Assessment Exemplars
Chemistry 30
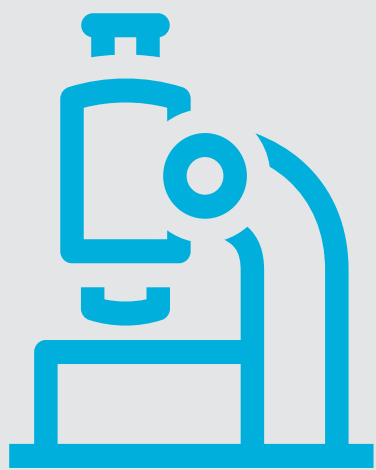
Alberta Provincial Diploma Examinations 2020–2021

Alberta

Chemistry 30 Assessment Exemplars

These Chemistry 30 assessment exemplars were developed by the Provincial Assessment Sector in cooperation with the Curriculum Branch of Alberta Education and Alberta Chemistry teachers to assist teachers with the interpretation of curricular outcomes in the program of studies (implemented in September 2007). The assessment exemplars, which include multiple-choice and numerical-response questions, illustrate how a particular concept can be assessed in a machine-scored format. Teachers are encouraged to use other assessment tools as well as machine-scored questions to assess the learning of their students.

This exemplar document parallels the Chemistry 30 Program of Studies. Each outcome is identified by a letter that indicates the unit of study (A, B, C, or D); by a number that indicates the general learner outcome within the unit; and by a number that indicates the specific outcome. Each specific outcome is further classified as knowledge (k); science, technology, and society (STS); or skills (s). For example, A2.1k indicates that the concept is from Unit A, general outcome 2, specific outcome 1, and that the outcome is knowledge-based.

This exemplars document is neither exhaustive nor prescriptive. Its purpose is simply to provide a variety of useful examples of how specific outcomes in the Chemistry 30 Program of Studies can be assessed.

Contents

Unit A—Thermochemical Changes

Use the following information to answer questions 1 and 2.

A student used an aluminium calorimeter as part of the apparatus below to determine the molar enthalpy of combustion for pentane, $C_5H_{12}(l)$.
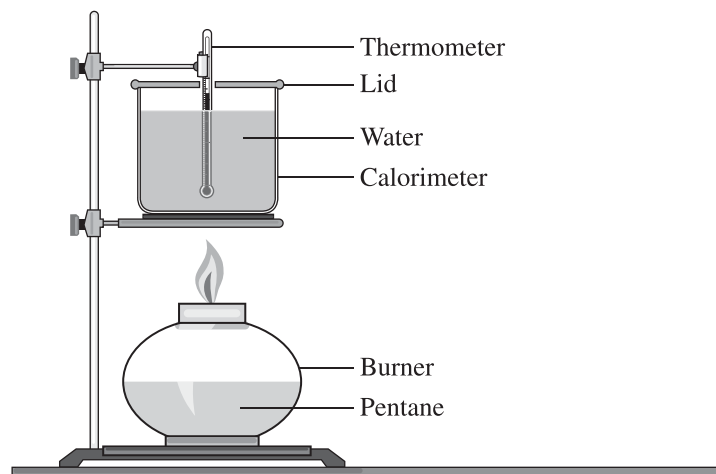
The following data were recorded when a sample of pentane was burned.

Mass of calorimeter	58.5 g
Mass of calorimeter and water	558.5 g
Initial temperature of water	21.2 °C
Final temperature of water	40.0 °C

1. The energy absorbed by the water in the calorimeter is

   A. 39.4 kJ
   B. 44.0 kJ
   C. 83.8 kJ
   D. 93.6 kJ

   Answer: A
   Outcome: A1.1k, A1.4s

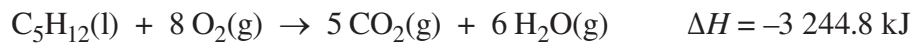$$C_5H_{12}(l) + 8 O_2(g) \rightarrow 5 CO_2(g) + 6 H_2O(g) \qquad \Delta H = -3\ 244.8 \text{ kJ}$$

2. If 1.07 g of pentane burns, the energy released is

   A. 45.0 kJ

   B. 48.1 kJ

   C. 3.03×10^3 kJ

   D. 3.47×10^3 kJ

   Answer: B
   Outcome: A1.5k

Use the following information to answer numerical-response question 1.

Hydrogen gas can be produced by the reaction of methane and water vapour in the presence of a nickel catalyst, as represented by the following equation.

$$CH_4(g) + H_2O(g) + 205.9 \text{ kJ} \xrightarrow{\text{Ni catalyst}} CO(g) + 3 H_2(g)$$
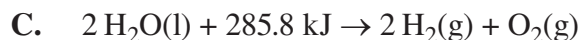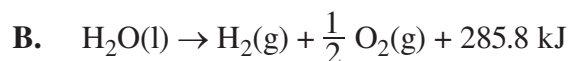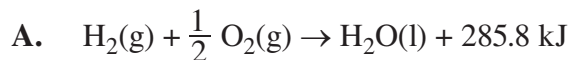
Numerical Response

1. The molar enthalpy of reaction for hydrogen gas in the reaction above
is +/–_____ kJ/mol.

(Record your **three-digit answer** in the numerical-response section on the answer sheet.)

Answer: 68.6
Outcome: A1.3k

3. Which of the following equations represents the balanced chemical equation for the decomposition of water into its elements and the energy transfer during the reaction?

   A. $H_2(g) + \frac{1}{2} O_2(g) \rightarrow H_2O(l) + 285.8$ kJ

   B. $H_2O(l) \rightarrow H_2(g) + \frac{1}{2} O_2(g) + 285.8$ kJ

   C. $2 H_2O(l) + 285.8$ kJ $\rightarrow 2 H_2(g) + O_2(g)$

   D. $H_2O(l) + 285.8$ kJ $\rightarrow H_2(g) + \frac{1}{2} O_2(g)$

   Answer: D
   Outcome: A1.4k

Use the following information to answer question 4.

When used as a fuel in automobiles, ethanol burns more efficiently than fossil fuels.

4. The balanced equation, including the appropriate enthalpy change for the complete combustion of ethanol, is

   A. $C_2H_5OH(l) + 3 O_2(g) \rightarrow 2 CO_2(g) + 3 H_2O(g)$ $\Delta H° = +1\ 234.8$ kJ

   B. $C_2H_5OH(l) + 3 O_2(g) \rightarrow 2 CO_2(g) + 3 H_2O(g)$ $\Delta H° = -1\ 234.8$ kJ

   C. $C_2H_5OH(l) \rightarrow 2 C(s) + 3 H_2(g) + \frac{1}{2} O_2(g)$ $\Delta H° = +277.6$ kJ

   D. $C_2H_5OH(l) \rightarrow 2 C(s) + 3 H_2(g) + \frac{1}{2} O_2(g)$ $\Delta H° = -277.6$ kJ
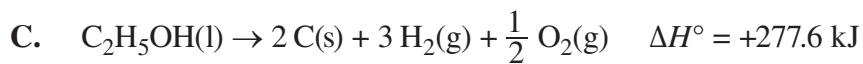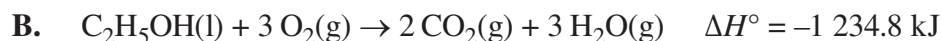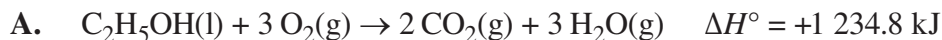
   Answer: B
   Outcome: A1.4k, A1.6k, C2.2k, C2.4k, A1.1sts

2. The energy released when 0.500 mol of AgI(s) is formed from its elements is _____ kJ.

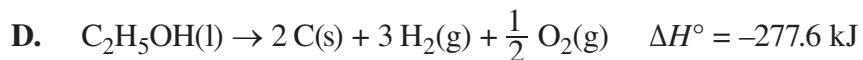(Record your **three-digit answer** in the numerical-response section on the answer sheet.)

Answer: 30.9
Outcome: A1.5k

Use the following information to answer question 5.

Disposable lighters contain butane gas, $C_4H_{10}(g)$, which undergoes combustion, as represented by the following equation.

$$2\,C_4H_{10}(g) \ + \ 13\,O_2(g) \ \rightarrow \ 8\,CO_2(g) \ + \ 10\,H_2O(g)$$
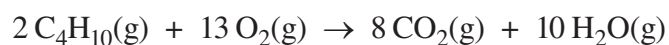
5. The molar enthalpy of combustion of butane is

A. $-2\,657.3$ kJ/mol

B. $-2\,877.3$ kJ/mol

C. $-5\,314.6$ kJ/mol

D. $-5\,754.6$ kJ/mol

Answer: A
Outcome: A1.3k, A1.6k, C2.4k, A1.1sts

Ammonium dichromate, $(NH_4)_2Cr_2O_7(s)$, is known as "Vesuvian Fire" because of its use in pyrotechnic displays. Its decomposition can be represented by the following equation.

$$(NH_4)_2Cr_2O_7(s) \rightarrow N_2(g) + 4H_2O(g) + Cr_2O_3(s) \qquad \Delta H = -300.9 \text{ kJ}$$
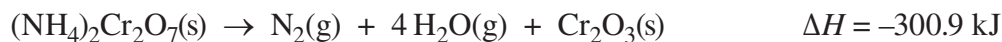
6. The molar enthalpy of formation for $(NH_4)_2Cr_2O_7(s)$ is

   A. -1 682.4 kJ/mol

   B. -1 806.0 kJ/mol

   C. -1 982.0 kJ/mol

   D. -2 106.9 kJ/mol

   Answer: B
   Outcome: A1.6k, A1.1sts

Equations Involving Nitrogen Oxides

$$N_2O_5(g) \rightarrow 2NO(g) + \frac{3}{2}O_2(g) \qquad \Delta H° = +225.7 \text{ kJ}$$

$$NO(g) + \frac{1}{2}O_2(g) \rightarrow NO_2(g) \qquad \Delta H° = -58.1 \text{ kJ}$$
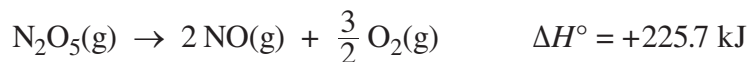
7. The enthalpy of the reaction represented by the equation $2NO_2(g) + \frac{1}{2}O_2(g) \rightarrow N_2O_5(g)$ is

   A. -167.6 kJ

   B. -109.5 kJ

   C. $+109.5$ kJ

   D. $+167.6$ kJ

   Answer: B
   Outcome: A1.7k

Use the following information to answer numerical-response question 3.

The complete combustion of cyclopropane, $C_3H_6(g)$, is represented below.

$$C_3H_6(g) + \tfrac{9}{2}O_2(g) \rightarrow 3\,CO_2(g) + 3\,H_2O(g) \qquad \Delta H° = -1\,959.2 \text{ kJ}$$

Numerical Response

3. The molar enthalpy of formation of cyclopropane is +/–_____ kJ/mol.

(Record your **three-digit answer** in the numerical-response section on the answer sheet.)
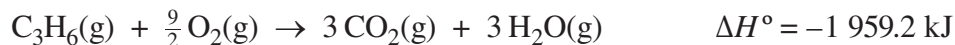
Answer: 53.3
Outcome: A1.6k

Use the following information to answer question 8.

The complete combustion of methanol, $CH_3OH(l)$, is represented below.

$$2\,CH_3OH(l) + 3\,O_2(g) \rightarrow 2\,CO_2(g) + 4\,H_2O(g) \qquad \Delta H° = -1\,275.8 \text{ kJ}$$
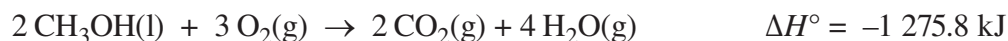
8. The amount of methanol that must be burned to raise the temperature of 250.0 g of water from 20.0 °C to 35.0 °C is

A. 6.16×10^{-3} mol

B. 1.23×10^{-2} mol

C. 2.46×10^{-2} mol

D. 2.46×10^{1} mol

Answer: C
Outcome: A1.8k, A1.4s

9. *The products of photosynthesis are* ___*i*___ , *and the products of hydrocarbon combustion in an open system are* ___*ii*___ .

