



### Energy Changes

- **Endothermic** reactions absorb energy.
  - Reactants contain less chemical energy than products do.
  - Reactants + energy  $\rightarrow$  products
- **Exothermic** reactions release energy.
  - Reactants contain more chemical energy than products do.
  - Reactants  $\rightarrow$  products + energy



### Lesson Objectives

By the end of this lesson, you should be able to:

- Differentiate between **heat** capacity and specific heat.
- Solve problems involving heat flow and temperature changes to calculate the **specific** heat of a substance.
- Define calorimetry and explain how calorimeters work.
- Use calorimetry to calculate the heat of a chemical process.

**Science Practice:** Perform mathematical calculations involving heat, mass, temperature change, and specific heat.

**Words to Know**

Fill in this table as you work through the lesson. You may also use the glossary to help you.

calorimetry	the use of a calorimeter to measure energy given off or absorbed during a physical or chemical process
heat capacity	the quantity of heat needed to raise the temperature of a given sample of a substance by one degree Celsius (kelvin)
specific heat capacity	the quantity of heat required to raise the temperature of one gram of a substance by one degree Celsius (kelvin) at constant pressure
calorie	a unit of energy equal to 4.18 J
calorimeter	a device used to measure the heat absorbed or evolved during a physical or chemical change

## Instruction

## Calorimetry

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## Lesson Question

How do scientists measure the amount of heat absorbed or released in a chemical or physical process?

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## Heat Capacity

- **Heat capacity:** the quantity of heat needed to raise the **temperature** of a given sample of a substance by one degree **Celsius** (Kelvin)
  - Units:  $J/^{\circ}C$ ,  $J/K$ ,  $cal/^{\circ}C$ ,  $cal/K$
  - **Extensive** property

## Specific Heat Capacity

- **Specific heat capacity ( $C_p$ ):** the quantity of heat required to raise the temperature of **one** gram of a substance by one degree Celsius (**Kelvin**) at constant pressure
  - Units:  $J/g \cdot ^{\circ}C$ ,  $J/g \cdot K$ ,  $cal/g \cdot ^{\circ}C$ ,  $cal/g \cdot K$
  - **Intensive** property



Brass:  $C_p = 0.380 J/g \cdot ^{\circ}C$



Lead:  $C_p = 0.128 J/g \cdot ^{\circ}C$



Tin:  $C_p = 0.226 J/g \cdot ^{\circ}C$



Aluminum:  $C_p = 0.900 J/g \cdot ^{\circ}C$

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### Specific Heat Capacities for Common Substances

Specific **heat**:

- is dependent on temperature, especially for **gases**.
- is related to **intermolecular** forces.

The higher the specific heat of a substance, the more **energy** is needed to raise the temperature of the substance.

Substance	$C_p$ (J/g·°C)	Substance	$C_p$ (J/g·°C)
H <sub>2</sub> O(l)	4.18	NaCl(s)	0.864
H <sub>2</sub> O(s)	2.03	CO <sub>2</sub> (g)	0.839
H <sub>2</sub> O(g)	2.08	NH <sub>3</sub> (l)	4.70
Fe(s)	0.450	H <sub>2</sub> SO <sub>4</sub> (l)	1.34
Al(s)	0.897	wood*	0.5
Cu(s)	0.385	plastic*	0.4
Sn(s)	0.227	gasoline	2.22
Pb(s)	0.129	olive oil	1.97
Au(s)	0.129	air*	1.01
Hg(l)	0.140	sea water*	3.93

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### Relating Heat and Specific Heat

$$q = mC_p \Delta T$$

- $q$  = heat gained or **lost**
- **$m$**  = mass
- $C_p$  = specific heat
- $\Delta T$  = change in temperature

## Instruction

## Calorimetry

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**Calculating Heat Absorbed**

An iron ball bearing with a mass of 125 g has an initial temperature of 25.0°C.

The ball bearing is heated to a **temperature** of 45.0°C. How much heat

does the iron absorb? The **C<sub>p</sub>** for iron is 0.450 J/g • °C.

