

UNIT 3 SELF-QUIZ

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1. False: A physical change usually involves a *larger* enthalpy change than does a chemical change.
2. True
3. False: The potential energy of the products is *smaller* than the potential energy of the reactants in an exothermic change.
4. True
5. False: An *endothermic* reaction absorbs heat from the surroundings.
6. True
7. True
8. False: *Three-quarters* of a radioisotope will have changed after two half-lives.
9. False: In an endothermic reaction, *only* the potential *energy* of the chemical system increases.
10. True
11. (b)
12. (c)
13. (e)
14. (a)
15. (e)
16. (c)
17. (b)
18. (d)
19. (b)
20. (e)
21. (b)
22. (a)
23. (c)
24. (c)
25. (e)
26. (c)
27. (b)
28. (d)
29. (c)
30. (d)

UNIT 3 REVIEW

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Understanding Concepts

1. $q_{\text{water}} = mc\Delta T$
 $= 1500 \text{ g} \times 4.18 \text{ J/(g}\cdot\text{°C)} \times (75 - 20)\text{°C}$
 $q_{\text{water}} = 340 \text{ kJ}$
2. $M_{\text{Cl}_2} = 70.9 \text{ g/mol}$
 $n_{\text{Cl}_2} = 2250 \text{ g} \times \frac{1 \text{ mol}}{70.9 \text{ g}}$
 $n_{\text{Cl}_2} = 31.7 \text{ mol}$
 $\Delta H = n_{\text{Cl}_2} \Delta H_{\text{vap}}$
 $= 31.7 \text{ mol} \times 20.7 \text{ kJ/mol}$
 $\Delta H = 657 \text{ kJ}$

$$3. (a) \quad q_{\text{water}} = mc\Delta T$$

$$= 100.0 \text{ g} \times 4.18 \text{ J/(g}\cdot^{\circ}\text{C)} \times 5.6^{\circ}\text{C}$$

$$q_{\text{water}} = 2341 \text{ J}$$

$$n_{\text{NaOH}} = MV$$

$$= 0.700 \text{ mol/L} \times 0.600 \text{ L}$$

$$n_{\text{NaOH}} = 0.420 \text{ mol}$$

$$n\Delta H_{\text{neut}} = q_{\text{water}}$$

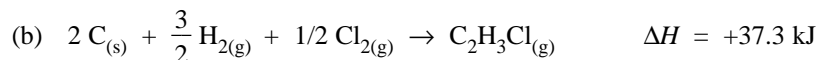
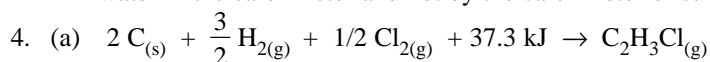
$$\Delta H_{\text{neut}} = \frac{q_{\text{water}}}{n}$$

$$= \frac{2341 \text{ J}}{0.420 \text{ mol}}$$

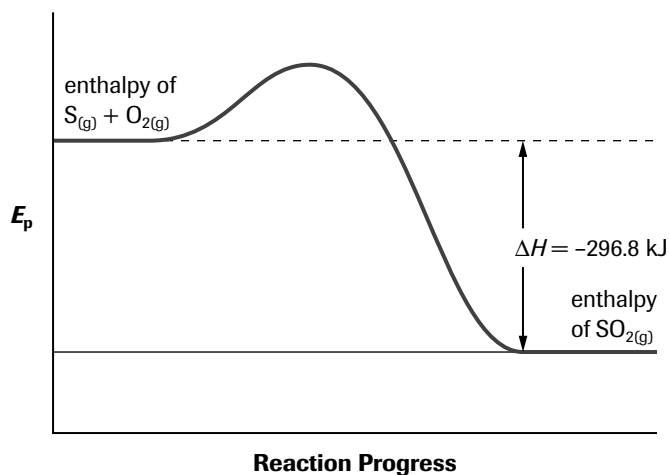
$$\Delta H_{\text{neut}} = 5573 \text{ J/mol, or } 5.57 \text{ kJ/mol}$$

Because the reaction is exothermic, $\Delta H_{\text{neut}} = -5.57 \text{ kJ/mol}$.