The statement above is completed by the information in row

Row	*i*	*ii*
A.	$CO_2(g)$ and $H_2O(l)$	$CO_2(g)$ and $H_2O(g)$
B.	$CO_2(g)$ and $H_2O(l)$	$CO_2(g)$ and $H_2O(l)$
C.	$C_6H_{12}O_6(s)$ and $O_2(g)$	$CO_2(g)$ and $H_2O(g)$
D.	$C_6H_{12}O_6(s)$ and $O_2(g)$	$CO_2(g)$ and $H_2O(l)$

Answer: C
Outcome: A1.9k

Use the following information to answer question 10.

In order to pollinate its flowers, the corpse plant generates heat to diffuse a chemical that attracts flies. The energy generated by the plant comes from the metabolism of fats, which can be represented by the following simplified equation.

$$C_5H_{11}COOH(l) + 8 O_2(g) \rightarrow 6 CO_2(g) + 6 H_2O(l) + 3\ 494.3 \text{ kJ}$$

10. *The products of fat metabolism are the same as those of* ___*i*___ . *In the photosynthesis reaction that also occurs in the plant, carbon dioxide,* $CO_2(g)$, *and water,* $H_2O(l)$, *are the* ___*ii*___ .

The statements above are completed by the information in row

Row	*i*	*ii*
A.	cellular respiration	products
B.	cellular respiration	reactants
C.	hydrocarbon combustion in an open system	products
D.	hydrocarbon combustion in an open system	reactants

Answer: B
Outcome: A1.9k

Use the following information to answer numerical-response question 4.

Nine Thermochemical Processes

1	The reaction that represents the $\Delta_f H°$ for $C_2H_4(g)$
2	The reaction that represents the $\Delta_f H°$ for $C_6H_{12}O_6(s)$
3	Photosynthesis
4	Cellular respiration
5	Hydrocarbon combustion
6	$PCl_5(s) + energy \rightarrow PCl_3(l) + Cl_2(g)$
7	$C_2H_4(g) + H_2(g) \rightarrow C_2H_6(g) + energy$
8	$CH_4(g) + H_2O(g) \rightarrow CO(g) + 3 H_2(g)$ $\Delta H = +205.9$ kJ
9	$CH_4(g) + Cl_2(g) \rightarrow CH_3Cl(g) + HCl(g)$ $\Delta H = –101.4$ kJ

Numerical Response

4. The thermochemical processes above that would be classified as endothermic are numbered _____, _____, _____, and _____.

(Record all **four digits** of your answer **in any order** in the numerical-response section on the answer sheet.)

Answer: 1368, any order
Outcome: A1.10k

_____

11. One reason that could explain why dynamite releases a large quantity of energy when it explodes is that the reaction is

   A.   endothermic, and the products have more potential energy than the reactants

   B.   endothermic, and the reactants have more potential energy than the products

   C.   exothermic, and the products have more potential energy than the reactants

   D.   exothermic, and the reactants have more potential energy than the products

Answer: D
Outcome: A1.10k, A2.2k, A1.1sts

Potential Energy Diagram
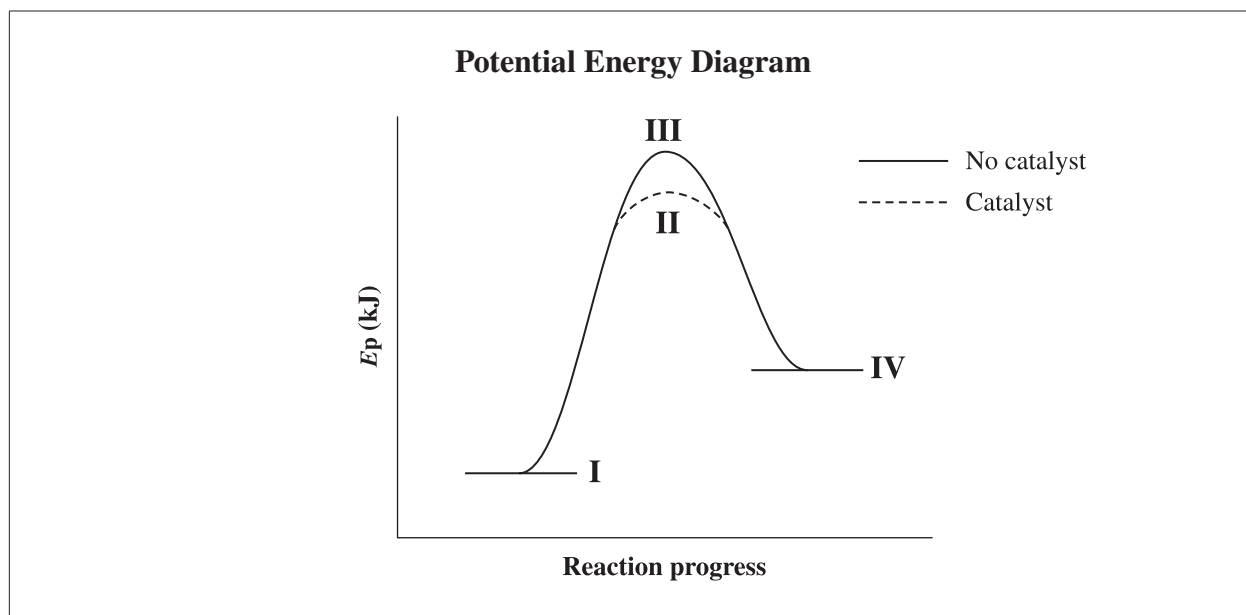
12. *The energy barrier that must be overcome for the forward catalyzed reaction to occur is called the ____i____ , and in the diagram above it is the difference between ____ii____ .*

The statement above is completed by the information in row
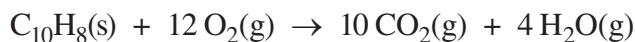
Row	i	ii
A.	enthalpy change	I and II
B.	enthalpy change	I and III
C.	activation energy	I and II
D.	activation energy	I and III

Answer: C
Outcome: A2.1k, A2.3k, A2.3s

Naphthalene, $C_{10}H_8(s)$, is commonly found in coal tar but has also been isolated from meteorites. Its combustion can be represented by the following equation.

$$C_{10}H_8(s) + 12\,O_2(g) \rightarrow 10\,CO_2(g) + 4\,H_2O(g)$$

When a 0.820 g sample of naphthalene was burned in a calorimeter containing 250 mL of water, a temperature change of 12.5 °C was observed.

13. *The chemical energy stored in naphthalene originally came from ____i____ , and during the combustion of naphthalene the chemical potential energy will ____ii____ .*

The statement above is completed by the information in row

Row	*i*	*ii*
A.	the Sun	decrease
B.	the Sun	increase
C.	a hydrocarbon	decrease
D.	a hydrocarbon	increase

Answer: A
Outcome: A1.2k, A2.2k, A1.1sts

Numerical Response

5. The experimental value for the molar enthalpy of combustion of naphthalene, $C_{10}H_8(s)$, expressed in scientific notation, is $+/-a.bc \times 10^d$ kJ/mol. The values of *a*, *b*, *c*, and *d* are _____, _____, _____, and _____.
$\quad\quad\quad\quad\quad a\quad\quad b\quad\quad c\quad\quad\quad\quad d$

(Record all **four digits** of your answer in the numerical-response section on the answer sheet.)

Answer: 2053
Outcome: A1.8k, A1.2s, A1.4s, A1.1sts

Use the following information to answer question 14.
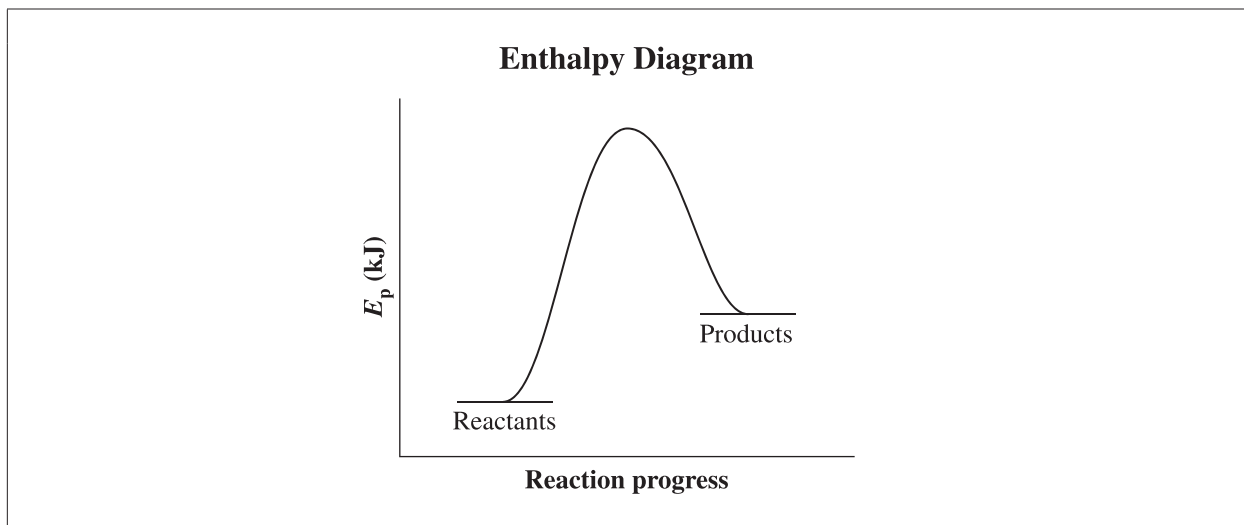
Enthalpy Diagram

14. *In the reaction represented by the enthalpy diagram above, the products are produced from the reactants as the result of chemical bonds ____**i**____ , and compared to the reactants, the potential energy of the products is ____**ii**____ .*

The statement above is completed by the information in row

Row	*i*	*ii*
A.	breaking and forming	less
B.	breaking and forming	greater
C.	breaking	less
D.	breaking	greater

Answer: B
Outcome: A2.2k, A2.3k, A2.3s

$$MgO(s) + CO_2(g) \rightarrow MgCO_3(s)$$
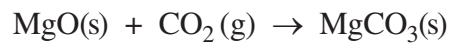
15. When a catalyst is added to the reaction above, the

    A.   enthalpy change for the reaction increases

    B.   enthalpy change for the reaction decreases

    C.   catalyst provides an alternative pathway at a higher energy

    D.   catalyst provides an alternative pathway at a lower energy

Answer: D
Outcome: A2.4k

Unit B—Electrochemical Changes

Use the following information to answer question 1.

Four Statements

    I   Sulfur forms stable ions by gaining electrons.

    II   Magnesium forms stable ions by losing electrons.

    III   The oxidation number of iron changes from +3 to +2.

   **IV**   The oxidation number of oxygen changes from -2 to -1.

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1. The statements numbered above that refer to oxidation are

    A.   I and III

    B.   I and IV

    C.   II and III

    D.   II and IV

Answer: D
Outcome: B1.1k, B1.2k

Leaching technology is used in the mining and refining of copper ore. In the first step of the leaching process, concentrated aqueous sulfuric acid, $H_2SO_4(aq)$, flows through a copper ore deposit. Solid copper(II) oxide, $CuO(s)$, reacts with sulfuric acid as represented by the following net ionic equation.

$$CuO(s) + 2H^+(aq) \rightarrow Cu^{2+}(aq) + H_2O(l)$$
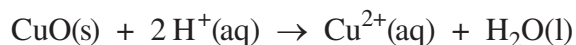
The resulting solution that contains copper(II) ions is transferred to an electrolytic cell where pure copper is produced.

2. In the reaction represented by the equation above, copper undergoes

   A. reduction only

   B. oxidation only

   C. both oxidation and reduction

   D. neither oxidation nor reduction

Answer: D
Outcome: B1.1k, B1.1sts

$$2H_2S(g) + 3O_2(g) \rightarrow 2SO_2(g) + 2H_2O(g)$$
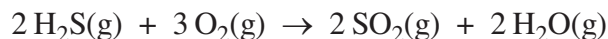
3. Which of the following rows identifies the process $O_2(g)$ undergoes and describes the change in oxidation number for sulfur?