- Calculate the temperature **change**.

$$\Delta T = T_f - T_i = 45.0^\circ\text{C} - 25.0^\circ\text{C} = \mathbf{20.0}^\circ\text{C}$$

- Substitute the given values and solve.

$$q = mC_p\Delta T = (125 \text{ g})(0.450 \text{ J/g} \cdot ^\circ\text{C})(20^\circ\text{C}) = 1125 \text{ J}$$

After rounding the answer up to account for the significant figures: **1130** J

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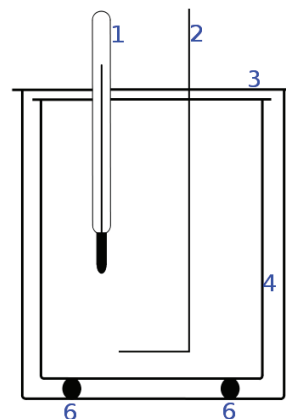
**Calorimetry**

- **Calorimetry**: the use of a calorimeter to measure energy given off or absorbed during a physical or

**chemical** process

- **Calorimeter**: a device used to measure the heat absorbed or evolved during a **physical** or chemical change

- **Calorie**: a **unit** of energy equal to 4.18 J

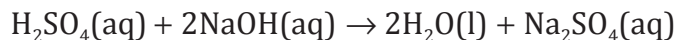


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**Calorimetric Calculations**

Sulfuric acid and sodium hydroxide react to form sodium **sulfate**:



If 25.0 mL of 1.00 M  $\text{H}_2\text{SO}_4$  is added to 50.0 mL of 1.00 M NaOH at 25.0°C in a coffee-cup calorimeter, the temperature of the aqueous solution increases to

33.9°C. How much **heat** is given off in this reaction? You can assume that the specific heat of the calorimeter and solution is 4.18 J/g•°C and that the density of the solution is 1.00 g/mL. You may ignore the mass of the calorimeter in the calculation.

- Calculate the mass of the solution.

$$25.0 \text{ mL} + 50.0 \text{ mL} = 75.0 \text{ mL}$$

$$(75.0 \text{ mL})(1.00 \text{ g/mL}) = \mathbf{75.0} \text{ grams}$$

- Calculate the temperature change of the solution.

$$\Delta T = T_f - T_i = 33.9^\circ\text{C} - 25.0^\circ\text{C} = \mathbf{8.9} \text{ }^\circ\text{C}$$

- Calculate the energy released by the reaction.

$$q = mC_p\Delta T = (75.0 \text{ g})(4.18 \text{ J/g}\cdot^\circ\text{C})(8.9^\circ\text{C}) = \mathbf{2800} \text{ J}$$

**Calorimetric Calculations**

How do you compute the specific heat of a metal inside a **calorimeter** given the masses of the water and metal and the changes in temperature?

First law of **thermodynamics**:

$$-q_{\text{metal}} = q_{\text{water}}$$

# Instruction | Calorimetry

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## Calorimetric Calculations

Formula for heat gained/lost:

$$q = cm\Delta T, \text{ or from the original equation: } q = mC_p\Delta T$$

Combining:

$$-c_m m_m \Delta T_m = c_w m_w \Delta T_w$$

Solving algebraically for  $c_{\text{metal}}$ :

$$c_{\text{metal}} = \frac{-c_{\text{water}} m_{\text{water}} \Delta T_{\text{water}}}{m_{\text{metal}} \Delta T_{\text{metal}}}$$

## Calorimetric Calculations

A 25.00 g sample of an unknown **metal** is heated to 22.00°C. It is then placed in a coffee-cup calorimeter filled with water. The calorimeter and the water have a combined mass of 120.0 g and an overall specific heat of 3.035 cal/g • °C. The initial temperature of the calorimeter is 5.00°C. The system reaches a final temperature of 6.08°C when the metal is added. What is the **specific** heat of the unknown metal?