(b) The assumption is that the reaction went to completion and that all heat from the reaction was absorbed by the water in the calorimeter and not by the calorimeter or surroundings.



(b) **Potential Energy Diagram of the Formation of Sulfur Dioxide**



$$(c) \quad M_{\text{SO}_2} = 64.07 \text{ g/mol}$$

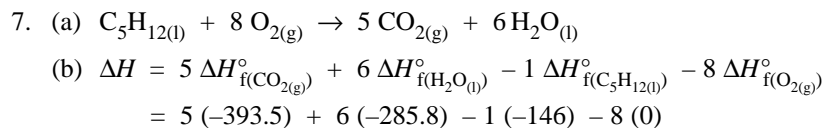
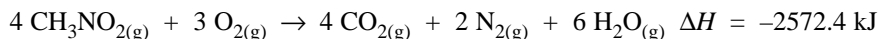
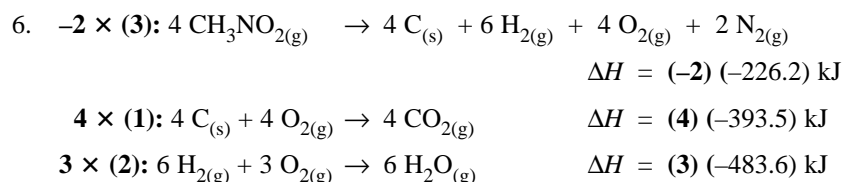
$$n_{\text{SO}_2} = 9.63 \text{ g} \times 1 \text{ mol}/64.07 \text{ g}$$

$$n_{\text{SO}_2} = 0.150 \text{ mol}$$

$$q = n_{\text{SO}_2} \Delta H_f$$

$$= 0.150 \text{ mol} \times 296.8 \text{ kJ}$$

$$q = 44.6 \text{ kJ}$$



$\Delta H = -3536.3 \text{ kJ}$

(c) $M_{\text{pentane}} = 72.0 \text{ g/mol}$

$n_{\text{pentane}} = 20 \text{ g} \times 1 \text{ mol} / 72.0 \text{ g}$

$n_{\text{pentane}} = 0.278 \text{ mol}$

$q = n \Delta H_{\text{comb}}$

$= 0.278 \text{ mol} \times 3536.3 \text{ kJ/mol}$

$q = 982 \text{ kJ}$

982 kJ would be released, when 20 g of pentane is burned.

8. Properties include colour, volume or pressure, and conductivity.

9. (a) As 1 mol of $\text{CO}_{(g)}$ is consumed, 1 mol of $\text{CO}_{2(g)}$ is produced.

At time 0, $[\text{CO}_{2(g)}] = 0 \text{ mol/L}$

At time 40, $[\text{CO}_{2(g)}] = 0.067 \text{ mol/L}$

At time 100, $[\text{CO}_{(g)}] = 0.017 \text{ mol/L}$

(b) As 1 mol of $\text{NO}_{2(g)}$ is consumed, 1 mol of $\text{CO}_{2(g)}$ is produced.

In 80 s, $\Delta[\text{CO}_{2(g)}] = 0.080 \text{ mol/L}$. Thus, $\Delta[\text{NO}_{2(g)}] = -0.080 \text{ mol/L}$.

