

## 7.E: Energy and Chemical Processes (Exercises)

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### 7.1: Energy and Its Units

#### Concept Review Exercises

1. What is the relationship between energy and heat?
2. What units are used to express energy and heat?

#### Answers

1. Heat is the exchange of energy from one part of the universe to another. Heat and energy have the same units.
2. Joules and calories are the units of energy and heat.

#### Exercises

1. Define *energy*.
2. What is heat?
3. What is the relationship between a calorie and a joule? Which unit is larger?
4. What is the relationship between a calorie and a kilocalorie? Which unit is larger?
5. Express 1,265 cal in kilocalories and in joules.
6. Express 9,043.3 J in calories and in kilocalories.
7. One kilocalorie equals how many kilojoules?
8. One kilojoule equals how many kilocalories?
9. Many nutrition experts say that an average person needs 2,000 Cal per day from his or her diet. How many joules is this?
10. Baby formula typically has 20.0 Cal per ounce. How many ounces of formula should a baby drink per day if the RDI is 850 Cal?

#### Answers

1. Energy is the ability to do work.
2. Heat is a form of energy (thermal) that can be transferred from one object to another.
3. 1 cal = 4.184 J; the calorie is larger.
4. 1 kilocalorie(1 Cal) = 1000 cal; the kcal is larger.
5. 1.265 kcal; 5,293 J
6. 2161.4 cal; 2.1614 kcal
7. 1 kcal = 4.184 kJ
8. 1 kJ = 0.239 kcal
9.  $8.4 \times 10^6$  J
10. 42.5 oz

### 7.2: Heat and Temperature

#### Concept Review Exercise

1. Describe the relationship between heat transfer and the temperature change of an object.
2. Describe what happens when two objects that have different temperatures come into contact with one another.

## Answer

1. Heat is equal to the product of the mass, the change in temperature, and a proportionality constant called the specific heat.
2. The temperature of the hot object decreases and the temperature of the cold object increases as heat is transferred from the hot object to the cold object. The change in temperature of each depends on the identity and properties of each substance.

## Exercises

1. The melting point of mercury is  $-38.84^{\circ}\text{C}$ . Convert this value to degrees Fahrenheit and Kelvin.
2. A pot of water is set on a hot burner of a stove. What is the direction of heat flow?
3. Some uncooked macaroni is added to a pot of boiling water. What is the direction of heat flow?
4. How much energy in calories is required to heat 150 g of  $\text{H}_2\text{O}$  from  $0^{\circ}\text{C}$  to  $100^{\circ}\text{C}$ ?
5. How much energy in calories is required to heat 125 g of Fe from  $25^{\circ}\text{C}$  to  $150^{\circ}\text{C}$ ?
6. If 250 cal of heat were added to 43.8 g of Al at  $22.5^{\circ}\text{C}$ , what is the final temperature of the aluminum?
7. If 195 cal of heat were added to 33.2 g of Hg at  $56.2^{\circ}\text{C}$ , what is the final temperature of the mercury?
8. A sample of copper absorbs 145 cal of energy, and its temperature rises from  $37.8^{\circ}\text{C}$  to  $41.7^{\circ}\text{C}$ . What is the mass of the copper?
9. A large, single crystal of sodium chloride absorbs 98.0 cal of heat. If its temperature rises from  $22.0^{\circ}\text{C}$  to  $29.7^{\circ}\text{C}$ , what is the mass of the NaCl crystal?
10. If 1.00 g of each substance in Table 7.2.1 were to absorb 100 cal of heat, which substance would experience the largest temperature change?
11. If 1.00 g of each substance in Table 7.2.1 were to absorb 100 cal of heat, which substance would experience the smallest temperature change?
12. Determine the heat capacity of a substance if 23.6 g of the substance gives off 199 cal of heat when its temperature changes from  $37.9^{\circ}\text{C}$  to  $20.9^{\circ}\text{C}$ .
13. What is the heat capacity of gold if a 250 g sample needs 133 cal of energy to increase its temperature from  $23.0^{\circ}\text{C}$  to  $40.1^{\circ}\text{C}$ ?