- Calculate the temperature change for the calorimeter and metal.

$$\Delta T_{\text{cal}} = T_f - T_i = 6.08^\circ\text{C} - 5.00^\circ\text{C} = \boxed{1.08}^\circ\text{C}$$

$$\Delta T_{\text{metal}} = T_f - T_i = 6.08^\circ\text{C} - 22.00^\circ\text{C} = \boxed{-15.92}^\circ\text{C}$$

$$C_{p,\text{metal}} = \frac{-m_{\text{cal}} C_{p,\text{cal}} \Delta T_{\text{cal}}}{m_{\text{metal}} \Delta T_{\text{metal}}}$$

- Substitute values for the variables in the following formula.

$$C_p = \frac{-(120.0 \text{ g})(3.035 \text{ cal/g} \cdot ^\circ\text{C})(1.08^\circ\text{C})}{(25.00 \text{ g})(-15.92^\circ\text{C})}$$

- Calculate the specific heat of the unknown metal.

$$C_m = \boxed{0.998} \text{ cal/g} \cdot ^\circ\text{C}$$

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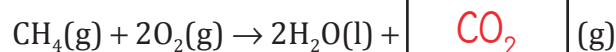
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**Bomb Calorimetry**

- A bomb calorimeter allows for the determination of the heat of **reaction**.
- Heat of reaction is the energy gained or lost during a chemical reaction.
- Heat of combustion is the energy gained or lost during a **combustion** reaction.

**Calculating Heat of Reaction**

**Methane** is a common fuel that burns according to the following equation:



A sample of methane with a mass of 0.3202 g is burned in a **bomb** calorimeter. The mass of the calorimeter is 2.000 kg, and its specific heat is 2.45 J/g•K. If the temperature of the calorimeter increases by 3.629 K during the reaction, what is the heat of combustion for the reaction?

- Convert **units**.

$$2.000 \text{ kg} \left( \frac{1000 \text{ g}}{1 \text{ kg}} \right) = 2,000 \text{ g}$$

- Calculate the energy released by the reaction.

$$(2000 \text{ g})(2.45 \text{ J/g} \cdot \text{K})(3.629 \text{ K}) = \text{17,782} \text{ J}$$

After rounding the answer up to account for the significant figures: 17.8 kJ

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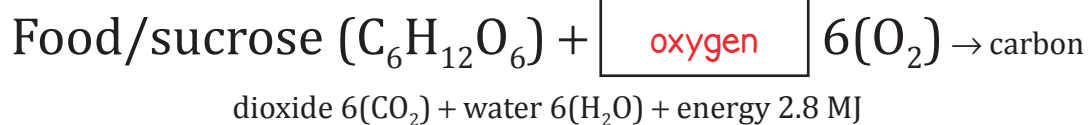
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**The Calorie Content of Foods**

- **Nutrition** information labels give **calorie** counts.
- Food calorie = **kilocalorie** (Calorie)

**The Calorie Content of Foods**

- Calorimetry is used to determine the energy content of **foods**.



## Summary

## Calorimetry

**Lesson Question**

How do scientists measure the amount of heat absorbed or released in a chemical or physical process?

**Answer**

(Sample answer) The heat that is released in a reaction is measured through a device known as a calorimeter. It works on the basis of heat capacities and specific heat capacities of substances. The process of measuring the heat by calorimeter is termed as calorimetry.

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**Heat Capacity and Specific Heat Capacity**

- The heat capacity of a substance is the amount of heat needed to raise its temperature by one degree Celsius (or one **Kelvin** ).
- The specific heat of a substance is the amount of heat needed to raise the temperature of one gram of the substance by one degree Celsius (or one Kelvin).
- The higher a substance's specific heat, the more **energy** the substance must absorb before its temperature changes.
- The equation  $q = mC_p\Delta T$  can be used to calculate the heat ( $q$ ), mass ( $m$ ), specific heat ( $C_p$ ), or temperature change ( $\Delta T$ ) of a substance that absorbs or releases heat.

# Summary | Calorimetry

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## Calorimetry

- Calorimetry is the process in which the amount of heat involved in a process is determined by measuring the **temperature** change of a known quantity of a substance with a known specific heat.
- A coffee-cup calorimeter uses water as the reference substance.
- Bomb calorimeters can be used to determine heats of reaction for reactions that cannot occur in **water**.
- The calorie contents of food are determined with calorimetry.

*Use this space to write any questions or thoughts about this lesson.*