c_A} && \text{substitute in the initial and final temperatures for } \Delta T_A\\
T_i &= T_f + \frac{m_w c_w \Delta T_w}{m_A c_A} && \text{solve for } T_i\\
T_i &= 25°C + \frac{500\text{ g} * 1\text{ cal/g°C} * (25°C - 20°C)}{500\text{ g} * .215\text{ cal/g°C}} && \text{plug in all the known values}\\
T_i &= 48.2°C
\end{aligned}
$$

Watch this Explanation



MEDIA

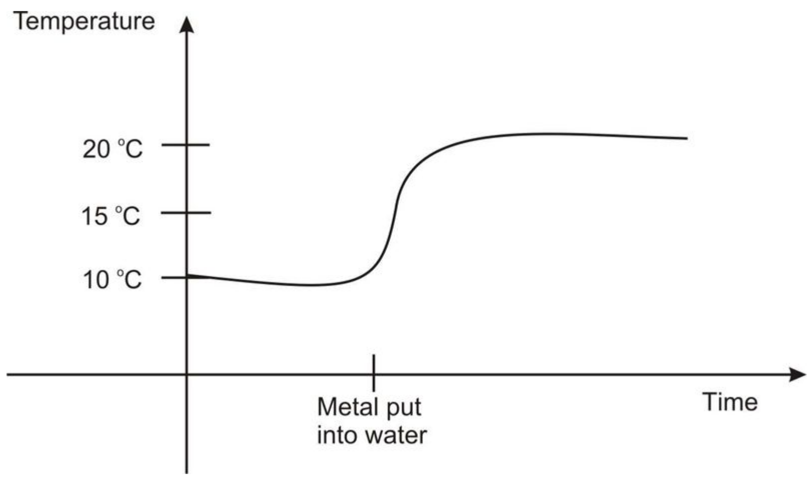
Click image to the left for more content.

Time for Practice

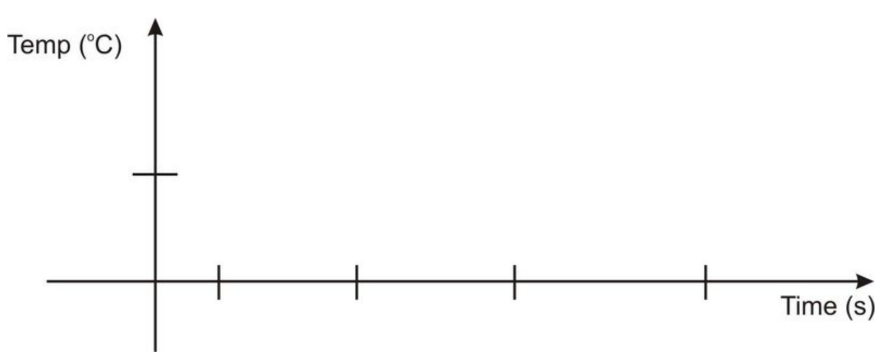
1. Why is it so cold when you get out of the shower wet, but not as cold if you dry off first before getting out of the shower?
2. Antonio is heating water on the stove to boil eggs for a picnic. How much heat is required to raise the temperature of his 10.0-kg vat of water from $20°C$ to $100°C$?
3. Amy wishes to measure the specific heat capacity of a piece of metal. She places the 75-g piece of metal in a pan of boiling water, then drops it into a styrofoam cup holding 50 g of water at $22°C$. The metal and water come to an equilibrium temperature of $25°C$. Calculate:
   a. The heat gained by the water

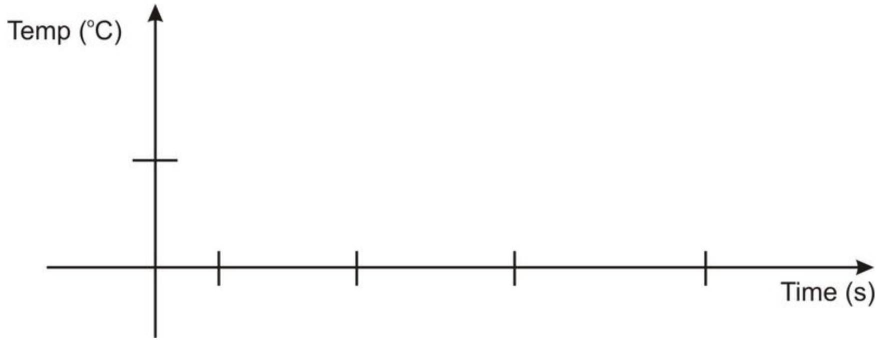
b. The heat lost by the metal
c. The specific heat of the metal

4. John wishes to heat a cup of water to make some ramen for lunch. His insulated cup holds 200 g of water at $20°C$. He has an immersion heater rated at 1000 W (1000 J/s) to heat the water.
   a. How many JOULES of heat are required to heat the water to $100°C$?
   b. How long will it take to do this with a 1000-W heater?
   c. Convert your answer in part b to minutes.
5. You put a 20g cylinder of aluminum $(c = 0.2\ cal/g/°C)$ in the freezer $(T = -10°C)$. You then drop the aluminum cylinder into a cup of water at $20°C$. After some time they come to a common temperature of $12°C$. How much water was in the cup?
6. Emily is testing her baby's bath water and finds that it is too cold, so she adds some hot water from a kettle on the stove. If Emily adds 2.00 kg of water at $80.0°C$ to 20.0 kg of bath water at $27.0°C$, what is the final temperature of the bath water?
7. You are trying to find the specific heat of a metal. You heated a metal in an oven to $250°C$. Then you dropped the hot metal immediately into a cup of cold water. To the right is a graph of the temperature of the water versus time that you took in the lab. The mass of the metal is 10g and the mass of the water is 100g. Recall that water has a specific heat of 1 $cal/g°C$.



8. How much heat is required to melt a 20 g cube of ice if
   a. the ice cube is initially at $0°C$
   b. the ice cube is initially at $-20°C$ (be sure to use the specific heat of ice)
9. A certain alcohol has a specific heat of 0.57 $cal/g°C$ and a melting point of $-114°C$. You have a 150 g cup of liquid alcohol at $22°C$ and then you drop a 10 g frozen piece of alcohol at $-114°C$ into it. After some time the alcohol cube has melted and the cup has come to a common temperature of $7°C$.
   a. What is the latent heat of fusion (i.e. the 'L' in the $Q = mL$ equation) for this alcohol?
   b. Make a sketch of the graph of the alcohol's temperature vs. time
   c. Make a sketch of the graph of the water's temperature vs. time





Answers

1. .
2. 800,000 cal or 3360 kJ
    1. 150 cal (630 J)
    2. same as a!
    3. 0.027 $cal/g°C$ $(0.11\ J/g°C)$

    1. 67,000 J
    2. 67.2 s
    3. 1.1 min
3. 11.0 g
4. 31.8$°C$
5. 0.44 $cal/g°C$
    1. 1600 cal (6720 J)
    2. 1800 cal (7560 J)
6. 59.3 cal/g