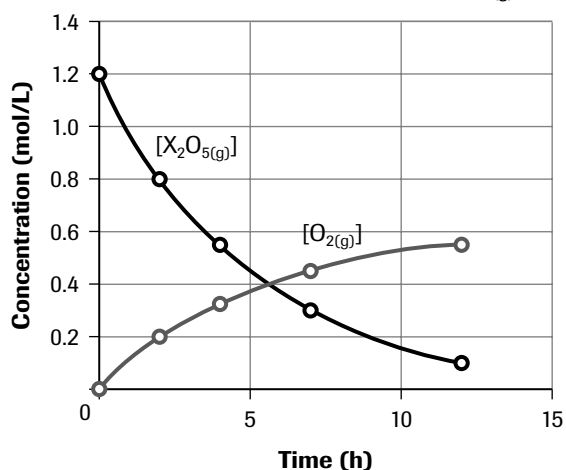
$[\text{NO}_{2(g)}]_{100 \text{ s}} = 0.250 \text{ mol/L} - 0.080 \text{ mol/L}$

$[\text{NO}_{2(g)}]_{100 \text{ s}} = 0.170 \text{ mol/L}$

10. Newspapers, particularly as they curl while burning and because of air trapped in their pages, expose much more surface area to reaction with air. They therefore start burning more easily, and burn more quickly, than an equivalent quantity of wood.

11. (a)

Graph of Decomposition of $\text{X}_2\text{O}_{5(g)}$



- (b) As 1 mol of $O_{2(g)}$ is produced, 4 mol of $XO_{2(g)}$ are produced. Therefore, the four values for $[XO_{2(g)}]$ (in mol/L) are: 0.80, 1.30, 1.80, and 2.20.

$$(c) (i) \quad \frac{-\Delta[X_2O_{5(g)}]}{\Delta t} = \frac{(1.20 - 1.00) \text{ mol/L}}{12.0 \text{ h}}$$

$$\frac{-\Delta[X_2O_{5(g)}]}{\Delta t} = 0.092 \text{ mol/(L}\cdot\text{h)}$$

In the first 12 h, the overall rate of consumption of $X_2O_{5(g)}$ is 0.092 mol/(L·h).

$$(ii) \quad \frac{+\Delta[O_{2(g)}]}{\Delta t} = \frac{0.55 \text{ mol/L}}{12.0 \text{ h}}$$

$$\frac{+\Delta[O_{2(g)}]}{\Delta t} = 0.046 \text{ mol/(L}\cdot\text{h)}$$

In the first 12 h, the overall rate of production of $O_{2(g)}$ is 0.046 mol/(L·h).

$$(iii) \quad \frac{+\Delta[XO_{2(g)}]}{\Delta t} = \frac{2.20 \text{ mol/L}}{12.0 \text{ h}}$$

$$\frac{+\Delta[XO_{2(g)}]}{\Delta t} = 0.183 \text{ mol/(L}\cdot\text{h)}$$

In the first 12 h, the overall rate of production of $XO_{2(g)}$ is 0.183 mol/(L·h).

- (d) When we use tangents to the curve, the rates of consumption of $X_2O_{5(g)}$ at 2.0 h and 7.0 h are 0.14 and 0.058 mol/(L·h), respectively.
- (e) The rate of consumption decreases as the concentration of reactant molecules able to collide and react decreases.
12. Aluminum powder has a much greater surface area, making it react much more quickly with oxygen in the air.
13. (a) The rate would double.
 (b) The rate would be halved.
 (c) Since both initial concentrations would be doubled, the rate would quadruple.
14. (a) This would have to be a multi-step mechanism because it involves six reactant molecules.
 (b) Rate of consumption of $O_{2(g)}$:

$$\frac{-\Delta[O_{2(g)}]}{\Delta t} = 5 \times 4.0 \times 10^{-3} \text{ mol/(L}\cdot\text{s)}$$

$$\frac{-\Delta[O_{2(g)}]}{\Delta t} = 2.0 \times 10^{-2} \text{ mol/(L}\cdot\text{s)}$$

Rate of production of $CO_{2(g)}$:

$$\frac{+\Delta[CO_2]}{\Delta t} = 3 \times 4.0 \times 10^{-3} \text{ mol/(L}\cdot\text{s)}$$

$$\frac{+\Delta[CO_2]}{\Delta t} = 1.2 \times 10^{-2} \text{ mol/(L}\cdot\text{s)}$$