Row	Process $O_2(g)$ Undergoes	Change in Oxidation Number for Sulfur
A.	Oxidation	Increases by two
B.	Oxidation	Increases by six
C.	Reduction	Increases by two
D.	Reduction	Increases by six

Answer: D
Outcome: B1.1k, B1.2k

4. Which of the following equations represents a disproportionation reaction?

A. $2\,Na(s) + I_2(s) \rightarrow 2\,NaI(s)$

B. $2\,F_2(g) + O_2(g) \rightarrow 2\,OF_2(g)$

C. $Cl_2(aq) + H_2O(l) \rightarrow HOCl(aq) + H^+(aq) + Cl^-(aq)$

D. $2\,NH_3(aq) + NaOCl(aq) \rightarrow N_2H_4(aq) + NaCl(aq) + H_2O(l)$

Answer: C
Outcome: B1.2k

Use the following information to answer question 5.

Three Equations

I $\quad NaCl(aq) + 3\,H_2O(l) \rightarrow NaClO_3(aq) + 3\,H_2(g)$

II $\quad\quad 3\,NaOCl(aq) \rightarrow NaClO_3(aq) + 2\,NaCl(aq)$

III $\quad NaClO_3(aq) + KCl(aq) \rightarrow KClO_3(aq) + NaCl(aq)$

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5. *The equations above that represent a redox reaction are equations* ___*i*___ *, and the equation that represents a disproportionation reaction is Equation* ___*ii*___ *.*

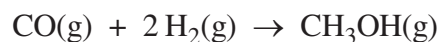The statement above is completed by the information in row

Row	*i*	*ii*
A.	I and II	II
B.	I and II	III
C.	II and III	II
D.	II and III	III

Answer: A
Outcome: B1.2k, B1.3k

Methanol gas, $CH_3OH(g)$, can be manufactured industrially by the catalytic hydrogenation of carbon monoxide, $CO(g)$, as represented by the following equation.

$$CO(g) + 2\,H_2(g) \rightarrow CH_3OH(g)$$

6. Which of the following rows identifies the process carbon undergoes and the type of agent $H_2(g)$ is acting as?

| Row	Process Carbon Undergoes	Type of Agent $H_2(g)$ is Acting As
A.	Oxidation	Reducing agent
B.	Oxidation	Oxidizing agent
C.	Reduction	Reducing agent
D.	Reduction	Oxidizing agent

Answer: C
Outcome: B1.2k, B1.1sts

7. During the catalytic hydrogenation of carbon monoxide, the total number of electrons transferred is

A.　2

B.　4

C.　6

D.　8

Answer: B
Outcome: B1.4k, B1.7k, B1.1sts

Cellular Respiration

$$C_6H_{12}O_6(s) + 6\,O_2(g) \rightarrow 6\,CO_2(g) + 6\,H_2O(l)$$
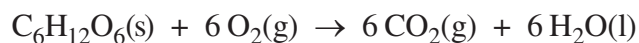
8. During cellular respiration, the oxidizing agent is

    A. $O_2(g)$

    B. $CO_2(g)$

    C. $H_2O(l)$

    D. $C_6H_{12}O_6(s)$

Answer: A
Outcome: B1.2k, B1.4k

Metallurgical Processes

    I $2\,Al_2O_3(s) \rightarrow 4\,Al(s) + 3\,O_2(g)$

    II $2\,PbO(s) + C(s) \rightarrow 2\,Pb(s) + CO_2(g)$

    III $Zn(s) + 2\,HCl(aq) \rightarrow ZnCl_2(aq) + H_2(g)$

    IV $Cu(s) + 4\,HNO_3(aq) \rightarrow Cu(NO_3)_2(aq) + 2\,NO_2(g) + 2\,H_2O(l)$

9. The metallurgical processes in which the metal loses electrons are

    A. I and II

    B. I and III

    C. II and IV

    D. III and IV

Answer: D
Outcome : B1.2k, B1.4k

Spontaneity of Reactions for Various Chemical Species

	$Be^{2+}(aq)$	$Cd^{2+}(aq)$	$Ra^{2+}(aq)$	$V^{2+}(aq)$
Be(s)	✗	✓	✗	✓
Cd(s)	✗	✗	✗	✗
Ra(s)	✓	✓	✗	✓
V(s)	✗	✓	✗	✗

✓ evidence of a spontaneous reaction
✗ no evidence of reaction

10. When listed in order from strongest to weakest, the oxidizing agents are
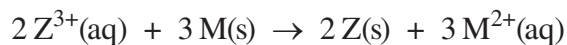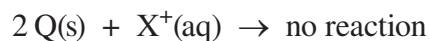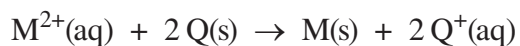
   A. Ra(s), Be(s), V(s), Cd(s)

   B. Cd(s), V(s), Be(s), Ra(s)

   C. $Ra^{2+}(aq)$, $Be^{2+}(aq)$, $V^{2+}(aq)$, $Cd^{2+}(aq)$

   D. $Cd^{2+}(aq)$, $V^{2+}(aq)$, $Be^{2+}(aq)$, $Ra^{2+}(aq)$

Answer: D
Outcome: B1.5k, B1.3s

During an investigation, a student mixed various chemicals and observed all evidence of reaction. The observations can be represented by the following equations.

$$M^{2+}(aq) + 2\,Q(s) \rightarrow M(s) + 2\,Q^+(aq)$$

$$2\,Q(s) + X^+(aq) \rightarrow \text{no reaction}$$

$$2\,Z^{3+}(aq) + 3\,M(s) \rightarrow 2\,Z(s) + 3\,M^{2+}(aq)$$

Reaction Types

1   Spontaneous

2   Nonspontaneous

Numerical Response

1. For each of the following, match the number describing the reaction type to the set of reactants.

$Z(s) + Q^+(aq)$ —————   (Record in the **first** column)

$M(s) + X(s)$ —————   (Record in the **second** column)

$Z^{3+}(aq) + X(s)$ —————   (Record in the **third** column)
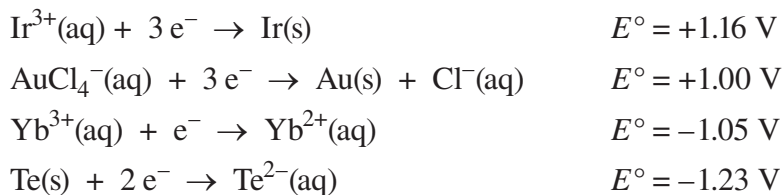
$M(s) + X^+(aq)$ —————   (Record in the **fourth** column)

(Record your answer in the numerical-response section on the answer sheet.)

Answer: 2212
Outcome: B1.5k, B1.6k, B1.3s

A student collected the data below.

$$Ir^{3+}(aq) + 3\,e^- \rightarrow Ir(s) \qquad\qquad E° = +1.16 \text{ V}$$
$$AuCl_4^-(aq) + 3\,e^- \rightarrow Au(s) + Cl^-(aq) \qquad\qquad E° = +1.00 \text{ V}$$
$$Yb^{3+}(aq) + e^- \rightarrow Yb^{2+}(aq) \qquad\qquad E° = -1.05 \text{ V}$$
$$Te(s) + 2\,e^- \rightarrow Te^{2-}(aq) \qquad\qquad E° = -1.23 \text{ V}$$

11. From the student's data, the strongest reducing agent is

A. $Ir^{3+}(aq)$

B. $Te^{2-}(aq)$

C. $Te(aq)$

D. $Ir(s)$

Answer: B
Outcome: B1.6k

---

12. Which of the following equations represents a spontaneous redox reaction?

A. $Zn^{2+}(aq) + Pb(s) \rightarrow Zn(s) + Pb^{2+}(aq)$

B. $Sn^{4+}(aq) + Fe(s) \rightarrow Sn^{2+}(aq) + Fe^{2+}(aq)$

C. $Zn^{2+}(aq) + Co(s) \rightarrow Zn(s) + Co^{2+}(aq)$

D. $O_2(g) + 2\,H_2O(l) + 4\,Br^-(aq) \rightarrow 2\,Br_2(l) + 4\,OH^-(aq)$

Answer: B
Outcome: B1.6k, B1.2s

13. The reducing agent that can convert 1.0 mol/L $Sn^{4+}(aq)$ ions to $Sn^{2+}(aq)$ but **not** 1.0 mol/L $Sn^{2+}(aq)$ to Sn(s) is

A. Cu(s)

B. Pb(s)

C. Ni(s)

D. Cr(s)

Answer: B
Outcome: B1.6k, B1.2s

The anammox process, carried out by certain bacteria, converts nitrite, $NO_2^-(aq)$, and ammonium ions, $NH_4^+(aq)$, directly to nitrogen, $N_2(g)$. The relevant half-reaction equations and reduction potentials are given below.

$$2\,NH_4^+(aq) \rightarrow N_2(g) + 8\,H^+(aq) + 6\,e^- \qquad E° = +0.28\text{ V}$$

$$2\,NO_2^-(aq) + 8\,H^+(aq) + 6\,e^- \rightarrow N_2(g) + 4\,H_2O(l) \qquad E° = +1.52\text{ V}$$
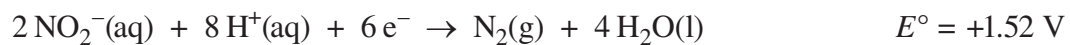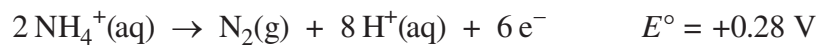
This process is used to treat municipal wastewater to remove nitrogenous waste.

14. An ion capable of reacting spontaneously with acidified $NO_2^-(aq)$ is

 A. $Zn^{2+}(aq)$
 B. $Pb^{2+}(aq)$
 C. $Ni^{2+}(aq)$
 D. $Cr^{2+}(aq)$

Answer: D
Outcome: B1.6k, B1.2s

$$\_\_OCl^-(aq) + \_\_I^-(aq) + \_\_H^+(aq) \rightarrow \_\_I_2(aq) + \_\_Cl^-(aq) + \_\_H_2O(l)$$
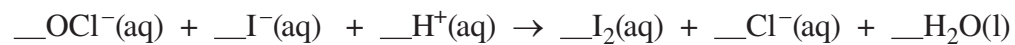
15. *When the equation above is balanced under acidic conditions, the lowest whole number coefficient for $H^+(aq)$ is* ____*i*____ *and the amount of electrons transferred is* ____*ii*____ *.*

The statement above is completed by the information in row

Row	*i*	*ii*
A.	1	1 mol
B.	1	2 mol
C.	2	1 mol
D.	2	2 mol

Answer: D
Outcome: B1.7k

Use the following information to answer numerical-response question 2 and question 16.

Two species that are important to biological cells are $NAD^+(aq)$, a biological oxidizing agent, and $NADH(aq)$, a biological reducing agent. Two half-reactions that occur are represented by the equations below.

Equation I $\quad O_2(aq) + 4H^+(aq) + 4e^- \rightarrow 2H_2O(l)$

Equation II $\quad\quad\quad\quad\quad\quad NADH(aq) \rightarrow NAD^+(aq) + H^+(aq) + 2e^-$

Numerical Response

2. When the net ionic equation is balanced with the lowest possible whole numbers, the coefficient for

$O_2(aq)$ is _____ (Record in the **first** column)

$H^+(aq)$ is _____ (Record in the **second** column)

$NADH(aq)$ is _____ (Record in the **third** column)

$H_2O(l)$ is _____ (Record in the **fourth** column)

(Record your answer in the numerical-response section on the answer sheet.)

Answer: 1222
Outcome: B1.7k, B1.3s

Use the following additional information to answer question 16.

Other important chemical species are also found in biological cells. A student collected the following data when studying the reactions of several of these species.

