SECTION 12.1 QUESTIONS

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Understanding Concepts

1. Specific heat is heat transferred per unit of mass, while specific heat capacity is heat transferred per unit of mass, per degree of temperature change.
2. The expression $q = mc\Delta t$ translates to an explanation of heat relationships. The amount of heat transferred depends directly on the mass of substance, the temperature change, and the specific heat capacity — which is a value for the heat transferred per unit of mass, per degree of temperature change, for a given substance.
3. $q = ?$

   $m = 1.1\ \cancel{\text{L}} \times 1\ \text{kg}/\cancel{\text{L}} = 1.1\ \text{kg}$

   $c = 4.18\ \text{J/(g} \cdot \text{°C)}$

   $\Delta t = |98°\text{C} - 12°\text{C}| = 86°\text{C}$

   $$\begin{aligned} q &= mc\Delta t \\ &= 1.1\ \text{k}\cancel{\text{g}} \times \frac{4.18\ \text{J}}{\cancel{\text{g}} \cdot \cancel{°\text{C}}} \times 86\cancel{°\text{C}} \\ q &= 395\ \text{kJ} \end{aligned}$$

   The quantity of heat transferred to the water is 395 kJ.
4. $q = 295\ \text{kJ}$

   $m = ?$

   $c = 4.18\ \text{J/(g} \cdot \text{°C)}$

   $\Delta t = |78°\text{C} - 5°\text{C}| = 73°\text{C}$

   $$\begin{aligned} q &= mc\Delta t \\ m &= \frac{q}{c\Delta t} \\ &= \frac{295\ \text{k}\cancel{\text{J}}}{\frac{4.18\ \cancel{\text{J}}}{\text{g} \cdot \cancel{°\text{C}}} \times 73\cancel{°\text{C}}} \\ m &= 0.967\ \text{kg} = 967\ \text{g} \end{aligned}$$

   The mass of water that can be warmed is 967 g.
5. (a) The lower specific heat capacity of alcohol means an equal mass would only work about half as well as water. The same temperature increase takes only half as much heat transfer to alcohol as for water — so there would be only half as much stored energy to release later.

   (b) For the same amount of heat to cause the same temperature change, the mass of alcohol would have to be about twice the mass of water.

12.2 CALORIMETRY

PRACTICE

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Understanding Concepts

1. For simple calorimeters we make assumptions that negligible heat transfers from the contents to the environment, that negligible heat transfers from the contents to the calorimeter materials, and that the specific heat capacity and density of the contents are negligibly different from water.

2. Either the mass or temperature measurements could limit the certainty of the result, depending on which value, m or Δt, has fewer significant digits. But the specific heat capacity of water is only given to three significant digits in this text (and, in fact, is only valid to this certainty since it varies slightly with temperature) — so no calculation using this value can possibly be more certain than three significant digits, no matter how certain the measurements are.
3. Specific heat is heat transferred per unit of mass, while specific heat capacity is heat transferred per unit of mass, per degree of temperature change.
4. $m_s = 10\ \text{g}$

   $h_s = ?$ (urea)

   $m_w = 150\ \cancel{\text{mL}} \times 1\ \text{g}/\cancel{\text{mL}} = 150\ \text{g}$ (water)

   $c = 4.18\ \text{J/(g} \cdot \text{°C)}$

   $\Delta t = |16.7\text{°C} - 20.4\text{°C}| = 3.7\text{°C}$

$$\Delta E_s = q$$
$$m_s h_s = m_w c \Delta t$$
$$h_s = \frac{m_w c \Delta t}{m_s}$$
$$= \frac{150\ \cancel{\text{g}} \times \frac{4.18\ \text{J}}{\cancel{\text{g}} \cdot \cancel{\text{°C}}} \times 3.7\cancel{\text{°C}}}{10\ \text{g}}$$
$$h_s = 2.3 \times 10^2\ \text{J/g} = 0.23\ \text{kJ/g}$$

   The specific heat of solution of urea is an endothermic 0.23 kJ/g.
5. $m_s = 275\ \text{g}$ (solute — calcium chloride)