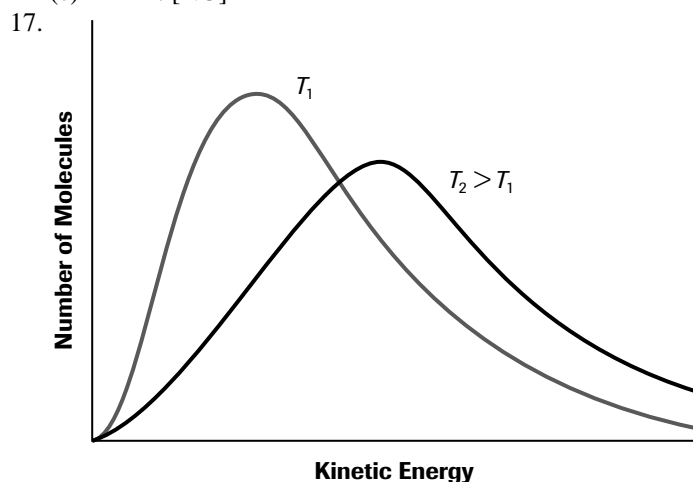
15. (a) When we compare Trials 2 and 3, we see that as $[HI]$ is doubled, rate is multiplied by 2; therefore, rate depends on $[HI]^1$.
 (b) When we compare Trials 1 and 2, we see that as $[O_2]$ is doubled, rate is multiplied by 2; therefore, rate depends on $[O_2]^1$.
 (c) The overall order is two.
 (d) $r = k [HI] [O_2]$
 (e) $k = \frac{r}{[HI] [O_2]}$

$$= \frac{0.0042 \text{ (mol/L}\cdot\text{s)}}{0.010 \text{ mol/L} \times 0.010 \text{ mol/L}}$$

$$k = 42 \text{ L/(mol}\cdot\text{s)}$$

- (f) One molecule each of HI and O_2 are involved: two molecules.
 (g) Five reactant molecules are unlikely to collide in a single step at any appreciable rate.

16. (a) $2 \text{NO}_{(\text{g})} + 2 \text{H}_{2(\text{g})} \rightarrow \text{N}_{2(\text{g})} + 2 \text{H}_2\text{O}_{(\text{g})}$
 (b) The reaction intermediates are $\text{N}_2\text{O}_{2(\text{g})}$ and $\text{N}_2\text{O}_{(\text{g})}$.
 (c) $r = k [\text{NO}]^2$



18. Reaction (a) should be faster because it is homogeneous. In reaction (b), reactions can only occur at the surface of the lead metal.
19. (a) The activation energy barrier, E_a , for white phosphorus is very low, whereas the E_a for diamond is very high.
 (b) In the potential energy diagram for phosphorus, the activation energy barrier will be very small and the reaction exothermic with a large ΔH ; in the potential energy diagram for diamond, the activation energy barrier will be very large and the reaction exothermic with a very small ΔH .