	Cu^{2+} cytochrome	Fe^{3+} ferredoxin	$NAD^+(aq) + H^+(aq)$	$O_2(g) + H^+(aq)$
Cu^+ cytochrome	—	✓	✗	✓
Fe^{2+} ferredoxin	✗	—	✗	✓
NADH(aq)	✓	✓	—	✓
$H_2O(l)$	✗	✗	✗	—

✓ = evidence of a spontaneous reaction
✗ = no evidence of a reaction
— = no experiment performed

16. When the reducing agents are listed from **strongest** to **weakest**, the order is

   A. $NAD^+(aq) + H^+(aq)$, Cu^{2+} cytochrome, Fe^{3+} ferredoxin, $O_2(g) + H^+(aq)$

   B. $O_2(g) + H^+(aq)$, Fe^{3+} ferredoxin, Cu^{2+} cytochrome, $NAD^+(aq) + H^+(aq)$

   C. $H_2O(l)$, Fe^{2+} ferredoxin, Cu^+ cytochrome, NADH(aq)

   D.   NADH(aq), Cu^+ cytochrome, Fe^{2+} ferredoxin, $H_2O(l)$

Answer: D
Outcome: B1.5k, B1.3s

High levels of nitrite ions, $NO_2^-(aq)$, in drinking water are a health concern. The concentration of nitrite ions can be determined by titrating acidified samples of drinking water with potassium permanganate, as represented by the following equation.

$$2\,MnO_4^-(aq) + 5\,NO_2^-(aq) + 6\,H^+(aq) \rightarrow 2\,Mn^{2+}(aq) + 5\,NO_3^-(aq) + 3\,H_2O(l)$$
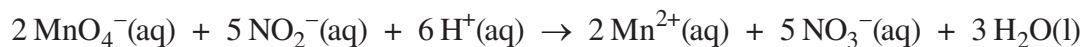
An average of 21.6 mL of 0.0300 mol/L $KMnO_4(aq)$ was required to react completely with the $NO_2^-(aq)$ in 25.0 mL samples of drinking water.

17. *When the incomplete half-reaction $NO_2^-(aq) \rightarrow NO_3^-(aq)$ is balanced in acidic conditions, $H_2O(l)$ will appear in the equation as a _____i_____ , and the equation will represent _____ii_____ half-reaction.*

    The statement above is completed by the information in row

Row	*i*	*ii*
A.	product	a reduction
B.	product	an oxidation
C.	reactant	a reduction
D.	reactant	an oxidation

    Answer: D
    Outcome: B1.1k, B1.7k, B1.1sts

18. The experimental concentration of $NO_2^-(aq)$ in the drinking water was

    A. 1.04×10^{-2} mol/L

    B. 2.59×10^{-2} mol/L

    C. 3.47×10^{-2} mol/L

    D. 6.48×10^{-2} mol/L

    Answer: D
    Outcome: B1.8k, B1.4s, B1.1sts

Use the following information to answer question 19.

A standardized 0.125 mol/L potassium dichromate solution, $K_2Cr_2O_7$ (aq), was used to titrate 20.0 mL samples of acidified Sn^{2+}(aq). The data is represented in the following table.

Titration Data

Trial	I	II	III
Final burette volume (mL)	15.35	27.65	39.85
Initial burette volume (mL)	3.25	15.35	27.65

19. The concentration of Sn^{2+}(aq) in the sample is

   A. 0.0254 mol/L

   B. 0.0763 mol/L

   C. 0.229 mol/L

   D. 0.615 mol/L

Amswer: C
Outcome: B1.8k, B1.4s

The Statue of Liberty is located on an island in New York Harbour which is surrounded by the Atlantic Ocean. The statue, which has a skin made of copper that is supported by iron ribs, has undergone many attempts to repair the damage caused by the corrosion of the iron ribs. Recently, the iron ribs have been replaced with stainless steel alloys, which resist corrosion.

20. *The corrosion of the Statue of Liberty occurred because the metal that was most readily oxidized was ____i____ , and the oxidation process caused this metal to act as ____ii____ .*

The statement above is completed by the information in row

Row	*i*	*ii*
A.	iron	an anode
B.	iron	a cathode
C.	copper	an anode
D.	copper	a cathode

Answer: A
Outcome: B1.6k, B1.1sts

Use the following information to answer question 21.

Electrochemical Cell

- Cu(s)
- C(s)
- 1.0 mol/L $Ag^+(aq)$, $NO_3^-(aq)$
- Porous cup
- 1.0 mol/L $Cu^{2+}(aq)$, $NO_3^-(aq)$
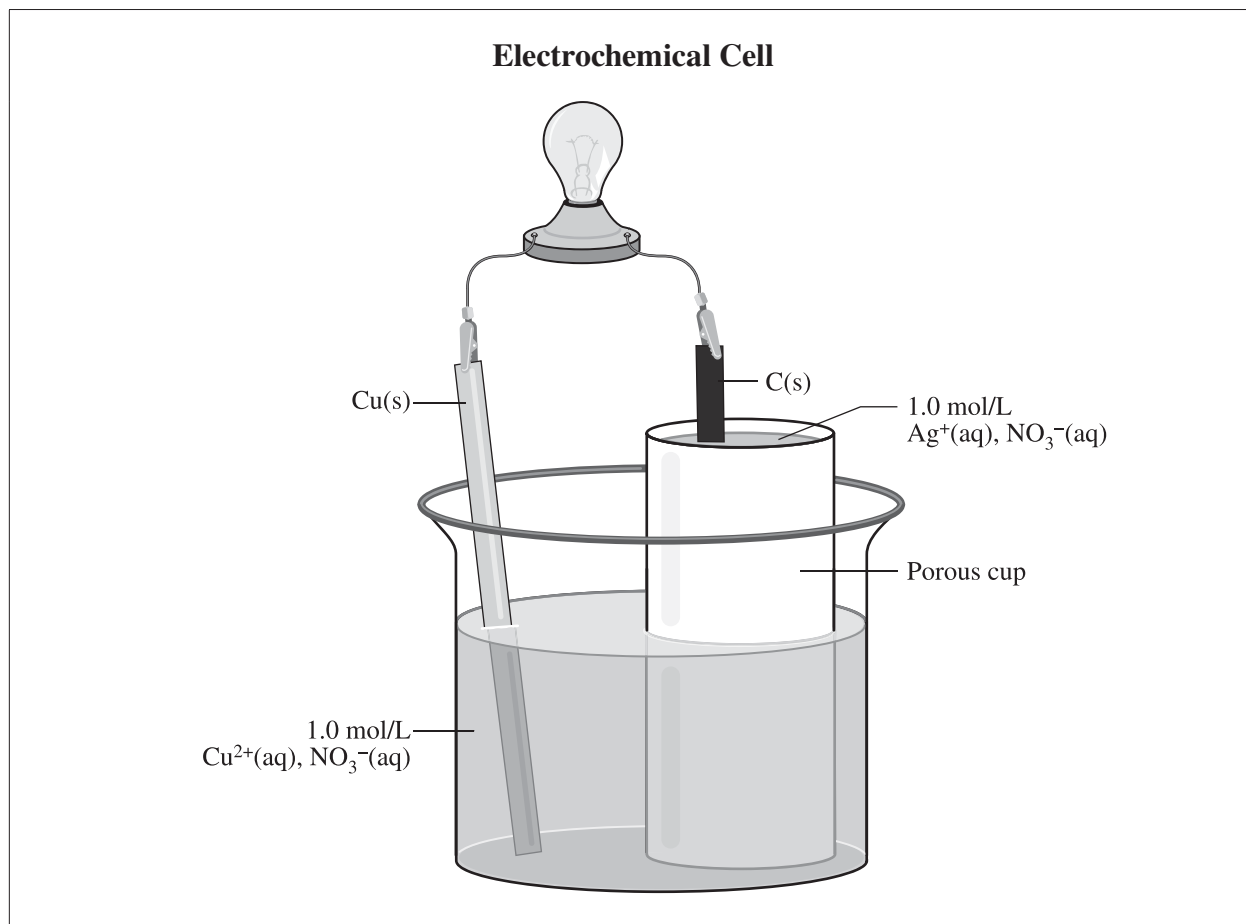
21. Which of the following rows identifies the direction the electrons would flow and the direction the anions would flow?

Row	Direction Electrons Would Flow	Direction Anions Would Flow
A.	From the C(s) electrode to the Cu(s) electrode	Toward the Cu(s) electrode
B.	From the C(s) electrode to the Cu(s) electrode	Away from the Cu(s) electrode
C.	From the Cu(s) electrode to the C(s) electrode	Toward the Cu(s) electrode
D.	From the Cu(s) electrode to the C(s) electrode	Away from the Cu(s) electrode

Answer: C
Outcome: B2.1k, B2.2s

Use the following information to answer question 22 and numerical-response question 3.

Pure aluminium metal can be extracted from aluminium oxide, Al_2O_3(l), through the process of electrolysis. A technician sets up an electrochemical cell to produce aluminium, Al(s). Two rods made of graphite, C(s), are used for the electrodes, and a current is applied to the cell. The reaction that occurs in the cell is represented by the equation below.

$$3\,C(s)\ +\ 2\,Al_2O_3(l)\ \rightarrow\ 4\,Al(s)\ +\ 3\,CO_2(g)$$
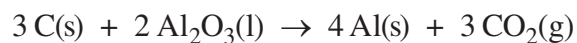
22. Which of the following rows identifies the type of reaction that occurs in the cell and the sign of the cell potential of the cell constructed by the technician?

Row	Type of Reaction	Sign of the Cell Potential
A.	Spontaneous	Positive
B.	Spontaneous	Negative
C.	Nonspontaneous	Positive
D.	Nonspontaneous	Negative

Answer: D
Outcome: B2.2k, B2.6k, B2.2sts

Eight Statements Regarding the Anode

1   It is a graphite rod.

2   It is a strip of aluminium.

3   Electrons move toward it.

4   Electrons move away from it.

5   Anions migrate toward it.

6   Cations migrate toward it.

7   It is the site where Al(s) is produced.

8   It is the site where $CO_2(g)$ is produced.

Numerical Response

3. The statements above that describe the anode in the cell constructed by the technician are numbered _____, _____, _____, and _____.

(Record all **four digits** of your answer **in any order** in the numerical-response section on the answer sheet.)

Answer: 1458, any order
Outcome: B2.1k, B2.3k, B2.3s, B2.2sts

Use the following information to answer numerical-response question 4.