   $h_s = 0.52\ \text{kJ/g}$

   $m_w = 750\ \cancel{\text{mL}} \times 1\ \text{g}/\cancel{\text{mL}} = 750\ \text{g}$ (water)

   $c = 4.18\ \text{J/(g} \cdot \text{°C)}$

   $\Delta t = ?$

$$\Delta E_s = q$$
$$m_s h = m_w c \Delta t$$
$$\Delta t = \frac{m_s h_s}{m_w c}$$
$$= \frac{275\ \cancel{\text{g}} \times \frac{0.52\ \text{k}\cancel{\text{J}}}{\cancel{\text{g}}}}{750\ \cancel{\text{g}} \times \frac{4.18\ \cancel{\text{J}}}{\cancel{\text{g}} \cdot \text{°C}}}$$
$$\Delta t = 0.046\ \text{k°C} = 46\text{°C}$$

   The maximum temperature change is 46°C.
6. $v_{HCl} = 43.1\ \text{mL}$

   $C_{HCl} = 11.6\ \text{mol/L}$

   $M_{HCl} = 36.46\ \text{g/mol}$

   $h_d = ?$ (of dilution — of hydrochloric acid)

   $m_w = 500\ \cancel{\text{mL}} \times 1\ \text{g}/\cancel{\text{mL}} = 500\ \text{g}$ (of solution — assume water)

   $c = 4.18\ \text{J/(g} \cdot \text{°C)}$

   $\Delta t = |21.8\text{°C} - 19.2\text{°C}| = 2.6\text{°C}$

$$n_{HCl} = 43.1\ \text{m}\cancel{\text{L}} \times \frac{11.6\ \text{mol}}{1\ \cancel{\text{L}}}$$

$$n_{HCl} = 500\ \text{mmol} = 0.500\ \text{mol}$$

$$m_{HCl} = 0.500\ \cancel{\text{mol}} \times \frac{36.46\ \text{g}}{1\ \cancel{\text{mol}}}$$

$$m_{HCl} = 18.2\ \text{g}$$

$$\Delta E_d = q$$

$$m_s h_d = m_w c \Delta t$$

$$h_d = \frac{m_w c \Delta t}{m_s}$$

$$= \frac{500\ \cancel{\text{g}} \times \frac{4.18\ \text{J}}{\cancel{\text{g}} \cdot \cancel{°\text{C}}} \times 2.6\cancel{°\text{C}}}{18.2\ \text{g}}$$

$$h_d = 3.0 \times 10^2\ \text{J/g} = 0.30\ \text{kJ/g}$$

The specific heat of dilution of the concentrated hydrochloric acid is an exothermic 0.30 kJ/g.

7. $m_s = ?$ (solute — ammonium nitrate)

$h_s = 0.31$ kJ/g

$m_w = 250\ \cancel{\text{mL}} \times 1\ \text{g}/\cancel{\text{mL}} = 250$ g (solution — assume water)

$c = 4.18$ J/(g · ºC)

$\Delta t = 5.0$ºC

$$\Delta E_s = q$$

$$m_s h_s = m_w c \Delta t$$

$$m_s = \frac{m_w c \Delta t}{h_s}$$

$$= \frac{250\ \cancel{\text{g}} \times \frac{4.18\ \cancel{\text{J}}}{\cancel{\text{g}} \cdot \cancel{°\text{C}}} \times 5.0\cancel{°\text{C}}}{\frac{0.31\ \text{k}\cancel{\text{J}}}{\text{g}}}$$

$$m_s = 1.7 \times 10^4\ \text{g/k} = 1.7 \times 10^4\ \text{g}/1000 = 17\ \text{g} \qquad (\text{k} = 1000)$$

The mass of ammonium nitrate required is 17 g.

Applying Inquiry Skills

8. (a) $\Delta E = q = ?$ (water)

$m = 100.00$ g

$c = 4.18$ J/(g · ºC)

$\Delta t = 5.0$ºC

$$q = mc\Delta t$$

$$= 100.00\ \cancel{\text{g}} \times \frac{4.18\ \text{J}}{\cancel{\text{g}} \cdot \cancel{°\text{C}}} \times 5.0\cancel{°\text{C}}$$

$$q = 2.1 \times 10^3\ \text{J} = 2.1\ \text{kJ}$$

The energy change of (heat transfer to) the water is 2.1 kJ.