Applying Inquiry Skills

20. Analysis

$$\begin{aligned}
 \text{(a) } q_{\text{water}} &= mc\Delta T \\
 &= 255 \text{ g} \times 4.18 \text{ J/(g}\cdot^\circ\text{C)} \times 28.8^\circ\text{C} \\
 q_{\text{water}} &= 30.7 \text{ kJ} \\
 q_{\text{copper}} &= mc\Delta T \\
 &= 305 \text{ g} \times 0.385 \text{ J/(g}\cdot^\circ\text{C)} \times 28.8^\circ\text{C} \\
 q_{\text{copper}} &= 3.38 \text{ kJ} \\
 q_{\text{water}} + q_{\text{copper}} &= 34.1 \text{ kJ} \\
 n\Delta H_{\text{reaction}} &= q_{\text{total}} \\
 m_{\text{C}_3\text{H}_6\text{O}} &= 1.01 \text{ g} \\
 M_{\text{C}_3\text{H}_6\text{O}} &= 58.0 \text{ g} \\
 n_{\text{C}_3\text{H}_6\text{O}} &= 1.01 \text{ g} \times \frac{1 \text{ mol}}{58.0 \text{ g}} \\
 n_{\text{C}_3\text{H}_6\text{O}} &= 0.0174 \text{ mol} \\
 \Delta H_{\text{comb}} &= \frac{q_{\text{total}}}{n_{\text{C}_3\text{H}_6\text{O}}} \\
 &= \frac{34.1 \text{ kJ}}{0.0174 \text{ mol}} \\
 \Delta H_{\text{comb}} &= 1958 \text{ kJ/mol propanal} \\
 \text{Because the reaction is exothermic, } \Delta H_{\text{comb}} &= -1.96 \text{ MJ/mol.}
 \end{aligned}$$

21. Analysis

- (a) Assume that 100.0 mL of solution is 100.0 g of water.

$$q_{\text{water}} = mc\Delta T \\ = 100.0 \text{ g} \times 4.18 \text{ J/(g}\cdot^{\circ}\text{C)} \times (35.6 - 14.5)^{\circ}\text{C}$$

$$q_{\text{water}} = 8.82 \text{ kJ}$$

$$n_{\text{NaOH}_{(s)}} = 3.40 \text{ g} \times \frac{1 \text{ mol}}{40.0 \text{ g}}$$

$$n_{\text{NaOH}_{(s)}} = 0.0850 \text{ mol}$$

$$n_{\text{HCl}_{(aq)}} = MV \\ = 0.850 \text{ mol/L} \times 0.100 \text{ L}$$

$$n_{\text{HCl}_{(aq)}} = 0.0850 \text{ mol}$$

$$n\Delta H_{\text{reaction}} = q_{\text{water}}$$

$$\Delta H_{\text{reaction}} = \frac{q_{\text{water}}}{n} \\ = \frac{8.82 \text{ kJ}}{0.0850 \text{ mol}}$$

$$\Delta H_{\text{reaction}} = 104 \text{ kJ/mol HCl}$$

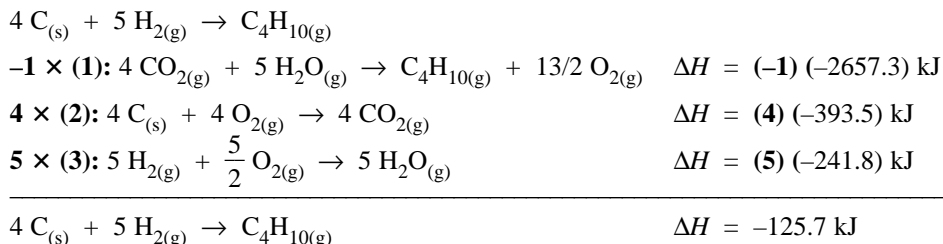
Because the reaction is exothermic, $\Delta H_{\text{reaction}}$ is -104 kJ/mol .

Evaluation

- (b) (Answers will vary.) The Experimental Design is adequate if careful bomb calorimetry is used.

22. Analysis

- (a) The target equation is:



Since this reaction is written for 1 mol of product, the molar enthalpy of formation of butane is -125.7 kJ/mol .

23. Experimental Design

- (a) The rate of reaction in terms of the rate of production of S will be measured by varying, one at a time, the initial concentrations of each of the reactants while controlling the other concentrations.