Seven Statements About Electrochemical Cells

1   Oxidation occurs at the anode.

2   The oxidizing agent reacts at the cathode.

3   Cations move through the wire to the cathode.

4   Cations move through the electrolyte to the cathode.

5   Electrons move through the wire to the cathode.

6   Electrical energy is converted to chemical energy.

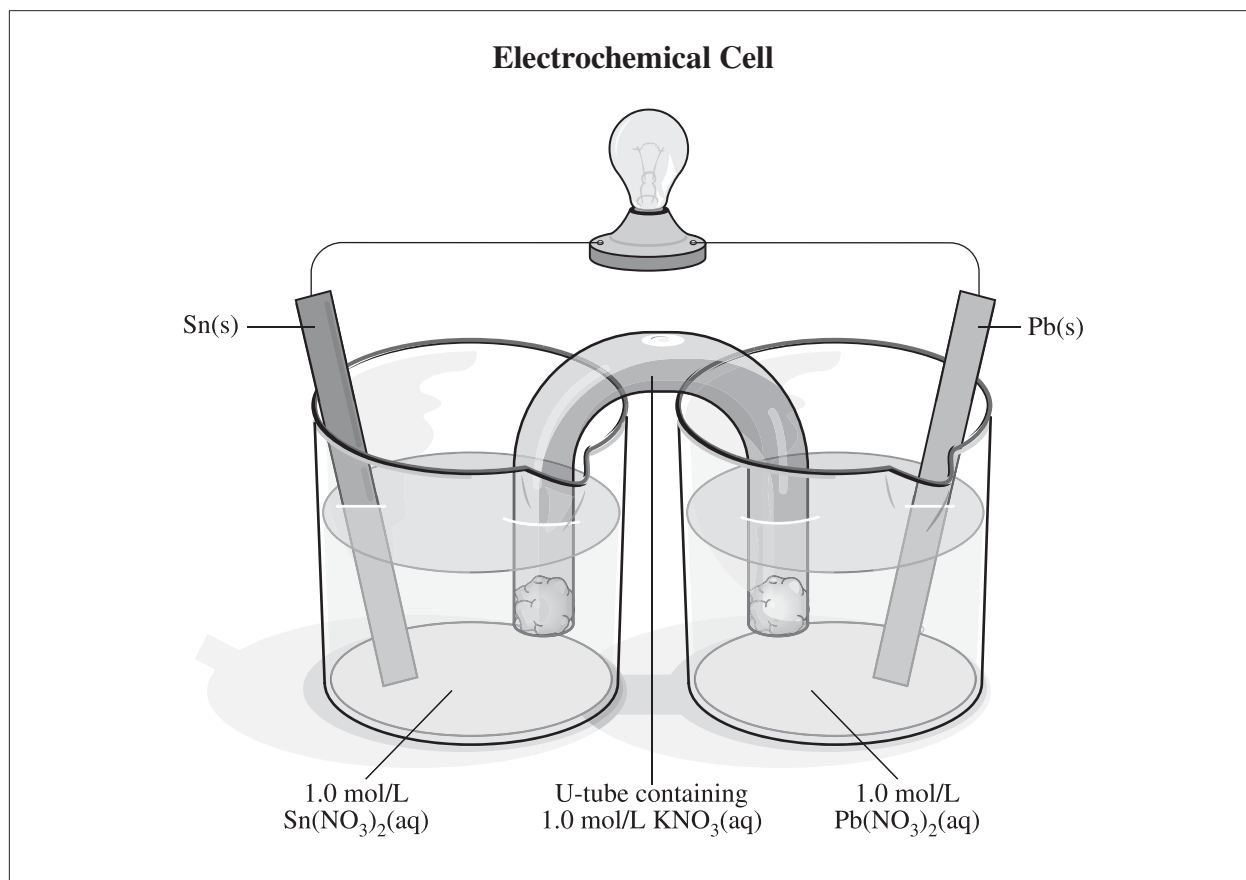7   Chemical energy is converted to electrical energy.

Numerical Response

4. The statements numbered above that apply to both electrolytic cells and voltaic cells are
_____, _____, _____, and _____.

(Record all **four digits** of your answer **in any order** in the numerical-response section on the answer sheet.)

Answer: 1245, any order
Outcome: B2.2k

Electrochemical Cell

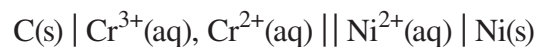| 1.0 mol/L $Sn(NO_3)_2(aq)$ | U-tube containing 1.0 mol/L $KNO_3(aq)$ | 1.0 mol/L $Pb(NO_3)_2(aq)$ |

23. The net ionic equation for the reaction that occurs in the electrochemical cell shown in the diagram above is

   A. $Sn(s) + 2\,Pb^{2+}(aq) \rightarrow Sn^{4+}(aq) + 2\,Pb(s)$

   B. $Sn(s) + Pb^{2+}(aq) \rightarrow Sn^{2+}(aq) + Pb(s)$

   C. $Sn^{4+}(aq) + 2\,Pb(s) \rightarrow Sn(s) + 2\,Pb^{2+}(aq)$

   D. $Sn^{2+}(aq) + Pb(s) \rightarrow Sn(s) + Pb^{2+}(aq)$

Answer: B
Outcome: B2.3k, B2.3s

Electrochemical Cell

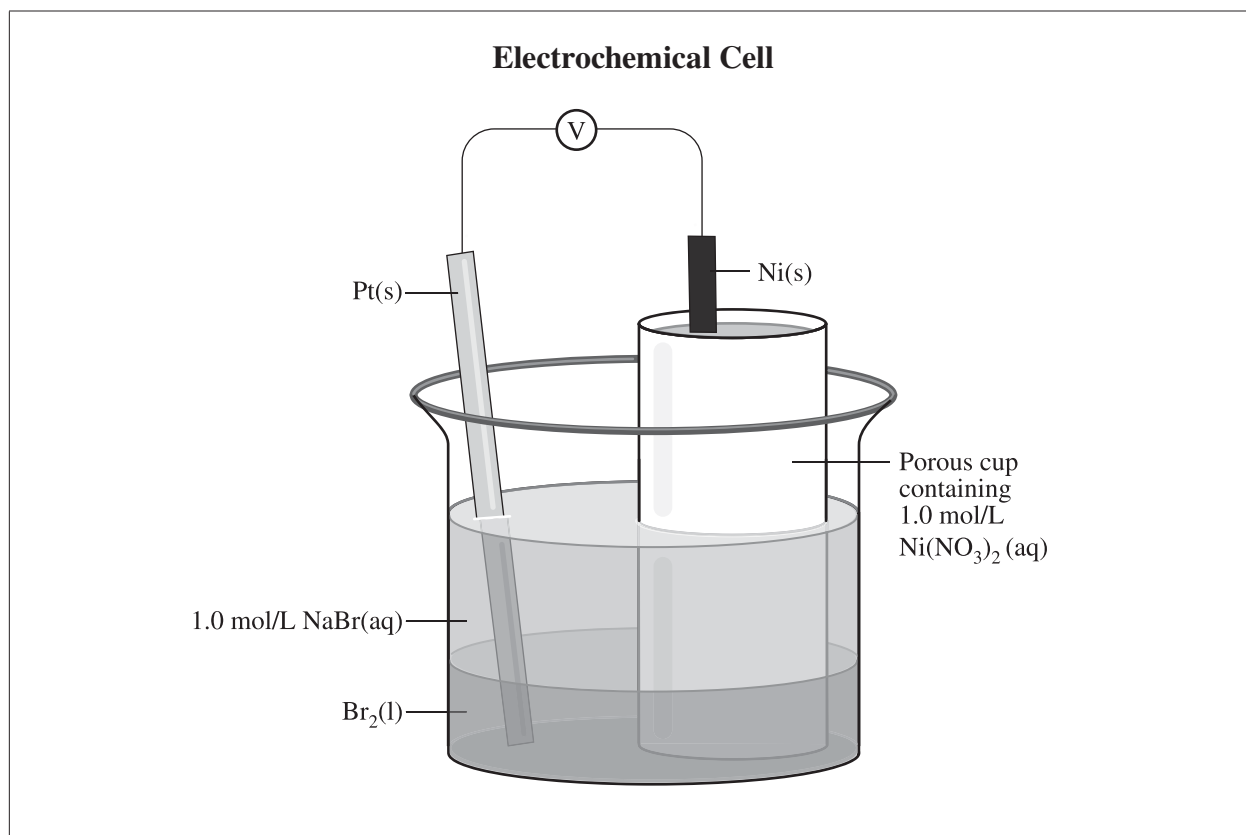$C(s) \mid Cr^{3+}(aq), Cr^{2+}(aq) \parallel Ni^{2+}(aq) \mid Ni(s)$

24. If the standard lead half-cell had been chosen as the reference half-cell instead of the standard hydrogen half-cell, then the cell potential for the electrochemical cell above would be

    A.   +0.15 V

    B.   +0.28 V

    C.   +0.65 V

    D.   +0.78 V

Answer: A
Outcome: B2.5k, B2.6k

Electrochemical Cell

**5.** The cell potential for the electrochemical cell in the diagram above is +/–_____ V.

(Record your **three-digit answer** in the numerical-response section on the answer sheet.)

Answer: 1.33
Outcome: B2.6k

A student designs an experiment that requires an electrochemical cell that uses a silver electrode and that produces an electrical potential of at least 1.20 V. The direction of electron flow is from metal electrode A to metal electrode B. The design is shown in the diagram below.

Salt bridge solution **D**

1.0 mol/L ionic solution **C**
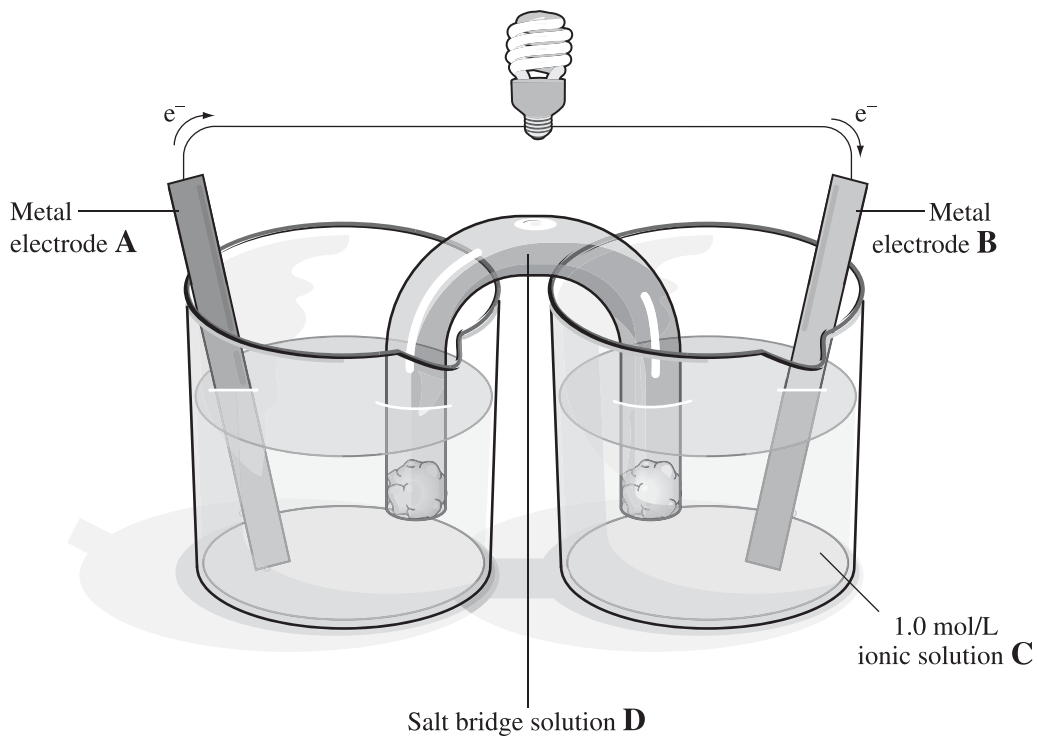
Available Materials

1	Silver metal, Ag(s)	**5**	Nickel(II) nitrate solution, $Ni(NO_3)_2(aq)$
2	Nickel metal, Ni(s)	**6**	Silver nitrate solution, $AgNO_3(aq)$
3	Zinc metal, Zn(s)	**7**	Zinc nitrate solution, $Zn(NO_3)_2(aq)$
4	Iron metal, Fe(s)	**8**	Iron(II) nitrate solution, $Fe(NO_3)_2(aq)$
		9	Sodium nitrate solution, $NaNO_3(aq)$

8. Using the numbers given, identify the best materials that the student should use to set up the electrochemical cell required in the experiment. (There is more than one correct answer.)

A suitable material for Electrode A is numbered _____. (Record in the **first** column)

A suitable material for Electrode B is numbered _____. (Record in the **second** column)

A suitable material for Solution C is numbered _____. (Record in the **third** column)

A suitable material for Solution D is numbered _____. (Record in the **fourth** column)

(Record your answer in the numerical-response section on the answer sheet.)

Answer: 3169, 4169, 4167
Outcome: B2.6k, B2.7k, B2.1s, B2.2s

Use the following information to answer question 25.