(b) $\Delta E = q = ?$ (cups)

$m = 3.58$ g

$c = 0.30$ J/(g · ºC)

$\Delta t = 5.0$ºC

$$q = mc\Delta t$$
$$= 3.58\ \cancel{g} \times \frac{0.30\ J}{\cancel{g} \cdot \cancel{°C}} \times 5.0\cancel{°C}$$
$$q = 5.4\ J$$

The energy change of (heat transfer to) the cups is 5.4 J.

$\Delta E = q = ?$ (stirring rod)

$m = 9.45$ g

$c = 0.84$ J/(g · ºC)

$\Delta t = 5.0$ ºC

$$q = mc\Delta t$$
$$= 9.45\ \cancel{g} \times \frac{0.84\ J}{\cancel{g} \cdot \cancel{°C}} \times 5.0\cancel{°C}$$
$$q = 40\ J$$

The energy change of (heat transfer to) the stirring rod is 40 J.

$\Delta E = q = ?$ (thermometer)

$m = 7.67$ g

$c = 0.87$ J/(g · ºC)

$\Delta t = 5.0$ºC

$$q = mc\Delta t$$
$$= 7.67\ \cancel{g} \times \frac{0.87\ J}{\cancel{g} \cdot \cancel{°C}} \times 5.0\cancel{°C}$$
$$q = 33\ J$$

The energy change of (heat transfer to) the thermometer is 33 J.

The total energy increase is (2.1 + 0.0054 + 0.040 + 0.033) kJ = 2.2 kJ

(c) difference = $|(5.4 + 40 + 33)\ J| = 82\ J = 0.082\ kJ$

$$\%\ \text{difference} = \frac{0.082\ \cancel{kJ}}{2.2\ \cancel{kJ}} \times 100\%$$

% difference = 3.7%

(d) Our assumption of negligible heat transfer to the calorimeter materials is evaluated based on the calculation that this transfer makes a percent difference of about 4%. This is well within the normal range of variation for high school lab work, and is also within the range of uncertainty for this calculation, since the answer is only certain to two significant digits. For this example, the transfer of heat to the calorimeter materials can be considered negligible.

Making Connections

9. Students will learn that self-heating packages involve a variety of chemical reactions, many involving oxidation with air when a seal is broken. Some similar, less powerful devices are sold to skiers/hikers as hand warmers.

   Typically, students will argue that the increased cost of these packaged meals is offset by their simplicity and portability. Soldiers in the field benefit by not having to carry/move a cooking unit, and more importantly, can dispense with the trouble and hazard of transporting fuel.

Reflecting

10. Water heaters are not designed to measure the heat absorbed by the water. They measure the quantity of fuel (or electrical energy) consumed. As well, they differ from calorimeters in that there is no attempt to ensure an even temperature by stirring, and in the fact that they are not sealed systems.

PRACTICE

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Understanding Concepts

11. $\Delta E_h = ?$ (zeolite)

$C = 157 \text{ kJ/°C}$

$\Delta t = |73\text{°C} - 27\text{°C}| = 46\text{°C}$

$$\Delta E_h = C\Delta t$$
$$= \frac{157 \text{ kJ}}{\text{°}\cancel{\text{C}}} \times 46\text{°}\cancel{\text{C}}$$
$$\Delta E_h = 7.2 \times 10^3 \text{ kJ} = 7.2 \text{ MJ}$$

The energy decrease of the zeolite is 7.2 MJ.

12. $m = 1.12 \text{ g}$

$h_c = ?$ (acetylene, $C_2H_{2(g)}$)

$C = 6.49 \text{ kJ/°C}$

$\Delta t = |27.15\text{°C} - 18.60\text{°C}| = 8.55\text{°C}$

$$\Delta E_c = q$$
$$mh_c = C\Delta t$$
$$h_c = \frac{C\Delta t}{m}$$
$$= \frac{\frac{6.49 \text{ kJ}}{\text{°}\cancel{\text{C}}} \times 8.55\text{°}\cancel{\text{C}}}{1.12 \text{ g}}$$
$$h_c = 49.5 \text{ kJ/g}$$

The exothermic specific heat of combustion of acetylene is 49.5 kJ/g.