## Answers

1.  $-37.91^{\circ}\text{F}$  and 234.31 K
2. Heat flows into the pot of water.
3. Heat flows to the macaroni.
4. 15,000 cal
5. 1,690 cal
6.  $49.0^{\circ}\text{C}$
7.  $234^{\circ}\text{C}$
8. 404 g
9. 61 g
10. Mercury would experience the largest temperature change.
11. hydrogen ( $\text{H}_2$ )
12.  $0.496 \text{ cal/g}\cdot^{\circ}\text{C}$
13.  $0.031 \text{ cal/g}\cdot^{\circ}\text{C}$

## 7.3: Phase Changes

## Concept Review Exercises

1. Explain what happens when heat flows into or out of a substance at its melting point or boiling point.
2. How does the amount of heat required for a phase change relate to the mass of the substance?
3. What is the direction of heat transfer in boiling water?
4. What is the direction of heat transfer in freezing water?
5. What is the direction of heat transfer in sweating?

## Answers

1. The energy goes into changing the phase, not the temperature.
2. The amount of heat is a constant per gram of substance.
3. Boiling. Heat is being added to the water to get it from the liquid state to the gas state.
4. Freezing. Heat is exiting the system in order to go from liquid to solid. Another way to look at it is to consider the opposite process of melting. Energy is consumed (endothermic) to melt ice (solid to liquid) so the opposite process (liquid to solid) must be exothermic.
5. Sweating. Heat is consumed to evaporate the moisture on your skin which lowers your temperature.

## Exercises

1. How much energy is needed to melt 43.8 g of Au at its melting point of 1,064°C?
2. How much energy is given off when 563.8 g of NaCl solidifies at its freezing point of 801°C?
3. What mass of ice can be melted by 558 cal of energy?
4. How much ethanol ( $\text{C}_2\text{H}_5\text{OH}$ ) in grams can freeze at its freezing point if 1,225 cal of heat are removed?
5. What is the heat of vaporization of a substance if 10,776 cal are required to vaporize 5.05 g? Express your final answer in joules per gram.
6. If 1,650 cal of heat are required to vaporize a sample that has a heat of vaporization of 137 cal/g, what is the mass of the sample?
7. What is the heat of fusion of water in calories per mole?
8. What is the heat of vaporization of benzene ( $\text{C}_6\text{H}_6$ ) in calories per mole?
9. What is the heat of vaporization of gold in calories per mole?
10. What is the heat of fusion of iron in calories per mole?

## Answers

1. 670 cal
2. 69,630 cal
3. 6.98 g
4. 27.10 g
5. 8,930 J/g
6. 12.0 g
7. 1,440 cal/mol
8. 7,350 cal/mol
9. 80,600 cal/mol
10. 3,530 cal/mol

## 7.4: Bond Energies and Chemical Reactions

### Concept Review Exercises

1. What is the connection between energy and chemical bonds?
2. Why does energy change during the course of a chemical reaction?
3. Two different reactions are performed in two identical test tubes. In reaction A, the test tube becomes very warm as the reaction occurs. In reaction B, the test tube becomes cold. Which reaction is endothermic and which is exothermic? Explain.
4. Classify "burning paper" as endothermic or exothermic processes.

### Answers

1. Chemical bonds have a certain energy that is dependent on the elements in the bond and the number of bonds between the atoms.
2. Energy changes because bonds rearrange to make new bonds with different energies.
3. Reaction A is exothermic because heat is leaving the system making the test tube feel hot. Reaction B is endothermic because heat is being absorbed by the system making the test tube feel cold.
4. "Burning paper" is exothermic because burning (also known as combustion) releases heat