The reduction half-reaction for a Hall–Héroult electrolytic cell is represented by the following equation.

$$Al^{3+}(l) \ + \ 3\,e^- \ \rightarrow \ Al(l)$$
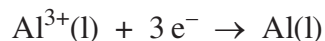
25. If a current of 10.0 A is applied for 5.00 h to the Hall–Héroult electrolytic cell, then the amount of electrons transferred is

A. 5.60 mol

B. 1.87 mol

C. 6.22×10^{-1} mol

D. 5.18×10^{-4} mol

Answer: B
Outcome: B2.8k, B2.4s

An electrolytic cell is used to produce molten aluminium from molten aluminium oxide, as represented by the simplified equation below.

$$2\,Al_2O_3(l) \rightarrow 4\,Al(l) + 3\,O_2(g)$$

26. If a current of 5.00×10^4 A were applied to the electrolytic cell for 5.00 h, then the predicted mass of aluminium produced would be

A. 9.33×10^3 g

B. 8.39×10^4 g

C. 2.52×10^5 g

D. 7.55×10^5 g

Answer: B
Outcome: B2.8k, B2.4s, B2.1sts

Unit C—Chemical Changes of Organic Compounds

Use the following information to answer numerical-response question 1.

Eight Chemical Compounds

1	$CO_2(g)$	**5**	$Co(OH)_2(s)$
2	$CH_3OH(l)$	**6**	$NaCN(s)$
3	$H_2CO_3(aq)$	**7**	$CH_3COOCH_3(aq)$
4	$ClCH_3(l)$	**8**	$HCOOH(l)$

Numerical Response

1. The chemical compounds numbered above that represent organic compounds
are _____, _____, _____, and _____.

(Record all **four digits** of your answer **in any order** in the numerical-response section on the answer sheet.)

Answer: 2478, any order
Outcome: C1.1k

Use the following information to answer numerical-response question 2.

Many gaseous compounds have been classified as air pollutants.

Eight Air Pollutants

1   $ICN(g)$

2   $CO(g)$

3   $CH_4(g)$

4   $CCl_2F_2(g)$

5   $NH_3(g)$

6   $CH_2O(g)$

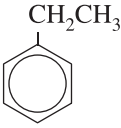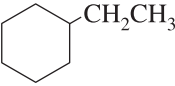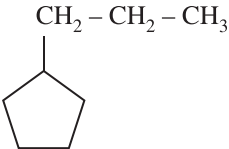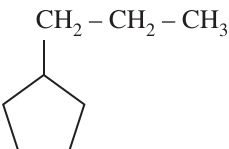7 $CO_2(g)$

8   $C_8H_{10}(g)$

Numerical Response

2. The air pollutants above that would be classified as organic compounds are numbered
_____, _____, _____, and _____.

(Record all **four digits** of your answer **in any order** in the numerical-response section on the answer sheet.)

Answer: 3468, any order
Outcome: C1.1k

1. Which of the following rows identifies the structural diagram and the corresponding IUPAC name of the compound with the chemical formula $C_8H_{16}(l)$?

Row	Structural Diagram	IUPAC Name
A.	CH_2CH_3 (attached to benzene ring)	ethylbenzene
B.	CH_2CH_3 (attached to cyclohexane ring)	ethylcyclohexane
C.	$CH_2 - CH_2 - CH_3$ (attached to cyclopentane ring)	cyclopentylpropane
D.	$CH_2 - CH_2 - CH_3$ (attached to cyclopentane ring)	propylcyclopentene

Answer: B
Outcome: C1.3k, C1.3s

Use the following information to answer question 2.

Condensed Structural Diagram

$$CH_3$$
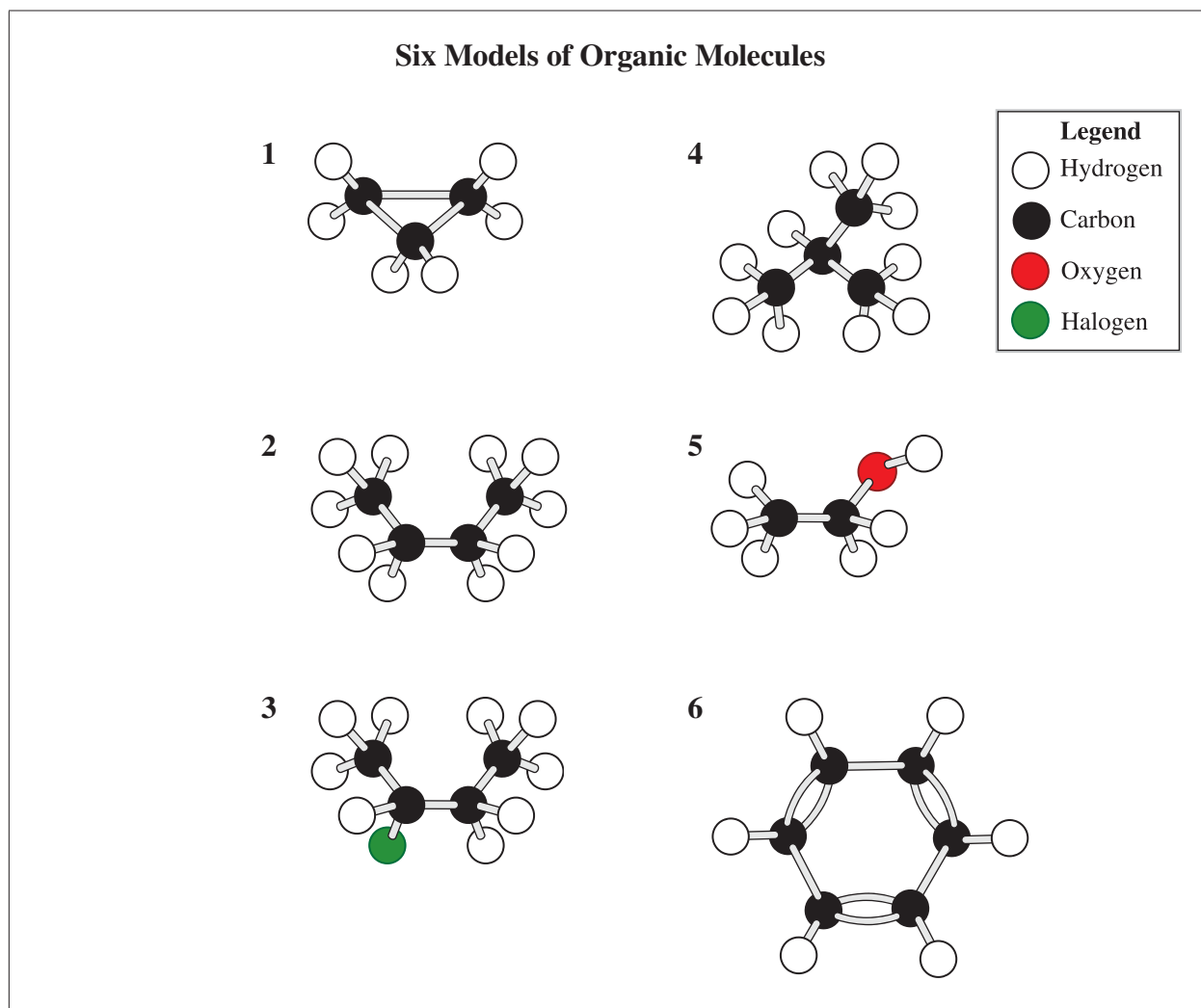$$CH - CH_2 - CH - CH - CH_3$$
$$CH_3 \qquad OH \quad OH$$
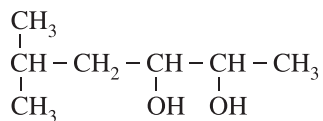
2. The IUPAC name for the organic molecule represented by the diagram above is

A. 2-methylhexane-4,5-diol

B. 5-methylhexane-2,3-diol

C. 1,1-dimethylpentane-3,4-diol

D. 5,5-dimethylpentane-2,3-diol

Answer: B
Outcome: C1.3k, C1.3s

Six Models of Organic Molecules

Numerical Response

3. Match the molecular models numbered above with the descriptions below.

Unbranched alkane _____ (Record in the **first** column)

Cyclic alkane _____ (Record in the **second** column)

Halogenated hydrocarbon _____ (Record in the **third** column)

Alcohol _____ (Record in the **fourth** column)

(Record your answer in the numerical-response section on the answer sheet.)

Answer: 2135
Outcome: C1.3k, C1.4k, C1.2s

Use the following information to answer question 3.

A student added a bromine solution, $Br_2(aq)$, to a hydrocarbon sample that contains an isomer of $C_6H_{12}(l)$. After shaking the sample, the student observed that the colour of the bromine solution changed from orange-brown to colourless.

3. *An interpretation that could be made from the student's observation is that the hydrocarbon sample is ____i____ and the IUPAC name of the sample could be ____ii____ .*

The statement above is completed by the information in row

Row	*i*	*ii*
A.	saturated	hex-2-ene
B.	saturated	cyclohexane
C.	unsaturated	hex-2-ene
D.	unsaturated	cyclohexane

Answer: C
Outcome: C1.3k, C1.5k, C1.3s

Sodium fluoroethanoate, $NaCH_2FCOO(aq)$, is a potent metabolic poison that can be used to kill rodents. The conjugate acid of the fluoroethanoate ion is fluoroethanoic acid, $CH_2FCOOH(aq)$.

Fluoroethanoic Acid
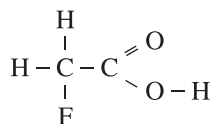
Structure

I   Methyl

II   Carboxyl

III Ester linkage

IV   Halogen
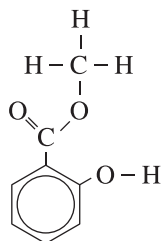
4. The structure(s) numbered above found in fluoroethanoic acid is/are

   A.   I and II

   B.   II only

   C.   II and IV

   D.   III and IV

Answer: C
Outcome: C1.4k, C1.1sts

The structural diagram of the active ingredient in many pain-relief medications is shown below.
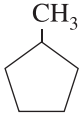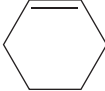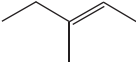

5. Which of the following rows identifies three classifications of the organic compound represented above?

Row	Classification One	Classification Two	Classification Three
A.	Aromatic	Carboxyl	Alkene
B.	Aromatic	Hydroxyl	Ester
C.	Aliphatic	Carboxyl	Alkene
D.	Aliphatic	Hydroxyl	Ester

Answer: B
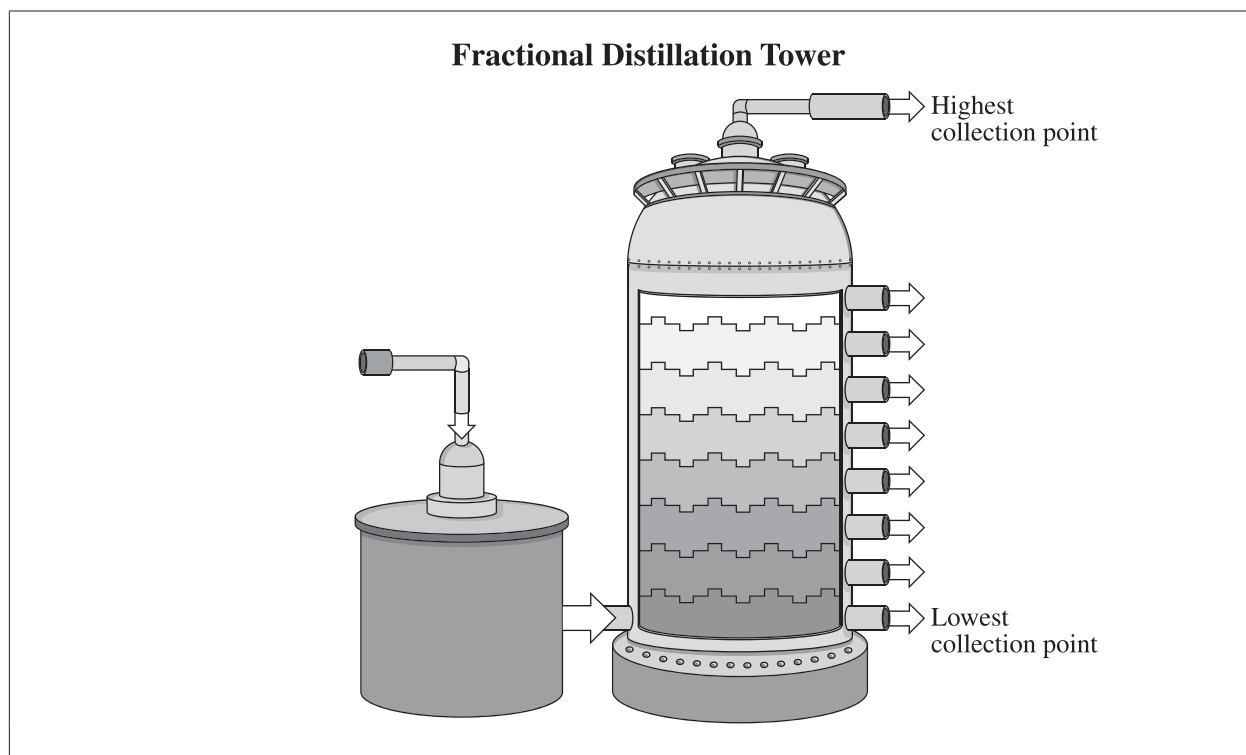Outcome: C1.3k, C1.4k, C1.1sts

6. Which of the following rows identifies a structural diagram and the IUPAC name of an isomer of C_6H_{12}?

Row	Condensed Structural Diagram or Line Diagram	IUPAC Name
A.	CH₃ cyclopentane ring with methyl	Methylcyclopentane
B.		Cyclohexene
C.		3-methylpent-3-ene
D.		Hex-3-yne

Answer: A
Outcome: C1.3k, C1.5k, C1.3s

Fractional Distillation Tower

Highest collection point

Lowest collection point

7. *When a mixture of dodecane, $C_{12}H_{26}(l)$, and hexadecane, $C_{16}H_{34}(l)$, is heated in the tower, the hydrocarbon that will condense at a lower collection point in the tower is* __*i*__ *because its boiling point is* __*ii*__ .