Applying Inquiry Skills

13. **Analysis**

(a) Trial 1

$m = 1.024 \text{ g}$ (benzoic acid, $HC_7H_5O_{2(s)}$)

$h_c = 26.46 \text{ kJ/g}$

$C = ?$

$\Delta t = |27.99\text{°C} - 24.96\text{°C}| = 3.03\text{°C}$

$$\Delta E_c = q$$
$$mh_c = C\Delta t$$
$$C = \frac{mh_c}{\Delta t}$$
$$= \frac{1.024 \text{ } \cancel{\text{g}} \times \frac{26.46 \text{ kJ}}{\cancel{\text{g}}}}{3.03\text{°C}}$$
$$C = 8.94 \text{ kJ/°C}$$

Trial 2

$m = 1.043$ g (benzoic acid, $HC_7H_5O_{2(s)}$)

$h_c = 26.46$ kJ/g

$C = ?$

$\Delta t = |28.10°C - 25.02°C| = 3.08°C$

$$\Delta E_c = q$$
$$mh_c = C\Delta t$$
$$C = \frac{mh_c}{\Delta t}$$
$$= \frac{1.043\ \cancel{g} \times \frac{26.46\ kJ}{\cancel{g}}}{3.08°C}$$
$$C = 8.96\ kJ/°C$$

Trial 3

$m = 1.035$ g (benzoic acid, $HC_7H_5O_{2(s)}$)

$h_c = 26.46$ kJ/g

$C = ?$

$\Delta t = |28.06°C - 25.00°C| = 3.06°C$

$$\Delta E_c = q$$
$$mh_c = C\Delta t$$
$$C = \frac{mh_c}{\Delta t}$$
$$= \frac{1.035\ \cancel{g} \times \frac{26.46\ kJ}{\cancel{g}}}{3.06°C}$$
$$C = 8.95\ kJ/°C$$

(b) Average value calculation: (8.94 + 8.96 + 8.95)/3 kJ/°C = 8.95 kJ/°C.

The average value for the heat capacity of the calorimeter is 8.95 kJ/°C.

Making Connections

14. (a) $v = 6.0$ L

density = 1.06 g/mL = 1.06 kg/L

$c = 3.8$ J/(g · °C)

$C = ?$ (coolant mix)

$$m = 6.0\ \cancel{L} \times \frac{1.06\ kg}{1\ \cancel{L}}$$
$$m = 6.4\ kg$$
$$C = mc$$
$$= 6.4\ \cancel{kg} \times \frac{3.8\ J}{\cancel{g} \cdot °C}$$

$$C = 24 \text{ kJ/°C}$$

The heat capacity for the coolant is 24 kJ/°C.

(b) $C = 24 \text{ kJ/°C}$

$\Delta E = ?$ (coolant mix)

$\Delta t = |185°\text{C} - 150°\text{C}| = 35°\text{C}$

$$\Delta E = C\Delta t$$
$$= \frac{24 \text{ kJ}}{°\cancel{\text{C}}} \times 35°\cancel{\text{C}}$$
$$\Delta E = 8.5 \times 10^2 \text{ kJ} = 0.85 \text{ MJ}$$

The energy removed from the coolant is 0.85 MJ.

15. Some factors in fuel evaluation are speed of reaction, cost, ease of handling, toxicity, and explosion hazard.

SECTION 12.2 QUESTIONS

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Understanding Concepts

1. (a) c J/(g · °C) — used in calorimetry to calculate energy change when mass and temperature change are known.
   (b) C J/°C — used in calorimetry to calculate energy change when temperature change is known.
   (c) h J/g — used to calculate energy change when mass of substance is known.
2. (a) $q = ?$

   $m = 125 \cancel{\text{mL}} \times 1 \text{ g/}\cancel{\text{mL}} = 125 \text{ g}$

   $c = 4.18 \text{ J/(g} \cdot °\text{C)}$

   $\Delta t = |30.8°\text{C} - 19.6°\text{C}| = 11.2°\text{C}$

   $$q = mc\Delta t$$
   $$= 125 \cancel{\text{g}} \times \frac{4.18 \text{ J}}{\cancel{\text{g}} \cdot °\cancel{\text{C}}} \times 11.2°\cancel{\text{C}}$$
   $$q = 5.85 \times 10^3 \text{ J} = 5.85 \text{ kJ}$$

   The quantity of heat entering the water is 5.85 kJ.