Analysis

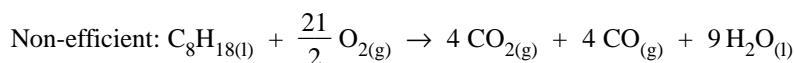
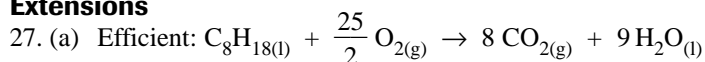
- (b) When we compare Trials 1 and 2, we see that as [A] is doubled, rate is multiplied by 2; therefore, rate depends on $[A]^1$.
When we compare Trials 2 and 3, we see that as [B] is doubled, rate is multiplied by 2; therefore, rate depends on $[B]^1$.
When we compare Trials 3 and 4, we see that as [C] is doubled, rate is multiplied by 1; therefore, rate depends on $[C]^0$.
Overall, $r = k [A]^1[B]^1$.

Making Connections

24. (Answers will vary.) Nuclear reactors have higher capital cost, involve reactant fuels that require considerable processing, and have associated serious safety issues related to transportation and storage of radioactive isotopes. Fossil fuels are finite resources, which are nonetheless readily available. The capital cost of plants burning these fuels is relatively low and they can easily be converted to burn a range of fuels. However, fossil fuels are “environmentally

- dirty” energy sources that foul the air with, at best, greenhouse emissions and, at worst, acid-rain-producing sulfur dioxide, particularly when lower grades of coal are used.
25. (Answers will vary.) Carbon-14 and uranium-238 decay can be used to determine the ages of artifacts and ancient rocks. Medical research scientists are interested in the shelf life or rate of decomposition of antibiotics and the rate of retention of environmental toxins in the body after exposure.
26. (a) Increased concentration increases the collision frequency.
 (b) Decreased temperature decreases the fraction of molecules with enough kinetic energy to exceed the activation energy barrier.
 (c) Increased temperature increases the fraction of molecules with enough kinetic energy to exceed the activation energy barrier.
 (d) Reactions require activation energy in order to occur.
 (e) Increased surface area increases the collision frequency.
 (f) Addition of a catalyst lowers the activation energy barrier and increases the fraction of molecules with enough kinetic energy to exceed the activation energy barrier.
 (g) Homogeneous reactions allow much better mixing of reacting molecules, thus increasing the collision frequency.

Extensions



(b) Efficient:

$$\begin{aligned} \Delta H &= 8 \Delta H_{\text{f}(\text{CO}_{2(g)})}^{\circ} + 9 \Delta H_{\text{f}(\text{H}_2\text{O}_{(l)})}^{\circ} - 1 \Delta H_{\text{f}(\text{C}_8\text{H}_{18(l)})}^{\circ} - \frac{25}{2} \Delta H_{\text{f}(\text{O}_{2(g)})}^{\circ} \\ &= 8(-393.5) + 9(-285.8) - 1(-250.1) - 12.5(0) \end{aligned}$$

$$\Delta H = -5470 \text{ kJ}$$

Non-efficient:

$$\begin{aligned} \Delta H &= 4 \Delta H_{\text{f}(\text{CO}_{2(g)})}^{\circ} + 4 \Delta H_{\text{f}(\text{CO}_{(g)})}^{\circ} + 9 \Delta H_{\text{f}(\text{H}_2\text{O}_{(l)})}^{\circ} - 1 \Delta H_{\text{f}(\text{C}_8\text{H}_{18(l)})}^{\circ} - 11.5 \Delta H_{\text{f}(\text{O}_{2(g)})}^{\circ} \\ &= 4(-393.5) + 4(-110.5) + 9(-285.8) - 1(-250.1) - 11.5(0) \end{aligned}$$

$$\Delta H = -4338 \text{ kJ}$$

$$(c) \% \text{ waste} = \frac{(5470 \text{ kJ} - 4338 \text{ kJ})}{5470 \text{ kJ}} \times 100\%$$

$$\% \text{ waste} = 21\%$$

$$(d) q_{\text{water}} = mc\Delta T$$

$$= 15\,000 \text{ g} \times 4.18 \text{ J/(g}\cdot^{\circ}\text{C)} \times (95 - (-15))^{\circ}\text{C}$$