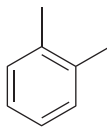The statement above is completed by the information in row

Row	*i*	*ii*
A.	hexadecane	lower
B.	hexadecane	higher
C.	dodecane	lower
D.	dodecane	higher

Answer: B
Outcome: C1.7k

o–Xylene can be used industrially to remove paraffin wax from pipes. The line diagram for o–xylene is given below.

8. *o–Xylene is classified as an ___i___ compound, and its solubility in water is expected to be ___ii___ .*

The statement above is completed by the information in row

Row	i	ii
A.	aliphatic	high
B.	aliphatic	low
C.	aromatic	high
D.	aromatic	low

Answer: D
Outcome: C1.3k, C1.6k, C1.2sts

Use the following information to answer numerical-response question 4.

Four Common Organic Equations

1 $C_2H_4(g) + H_2(g) \rightarrow C_2H_6(g)$

2 $C_2H_5OH(l) \rightarrow C_2H_4(g) + H_2O(l)$

3 $C_6H_6(l) + Br_2(l) \rightarrow C_6H_5Br(l) + HBr(g)$

4 $CH_3COOH(l) + CH_3OH(l) \rightarrow CH_3COOCH_3(l) + H_2O(l)$

Numerical Response

4. Match each equation numbered above with the corresponding reaction type below. (Use each number only once.)

Addition _____ (Record in the **first** column)

Substitution _____ (Record in the **second** column)

Elimination _____ (Record in the **third** column)

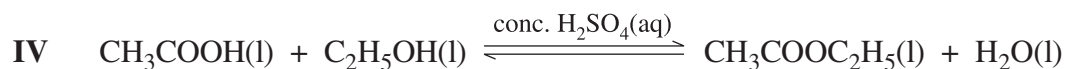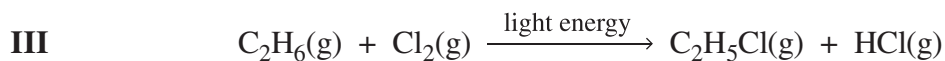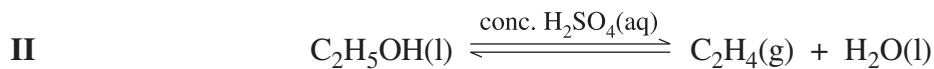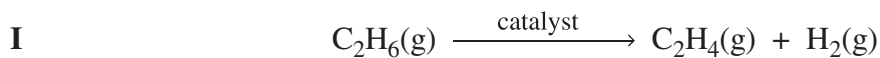Esterificaton _____ (Record in the **fourth** column)

(Record your answer in the numerical-response section on the answer sheet.)

Answer: 1324
Outcome: C2.1k

Use the following information to answer questions 9 and 10.

Four Equations

I $\qquad$ $C_2H_6(g) \xrightarrow{\text{catalyst}} C_2H_4(g) + H_2(g)$

II $\qquad$ $C_2H_5OH(l) \underset{}{\overset{\text{conc. } H_2SO_4(aq)}{\rightleftharpoons}} C_2H_4(g) + H_2O(l)$

III $\qquad$ $C_2H_6(g) + Cl_2(g) \xrightarrow{\text{light energy}} C_2H_5Cl(g) + HCl(g)$

IV $\quad$ $CH_3COOH(l) + C_2H_5OH(l) \underset{}{\overset{\text{conc. } H_2SO_4(aq)}{\rightleftharpoons}} CH_3COOC_2H_5(l) + H_2O(l)$

---

9. Which of the following rows identifies the equations that contain the organic reactant with the lowest boiling point and the organic product with the highest boiling point?

Row	Reactant with Lowest Boiling Point	Product with Highest Boiling Point
A.	I	II
B.	IV	III
C.	IV	I
D.	III	IV

Answer: D
Outcome: C1.6k

10. An elimination reaction is represented by Equation

A. I or II only

B. I, II, or IV

C. II only

D. III or IV

Answer: A
Outcome: C2.1k

Below are two methods for chemically producing ethanol.

Method I

Possible reactant + NaOH(aq) → H−C−C−O + NaI(aq)

(with structure showing H−C−C−O with H atoms and an H on the oxygen)
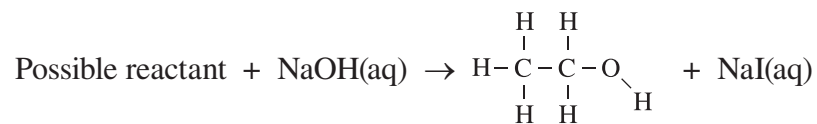
Method II

Possible reactant + HOH(l) → H−C−C−O

(with structure showing H−C−C−O with H atoms and an H on the oxygen)
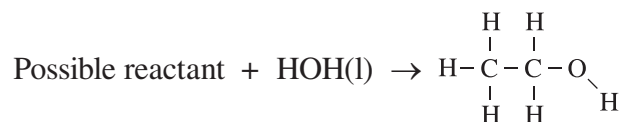
Possible Reactants	Possible Reaction Types
1 H−C−C−H (with H H above and H H below)	**5** Addition
2 C=C (with H H on left and H H on right)	**6** Substitution
3 H−C≡C−H	**7** Elimination
4 H−C−C−H (with H H above, H I below)	**8** Condensation

5. Match the numbers above with the descriptions below to identify the possible reactants and reaction types for Method I and Method II.

The reactant in Method I is numbered _____ (Record in the **first** column)

The reaction type of Method I is numbered _____ (Record in the **second** column)

The reactant in Method II is numbered _____ (Record in the **third** column)

The reaction type of Method II is numbered _____ (Record in the **fourth** column)

(Record your answer in the numerical-response section on the answer sheet.)

Answer: 4625
Outcome: C2.1k, C2.2k

_____

11. When methanol and ethanoic acid react, the product(s) is/are

A. ethyl methanoate only

B. methyl ethanoate only

C. ethyl methanoate and water

D. methyl ethanoate and water

Answer: D
Outcome: C2.2k, C2.1s

12. *The type of reaction that occurs when ethene gas and chlorine gas react is _____i_____, and the name of the organic compound produced is _____ii_____.*

The statement above is completed by the information in row
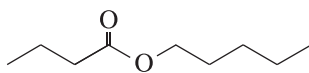
Row	i	ii
A.	addition	1,2-dichloroethane
B.	addition	1-chloroethene
C.	substitution	1,2-dichloroethane
D.	substitution	1-chloroethene

Answer: A
Outcome: C2.1k, C2.2k

Many esters are responsible for the odour and taste of fruits such as apricots, pears, and pineapples. The line diagram for one of these molecules is shown below.

13. A structural isomer of the ester represented above is

    A.   ethyl octanoate

    B.   methyl heptanoate

    C.   2-methyloctanoic acid

    D.   3-propylheptanoic acid

Answer: C
Outcome: C1.3k, C1.5k, C1.3s

14. Which of the following rows contains the structural diagrams of the reactants necessary to produce the ester represented above?
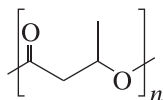
Row	Structural Diagrams	
A.		
B.		
C.		
D.		

Answer: A
Outcome: C2.2k, C2.3s

Certain bacteria manufacture an organic polymer to store energy. The structural diagram that represents a segment of this polymer is given below.

15. *The monomer that makes up this polymer contains a _____i_____ , and the structure of this polymer closely resembles the structure of the polymer found in _____ii_____ .*

The statement above is completed by the information in row

Row	i	ii
A.	carbon–carbon double bond	polyester
B.	carbon–carbon double bond	polypropene
C.	carboxyl and a hydroxyl functional group	polyester
D.	carboxyl and a hydroxyl functional group	polypropene

Answer: C
Outcome: C2.3k, C2.3s
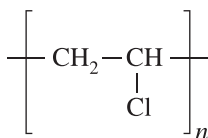
16. Which of the following monomers is required to produce the polymer in the structural diagram above?

A. $CH_2-Cl-CH_2-Cl$

B. CH_3-CH_2-Cl

C. $CH_2=CHCl$

D. $CH\equiv CCl$

Answer: C
Outcome: C2.3k, C2.3s

Unit D—Chemical Equilibrium Focusing on Acid–Base Systems

Use the following information to answer question 1.

$$N_2O_4(g) + heat \rightleftharpoons 2\,NO_2(g)$$
colourless   brown
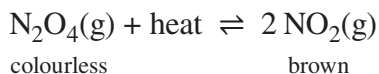
1. Which of the following properties would **not** be used to determine if the equilibrium system represented by the equation above is at equilibrium?

    A. Temperature

    B. Pressure

    C. Colour

    D. Mass

    Answer: D
    Outcome: D1.1k

---

2. When applied to an equilibrium system, which of the following stresses would cause a change in the K_c value after the equilibrium has been re-established?

    A. Addition of a catalyst

    B. Decrease in temperature by cooling the system

    C. Addition of an inert gas to increase the pressure

    D. Decrease in concentration by removing a product

    Answer: B
    Outcome: D1.3k

Use the following information to answer numerical-response question 1.

$$2\,NO_2(g) \rightleftharpoons N_2O_4(g) + heat$$

brown   colourless
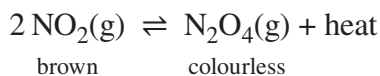
Stresses Applied to an Equilibrium System

1 Increase volume   **5** Increase $NO_2(g)$ concentration

2 Decrease volume   **6** Decrease $NO_2(g)$ concentration

3 Increase temperature   **7** Increase $N_2O_4(g)$ concentration

4 Decrease temperature   **8** Decrease $N_2O_4(g)$ concentration

Numerical Response

1. The stresses numbered above that will cause the equilibrium system to shift toward the reactants are _____, _____, _____, and _____.

(Record all **four digits** of your answer **in any order** in the numerical-response section on the answer sheet.)

Answer: 1367, any order
Outcome: D1.3k, D1.3s

$$HNO_2(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + NO_2^-(aq) \qquad K_a = 5.6 \times 10^{-4}$$
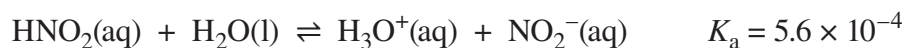
3. Which of the following rows identifies the equilibrium-law expression and compares the amount of products and reactants present at equilibrium?