   (b) The change in the chemical sysytem was exothermic. Since energy transfers to the surrounding water (because it warms), the energy must have transferred from the chemical system.

Applying Inquiry Skills

3. **Analysis**

   (a) $m = 1.14 \text{ g}$

   $C = 8.57 \text{ kJ/°C}$

   $h_c = ?$ (combustion of stearic acid, $HC_{18}H_{35}O_{2(s)}$)

   $\Delta t = |30.28°\text{C} - 25.00°\text{C}| = 5.28°\text{C}$

   $$\Delta E_c = q$$
   $$mh_c = C\Delta t$$
   $$h_c = \frac{C\Delta t}{m}$$

$$= \frac{\frac{8.57\text{ kJ}}{\cancel{°C}} \times 5.28\cancel{°C}}{1.14\text{ g}}$$

$h_c = 39.7\text{ kJ/g}$

The exothermic specific heat of combustion of stearic acid is 39.7 kJ/g.

(b) The energy release from burning a gram of fat is more than double that of a gram of sucrose. The specific heat of fat is 39.7/16.5 = 2.4 times as great as the specific heat of sucrose.

Making Connections

4. Student answers will vary widely, but will indicate clearly that fats and oils are very high in energy, while carbohydrates and proteins are lower.
5. (a) The energy characteristic of gasoline that we use is its exothermic heat of combustion — converting the gasoline to heat and mechanical energy to move the vehicle.
   (b) Things like the speed with which the gasoline burns, the degree of pollution it produces, and the toxicity might also be important characteristics.

12.3 HEATS OF REACTION

PRACTICE

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Understanding Concepts

1. Calorimetry is used to determine heats of reaction.
2. The term *specific* for a scientific quantity means "per unit of mass."
3. Specific heat of reaction has units such as kJ/g. Molar heat of reaction has units such as kJ/mol.
4. Molar mass will convert specific heat of reaction to molar heat of reaction.
5. Combustion reactions are exothermic, such as the burning of gasoline, propane, natural gas, and candle wax.
6. (a) $h_c = 49.90\text{ kJ/g}$
   $M = 26.04\text{ g/mol}$
   $\Delta H_c = ?$ (combustion of acetylene, $C_2H_{2(g)}$)

$$\Delta H_c = \frac{49.90\text{ kJ}}{1\ \cancel{g}} \times \frac{26.04\ \cancel{g}}{1\text{ mol}}$$

$$\Delta H_c = 1299\text{ kJ/mol}$$

The exothermic molar heat of combustion of acetylene is 1299 kJ/mol.

(b) $C_2H_{2(g)} + 3/2\ O_{2(g)} \rightarrow CO_{2(g)} + H_2O_{(g)} + 1299\text{ kJ}$

or $2\ C_2H_{2(g)} + 3\ O_{2(g)} \rightarrow 2\ CO_{2(g)} + 2\ H_2O_{(g)} + 2598\text{ kJ}$

7. (a) $h_r = 10.9\text{ kJ/g}$

   $M = 12.01\text{ g/mol}$

   $\Delta H_r = ?$ (reaction of carbon, $C_{(s)}$)

$$\Delta H_r = \frac{10.9\text{ kJ}}{1\ \cancel{g}} \times \frac{12.01\ \cancel{g}}{1\text{ mol}}$$

$$\Delta H_r = 131\text{ kJ/mol}$$

The exothermic molar heat of reaction of carbon is 131 kJ/mol.

(b) $C_{(s)} + H_2O_{(g)} \rightarrow CO_{(g)} + H_{2(g)} + 131\text{ kJ}$