24. $\Delta H^\circ_r = \Sigma(n\Delta H^\circ_f \text{ products}) - \Sigma(n\Delta H^\circ_f \text{ reactants})$

$= [(2 \text{ mol})(\Delta H^\circ_f \, Fe_2O_3(s)) + (8 \text{ mol})(\Delta H^\circ_f \, SO_2(g))]$
$\quad - [(4 \text{ mol})(\Delta H^\circ_f \, FeS_2(s)) + (11 \text{ mol})(\Delta H^\circ_f \, O_2(g))]$

$= [(2 \text{ mol})(-824.2 \text{ kJ/mol}) + (8 \text{ mol})(-296.8 \text{ kJ/mol})]$
$\quad - [(4 \text{ mol})(-178.2 \text{ kJ/mol}) + (11 \text{ mol})(0 \text{ kJ/mol})]$

$= (-4022.8 \text{ kJ}) - (-712.8 \text{ kJ}) = -3.310 \times 10^3 \text{ kJ}$

The reaction is exothermic; the reactants have 3.310×10^3 kJ more potential energy than the products.

25. To determine the ΔH°_{comb} data experimentally with even one alkane and its corresponding alkene, e.g. propane and prop-1-ene, would require a lengthy experiment and the availability of these hydrocarbons. The data is available in the Handbook of Chemistry and Physics or from Internet sources.

Draw up a table of ΔH°_{comb} data for alkanes and the corresponding alkenes having a double bond between C_1 and C_2. For the alkanes and alkenes having from two to five carbon atoms, the data would be as shown below.

Alkane	ΔH°_{comb} (kJ/mol)	Alkene	ΔH°_{comb} (kJ/mol)
Ethane	1560	Ethene	1411
Propane	2219	Prop-1-ene	2058
Butane	2877	But-1-ene	2711
Pentane	3509	Pen-1-tene	3363

Analysis of the results will show that the enthalpy of combustion for each group of hydrocarbons increases as the number of carbon atoms increases and that alkenes with a double bond have a lower enthalpy of combustion than the corresponding alkane. A plot of H°_{comb} vs. number of carbon atoms in the alkane and in the alkene can be used to extrapolate to longer chain hydrocarbons in the same series.

Chapter 6 Rates of Reaction

Answers to Learning Check Questions

(Student textbook page 357)

1. Measure the change in mass of the reactant, limestone, over a period of time or the volume of product, $CO_2(g)$, generated over a period of time. The former is the more practical option.

2. *Sample answer*: A balanced chemical equation does not give information about the rate at which the chemical reaction occurs.

3. Since the concentration increased from 0.25 mol/L to 0.420 mol/L over time, a product was measured.

4. The graph should show that the tangent is a line drawn so it just touches the curve at one point. The instantaneous rate at the point where the tangent touches the curve is calculated by measuring the slope of the tangent. This is done by determining the rise and the run of the line and dividing the rise by the run. The rise is the change in concentration and the run is the change in time.

5. **a.** Molecules of A that remain = 30; molecules of B that remain = 10

   b. The average rate of reaction can be determined using the number of molecules of A that are consumed or the number of molecules of B that are produced over a period of time.

   $$\frac{\Delta A}{\Delta t} = \frac{30 \text{ molecules} - 40 \text{ molecules}}{10 \text{ s} - 0 \text{ s}}$$
   $$= -1 \text{ molecule/s}$$
   $$\frac{\Delta B}{\Delta t} = \frac{10 \text{ molecules} - 0 \text{ molecules}}{10 \text{ s} - 0 \text{ s}}$$
   $$= +1 \text{ molecule/s}$$

   c. The average rate of change in the number of molecules of A and of B is the equal but opposite.

6. The manager would be concerned about the average rate of spoilage. It represents how long the fruit could be left on the shelf. The instantaneous rate indicates only how fast the fruit was spoiling at one point in time.

(Student textbook page 367)

7. The particles must collide with the proper orientation to one another and have sufficient kinetic energy to overcome the potential energy barrier (activation energy) between reactants and products.