$$q_{\text{water}} = 6.9 \times 10^3 \text{ kJ}$$

$$q_{\text{block}} = mc\Delta T$$

$$= 200\,000 \text{ g} \times 0.50 \text{ J/(g}\cdot^{\circ}\text{C)} \times (95 - (-15))^{\circ}\text{C}$$

$$q_{\text{block}} = 1.1 \times 10^4 \text{ kJ}$$

$$q_{\text{total}} = 1.7(9) \times 10^4 \text{ kJ}$$

$$q_{\text{total}} = n_{\text{octane}} \Delta H_{\text{comb}}$$

$$n_{\text{octane}} = \frac{q_{\text{total}}}{\Delta H_{\text{comb}}}$$

$$= \frac{1.7(9) \times 10^4 \text{ kJ}}{5470 \text{ kJ}}$$

$$n_{\text{octane}} = 3.2(7) \text{ mol octane}$$

$$\begin{aligned}
 m_{\text{octane}} &= n_{\text{octane}} M \\
 &= 3.2(7) \text{ mol} \times 114 \text{ g/mol} \\
 m_{\text{octane}} &= 373 \text{ g, or } 3.7 \times 10^2 \text{ g}
 \end{aligned}$$

To raise the temperature of the engine to operating temperature, 373 g of octane must be burned.

- (e) You must assume that all of the energy produced by the burning of octane goes into the sum of temperature changes in the engine and motion of the vehicle.

To drive 2 km, when warmed up,

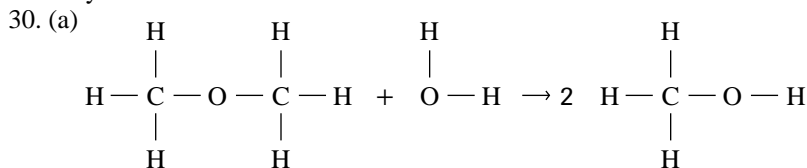
$$\begin{aligned}
 m_{\text{octane}} &= 2 \text{ km} \times 0.150 \text{ L/km} \times 800 \text{ g/L} \\
 m_{\text{octane}} &= 240 \text{ g}
 \end{aligned}$$

To warm up the engine *and* drive 2 km,

$$\begin{aligned}
 \text{total } m_{\text{octane}} &= 373 + 240 \\
 \text{total } m_{\text{octane}} &= 613 \text{ g, or } 6.1 \times 10^2 \text{ g}
 \end{aligned}$$

28. (Sample answer) In recent years, there have emerged worldwide infectious bacterial agents that are causing concern. These include: methicillin-resistant *Staphylococcus aureus*, multiple-drug resistant *tuberculosis*, and vancomycin-resistant *enterococci* (VRE). There is extensive evidence that associates these resistances with the use, or abuse, of antibiotics in humans both in hospital and in the community. There is some suggestion that, with VRE, these resistances might originate from the several decades of use of animal feed additives.

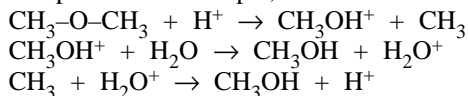
29. Plant enzymes or meat marinades have been used for centuries to tenderize meats. For example, food might be wrapped in papaya leaves prior to cooking. Papain is an enzyme derived from these leaves, which catalyzes the breakdown of the muscle tissue, thus making the meat more tender. Figs and pineapples also contain protein-digesting enzymes which are produced as commercial meat tenderizers. These enzymes can only act on the surface of the meat, unless holes are poked in the surface, but the greater resultant fluid loss can be a problem in cooking. Most of these enzymes are most effective from 60–80°C but are denatured and rendered ineffective at boiling temperature.



- (b) The acid is a catalyst.

- (c) $\text{CH}_3\text{-O-CH}_3$ must be in the rate-determining step.

- (d) Any series of steps that uses up reactants, produces products, and consumes and regenerates the catalyst will be acceptable. For example,



- (e) **Potential Energy Diagram of a Proposed Three-Step Mechanism for the Hydrolysis of Dimethyl Ether**