### Exercises

1. Using the data in Table 7.4.1, calculate the energy of one C–H bond (as opposed to 1 mol of C–H bonds). Recall that  $1 \text{ mol} = 6.022 \times 10^{23} \text{ C–H bonds}$
2. Using the data in Table 7.4.1, calculate the energy of one C=C bond (as opposed to 1 mol of C=C bonds). Recall that  $1 \text{ mol} = 6.022 \times 10^{23} \text{ C=C bonds}$
3. Is a bond-breaking process exothermic or endothermic?
4. Is a bond-making process exothermic or endothermic?
5. Is each chemical reaction exothermic or endothermic?
  - a.  $2\text{SnCl}_2(\text{s}) + 33 \text{ kcal} \rightarrow \text{Sn}(\text{s}) + \text{SnCl}_4(\text{s})$
  - b.  $\text{CH}_4(\text{g}) + 2\text{O}_2(\text{g}) \rightarrow \text{CO}_2(\text{g}) + 2\text{H}_2\text{O}(\ell) + 213 \text{ kcal}$
6. Is each chemical reaction exothermic or endothermic?
  - a.  $\text{C}_2\text{H}_4(\text{g}) + \text{H}_2(\text{g}) \rightarrow \text{C}_2\text{H}_6(\text{g}) + 137 \text{ kJ}$
  - b.  $\text{C}(\text{s, graphite}) + 1.9 \text{ kJ} \rightarrow \text{C}(\text{s, diamond})$

### Answers

1.  $1.661 \times 10^{-19} \text{ cal}$
2.  $2.408 \times 10^{-19} \text{ cal}$
3. endothermic
4. exothermic
5.
  - a. endothermic
  - b. exothermic
6.
  - a. exothermic
  - b. endothermic

## 7.5: The Energy of Biochemical Reactions

### Concept Review Exercise

1. What is the energy content per gram of proteins, carbohydrates, and fats?

### Answer

1. proteins and carbohydrates: 4 kcal/g; fats: 9 kcal/g

### Exercises

1. An 8 oz serving of whole milk has 8.0 g of fat, 8.0 g of protein, and 13 g of carbohydrates. Approximately how many kilocalories does it contain?
2. A serving of potato chips has 160 kcal. If the chips have 15 g of carbohydrates and 2.0 g of protein, about how many grams of fat are in a serving of potato chips?
3. The average body temperature of a person is 37°C, while the average surrounding temperature is 22°C. Is overall human metabolism exothermic or endothermic?
4. Cold-blooded animals absorb heat from the environment for part of the energy they need to survive. Is this an exothermic or an endothermic process?
5. If the reaction  $\text{ATP} \rightarrow \text{ADP}$  gives off 7.5 kcal/mol, then the reverse process,  $\text{ADP} \rightarrow \text{ATP}$  requires 7.5 kcal/mol to proceed. How many moles of ADP can be converted to ATP using the energy from 1 serving of potato chips (see Exercise 2)?
6. If the oxidation of glucose yields 670 kcal of energy per mole of glucose oxidized, how many servings of potato chips (see Exercise 2) are needed to provide the same amount of energy?