8. Many collisions have the wrong collision geometry, and only a fraction of the collisions have sufficient energy to overcome the potential energy barrier (activation energy).

9. The angle at which the reactants collide must align with the angle at which the new bond or bonds in the products will form.

10. Diagrams for exothermic reactions show reactants with a higher potential energy than the potential energy for the products. Diagrams for endothermic reactions show reactants with a lower potential energy than that for the products.

11. a. The minimum kinetic energy required for a collision to result in a reaction between reactant particles.

b. Only the collisions with a kinetic energy equal to or greater than E_a will result in a reaction. For a reaction at room temperature with a high E_a, there will be few particles having sufficient energy to overcome the energy barrier when they collide.

12. The enthalpy change, the activation energy, and whether the reaction is endothermic or exothermic are three characteristics of a reaction that you can determine from a potential energy diagram. The enthalpy change is the difference between the initial (reactant) and final (product) potential energies. The activation energy is the difference between the initial potential energy and the maximum potential energy. The relative values of the potential energy of the reactants and products indicate whether it is an endothermic or exothermic reaction.

(Student textbook page 369)

13. The greater the activation energy, the slower the rate; the lower the activation energy, the faster the rate

14. a. The flame increases the energy of a few reactant particles so that when collisions occur, the reactant particles have energy equal to or greater than the activation energy. After a few successful collisions occur, the reaction itself releases enough energy to provide energy for the rest of the particles to react.

b. Combustion reactions such as the burning of natural gas are exothermic processes. The thermal energy given off provides the energy for further particles to react.

15. The thermochemical equation does not show the activation energy, which you would expect to be high, since graphite does not spontaneously change to diamond. Graphite and diamond have different arrangements of carbon atoms. Although the overall energy difference is small, to make the change, carbon-carbon bonds would need be broken and the atoms re-arranged.

16. a. An activated complex is an unstable, temporary chemical species formed of the reactant and product; it will break apart either to form the product(s) or reform the reactants.

b. The nitrogen atom in the NO collides with an oxygen atom in the NO_3. Student sketches should show dotted lines indicating new bonds forming between the N of NO and the O of NO_3 and dotted lines indicating the breaking of bonds between the O and N of NO_3.

17. Exothermic; $\Delta H = E_{a(fwd)} - E_{a(rev)} = 45 \text{ kJ} - 50 \text{ kJ}$
$= -5 \text{ kJ}$

18. Since the reverse of the reaction shown is endothermic, student sketches should indicate the product (carbon disulfide) with higher potential energy than the reactants (carbon and sulfur); the difference between the two values is 89 kJ.

(Student textbook page 374)

19. Any change that increases the number of collisions between reactant particles will increase the rate of reaction. Any change that decreases the number of collisions between reactant particles will decrease the rate of reaction.

20. Factors that can alter the rate of a chemical reaction include a change in the nature of the reactant(s); a change in the concentration of the reactant(s); a change in temperature; a change in pressure, if the reactants are gases; a change in the total surface area of the reactant material; and the introduction of a catalyst.

21. Only collisions having kinetic energy equal to or exceeding the activation energy will lead to formation of product. At lower temperatures, there are fewer reactant particles with sufficient kinetic energy and the rate of reaction is slower.

22. *Sample answer*: The rate of rusting would be slowed down by reducing the number of collisions between Fe(s) and O_2(g). Decreasing the temperature and covering the iron with a protective coating would be two ways to accomplish this.

23. Sawdust and bulk plant material have a larger total exposed surface area than the pellets and there will be many more collisions between reactant particles. As successful collisions occur, heat is given off, which rapidly leads to more collisions between particles having kinetic energy greater than the activation energy. The result is a rapid, uncontrollable, and possibly explosive combustion. This is not desirable for a fuel. It is more important for fuels to burn slowly so that the heat from this burning can be distributed for a required use. Moreover, when the size and density of the pellets are consistent, the rate of the reaction will not only be smaller but also more predictable, so that the energy produced over time can be determined, assuming the materials of which the pellets are made burn at a consistent rate.

24. *Sample answer*: Since the temperature is already high, an increase in temperature would not be expected to have much effect. The high temperature suggests that