### Answers

1. 156 kcal
2. 10.2 g
3. exothermic
4. endothermic
5. 21.3 mol
6. 4.2 servings

### Additional Exercises

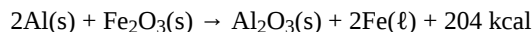
1. Sulfur dioxide ( $\text{SO}_2$ ) is a pollutant gas that is one cause of acid rain. It is oxidized in the atmosphere to sulfur trioxide ( $\text{SO}_3$ ), which then combines with water to make sulfuric acid ( $\text{H}_2\text{SO}_4$ ).
  - a. Write the balanced reaction for the oxidation of  $\text{SO}_2$  to make  $\text{SO}_3$ . (The other reactant is diatomic oxygen.)
  - b. When 1 mol of  $\text{SO}_2$  reacts to make  $\text{SO}_3$ , 23.6 kcal of energy are given off. If 100 lb (1 lb = 454 g) of  $\text{SO}_2$  were converted to  $\text{SO}_3$ , what would be the total energy change?
2. Ammonia ( $\text{NH}_3$ ) is made by the direct combination of  $\text{H}_2$  and  $\text{N}_2$  gases according to this reaction:
$$\text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \rightarrow 2\text{NH}_3(\text{g}) + 22.0 \text{ kcal}$$
  - a. Is this reaction endothermic or exothermic?
  - b. What is the overall energy change if 1,500 g of  $\text{N}_2$  are reacted to make ammonia?
3. A 5.69 g sample of iron metal was heated in boiling water to 99.8°C. Then it was dropped into a beaker containing 100.0 g of  $\text{H}_2\text{O}$  at 22.6°C. Assuming that the water gained all the heat lost by the iron, what is the final temperature of the  $\text{H}_2\text{O}$  and Fe?
4. A 5.69 g sample of copper metal was heated in boiling water to 99.8°C. Then it was dropped into a beaker containing 100.0 g of  $\text{H}_2\text{O}$  at 22.6°C. Assuming that the water gained all the heat lost by the copper, what is the final temperature of the  $\text{H}_2\text{O}$  and Cu?
5. When 1 g of steam condenses, 540 cal of energy is released. How many grams of ice can be melted with 540 cal?

6. When 1 g of water freezes, 79.9 cal of energy is released. How many grams of water can be boiled with 79.9 cal?
7. The change in energy is +65.3 kJ for each mole of calcium hydroxide  $[\text{Ca}(\text{OH})_2]$  according to the following reaction:



How many grams of  $\text{Ca}(\text{OH})_2$  could be reacted if 575 kJ of energy were available?

8. The thermite reaction gives off so much energy that the elemental iron formed as a product is typically produced in the liquid state:



How much heat will be given off if 250 g of Fe are to be produced?

9. A normal adult male requires 2,500 kcal per day to maintain his metabolism.
  - a. Nutritionists recommend that no more than 30% of the calories in a person's diet come from fat. At 9 kcal/g, what is the maximum mass of fat an adult male should consume daily?
  - b. At 4 kcal/g each, how many grams of protein and carbohydrates should an adult male consume daily?
10. A normal adult male requires 2,500 kcal per day to maintain his metabolism.
  - a. At 9 kcal/g, what mass of fat would provide that many kilocalories if the diet was composed of nothing but fats?
  - b. At 4 kcal/g each, what mass of protein and/or carbohydrates is needed to provide that many kilocalories?
11. The volume of the world's oceans is approximately  $1.34 \times 10^{24} \text{ cm}^3$ .
  - a. How much energy would be needed to increase the temperature of the world's oceans by  $1^\circ\text{C}$ ? Assume that the heat capacity of the oceans is the same as pure water.
  - b. If Earth receives  $6.0 \times 10^{22} \text{ J}$  of energy per day from the sun, how many days would it take to warm the oceans by  $1^\circ\text{C}$ , assuming all the energy went into warming the water?
12. Does a substance that has a small specific heat require a small or large amount of energy to change temperature? Explain.
13. Some biology textbooks represent the conversion of adenosine triphosphate (ATP) to adenosine diphosphate (ADP) and phosphate ions as follows:



What is wrong with this reaction?

14. Assuming that energy changes are additive, how much energy is required to change 15.0 g of ice at  $-15^\circ\text{C}$  to 15.0 g of steam at  $115^\circ\text{C}$ ? (Hint: you will have five processes to consider.)

## Answers

1.
  - a.  $2\text{SO}_2 + \text{O}_2 \rightarrow 2\text{SO}_3$
  - b. 16,700 kcal
2.
  - a. exothermic
  - b. 1177 kcal
3. about  $23.1^\circ\text{C}$
4. about  $23.0^\circ\text{C}$
5. 6.76 g
6. 0.148 g

7. 652 g
8. 457 kcal
- 9.
- a. 83.3 g
- b. 438 g
- 10.
- a. 278 g
- b. 625 g
- 11.
- a.  $1.34 \times 10^{24}$  cal
- b. 93 days
12. A substance with **smaller specific heat** requires **less energy** per unit of mass to raise its temperature,
13. A reactant is missing: H<sub>2</sub>O is missing.
14. Total energy = 11,019 cal

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