Row	Equilibrium-law Expression	Equilibrium Comparison
A.	$K_a = \dfrac{[H_3O^+(aq)][NO_2^-(aq)]}{[HNO_2(aq)]}$	Amount of products is less than the amount of reactants
B.	$K_a = \dfrac{[H_3O^+(aq)][NO_2^-(aq)]}{[HNO_2(aq)]}$	Amount of products is greater than the amount of reactants
C.	$K_a = \dfrac{[H_3O^+(aq)][NO_2^-(aq)]}{[HNO_2(aq)][H_2O(l)]}$	Amount of products is less than the amount of reactants
D.	$K_a = \dfrac{[H_3O^+(aq)][NO_2^-(aq)]}{[HNO_2(aq)][H_2O(l)]}$	Amount of products is greater than the amount of reactants

Answer: A
Outcome: D1.4k, D1.3s

When samples of CO(g) and H$_2$O(g) are added to an empty reaction container, the system at equilibrium is represented by the following equilibrium equation.

$$CO(g) + H_2O(g) \rightleftharpoons CO_2(g) + H_2(g) \qquad K_c = 4.2$$
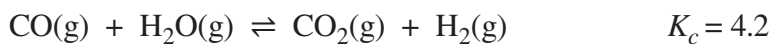
Statements About Equilibrium Systems

1 There are more moles of products present than moles of reactants.

2 There are more moles of reactants present than moles of products.

3 Less than 50% of the reactants will be converted to products.

4 More than 50% of the reactants will be converted to products.

5 The system could be represented by the following diagram.
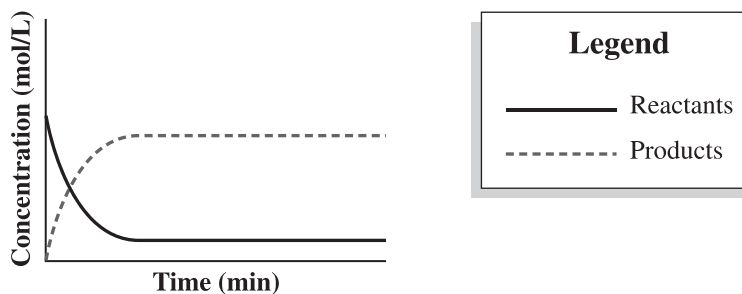
6 The system could be represented by the following diagram.
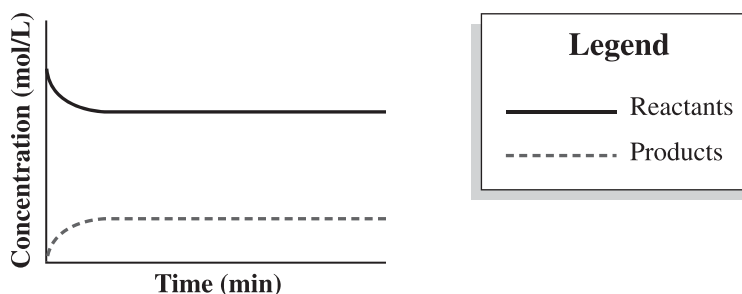
Numerical Response

2. The statements that apply to the equilibrium system above are numbered _____, _____, and _____.

(Record all **three digits** of your answer **in any order** in the numerical-response section on the answer sheet.)

Answer: 145, any order
Outcome: D1.1k, D1.4k, D1.3s

4. *With the addition of a catalyst to the equilibrium system on the previous page, the amount of products present would ____i____ . Another stress that would cause the same effect on the amount of products is an ____ii____ .*

The statements above are completed by the information in row

Row	*i*	*ii*
A.	increase	increase in the volume
B.	increase	addition of CO(g)
C.	not change	increase in the volume
D.	not change	addition of CO(g)

Answer: C
Outcome: D1.3k, D1.3s

Use the following information to answer question 5.

$$K_a = \frac{[NO_2(g)]^2}{[NO(g)]^2\,[O_2(g)]}$$

5. The equation that is represented by the equilibrium-law expression above is

A. $2\,NO_2(g) \rightleftharpoons 2\,NO(g) + O_2(g)$

B. $2\,NO(g) + O_2(g) \rightleftharpoons 2\,NO_2(g)$

C. $NO_2(g) \rightleftharpoons NO(g) + O_2(g)$

D. $NO(g) + O_2(g) \rightleftharpoons NO_2(g)$

Answer: B
Outcome: D1.4k, D1.3s

Some oil fractions are treated with hydrogen to remove impurities such as sulfur and nitrogen. The hydrogen needed for this treatment can be produced by the steam-reforming process, represented by the following **unbalanced** equilibrium equation.

$$\_\_CH_4(g) \ + \ \_\_H_2O(g) \ \rightleftharpoons \ \_\_H_2(g) \ + \ \_\_CO_2(g)$$
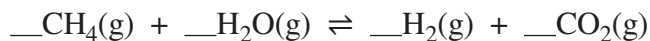
Equilibrium-law Expression

$$K_c = \frac{[W]^w[X]^x}{[Y]^y[Z]^z}$$

Numerical Response

3. When the reactants and products are entered into the equilibrium-law expression above, the values of the exponents *w*, *x*, *y,* and *z* are _____, _____, _____, and _____.
                               w   *x*   *y*   *z*

(Record all **four digits** of your answer in the numerical-response section on the answer sheet.)

Answer: 4112, 4121, 1412, 1421
Outcome: D1.4k, D1.3s

_____

6. Which of the following substances can act as a Brønsted–Lowry base?

   A. NaCl(aq)

   B. CH_3OH(aq)

   C. HCOOH(aq)

   D. $NaHCO_3$(aq)

Answer: D
Outcome: D1.5k

A Venn diagram is used to identify the similarities and differences between acids and bases.
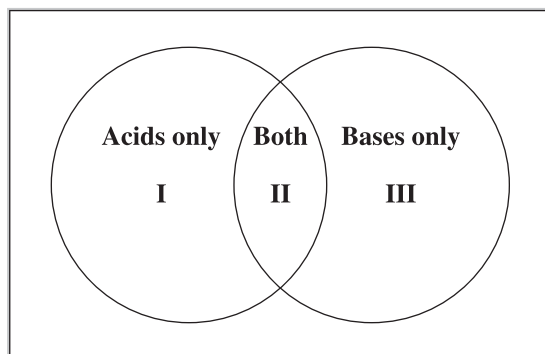
Characteristics and Examples of Acids and Bases

1	Water
2	Carbonic acid
3	Sodium carbonate
4	Sodium hydrogen carbonate
5	Can be diprotic
6	Can be monoprotic
7	Accepts protons
8	Donates protons

Numerical Response

4. The characteristics and examples that belong in Section II of the Venn diagram are numbered _____, _____, _____, and _____.

(Record all **four digits** of your answer **in any order** in the numerical-response section on the answer sheet.)

Answer: 1456, any order
Outcome: D1.5k, D1.6k, D1.3s

$$HCO_3^-(aq) + HSO_3^-(aq) \rightleftharpoons H_2CO_3(aq) + SO_3^{2-}(aq)$$
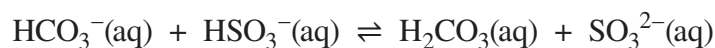
7. The Brønsted–Lowry acids in the reaction equation above are

A. $HCO_3^-(aq)$ and $HSO_3^-(aq)$

B. $HCO_3^-(aq)$ and $H_2CO_3(aq)$

C. $HSO_3^-(aq)$ and $H_2CO_3(aq)$

D. $HSO_3^-(aq)$ and $SO_3^{2-}(aq)$

Answer: C
Outcome: D1.5k

8. Which of the following equations represents an equilibrium system that favours the products?

A. $HOCl(aq) + HCO_3^-(aq) \rightleftharpoons OCl^-(aq) + H_2CO_3(aq)$

B. $H_2SO_3(aq) + Cl^-(aq) \rightleftharpoons HSO_3^-(aq) + HCl(aq)$

C. $HF(aq) + NO_2^-(aq) \rightleftharpoons F^-(aq) + HNO_2(aq)$

D. $H_2S(aq) + F^-(aq) \rightleftharpoons HS^-(aq) + HF(aq)$

Answer: C
Outcome: D1.6k

9. Which of the following rows identifies the equilibrium equation and solution colour that would occur when a few drops of phenol red indicator, $HPr(aq)/Pr^-(aq)$, are added to a 100.00 mL sample of 0.50 mol/L nitrous acid?

Row	Equilibrium Equation	Solution Colour
A.	$HNO_2(aq) + Pr^-(aq) \rightleftharpoons NO_2^-(aq) + HPr(aq)$	Yellow
B.	$HNO_2(aq) + Pr^-(aq) \rightleftharpoons NO_2^-(aq) + HPr(aq)$	Red
C.	$HNO_2(aq) + HPr(aq) \rightleftharpoons NO_2^-(aq) + H_2Pr^+(aq)$	Yellow
D.	$HNO_2(aq) + HPr(aq) \rightleftharpoons NO_2^-(aq) + H_2Pr^+(aq)$	Red

Answer: A
Outcome: D1.6

The following equilibrium system describes a buffer that maintains a constant pH in the intracellular fluid in the body.

$$H_2PO_4^-(aq) + H_2O(l) \rightleftharpoons HPO_4^{2-}(aq) + H_3O^+(aq)$$
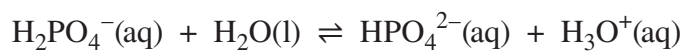
10. Which of the following ions would react with this buffer in a reaction that would favour the products?

    A. Carbonate ion, $CO_3^{2-}(aq)$

    B. Acetate ion, $CH_3COO^-(aq)$

    C. Oxalate ion, $OOCCOO^{2-}(aq)$

    D. Benzoate ion, $C_6H_5COO^-(aq)$

    Answer: A
    Outcome: D1.6k, D1.8k

11. Which of the following substances is an amphiprotic species?

    A. $CH_4(g)$

    B. $CH_3OH(aq)$

    C. $CH_3COO^-(aq)$

    D. $HOOCCOO^-(aq)$

    Answer: D
    Outcome: D1.7k

$$HNO_2(aq) + H_2BO_3^-(aq) \rightleftharpoons NO_2^-(aq) + H_3BO_3(aq)$$
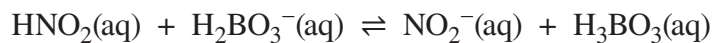
12. *In the reaction represented by the equation above, an amphiprotic species is* ___*i*___ ,
and a conjugate acid–base pair is ___*ii*___ .

The statement above is completed by the information in row

Row	*i*	*ii*
A.	$HNO_2(aq)$	$HNO_2(aq)$ and $NO_2^-(aq)$
B.	$HNO_2(aq)$	$H_2BO_3^-(aq)$ and $NO_2^-(aq)$
C.	$H_2BO_3^-(aq)$	$HNO_2(aq)$ and $NO_2^-(aq)$
D.	$H_2BO_3^-(aq)$	$H_2BO_3^-(aq)$ and $NO_2^-(aq)$

Answer: C
Outcome: D1.7k

Isocitric acid, $C_3H_5O(COOH)_3(aq)$, is found in low concentrations in citrus fruits. The equilibrium formed by isocitric acid in solution can be represented by the following equation.

$$C_3H_5O(COOH)_3(aq) + H_2O(l) \rightleftharpoons C_3H_5O(COOH)_2COO^-(aq) + H_3O^+(aq) \qquad K_a = 5.1 \times 10^{-4}$$

13. Which of the following rows identifies the number of conjugate acid–base pairs and the number of amphiprotic species in the equation above?

Row	Number of Conjugate Acid–base Pairs	Number of Amphiprotic Species
A.	1	2
B.	1	3
C.	2	2
D.	2	3

Answer: C
Outcome: D1.7k

14. *In order to prepare a suitable buffer with a solution of isocitric acid, a student could add ____i____ until the ____ii____ .*

The statement above is completed by the information in row

Row	i	ii
A.	$NaC_3H_5O(COOH)_2COO(aq)$	pH is equal to 7
B.	$NaC_3H_5O(COOH)_2COO(aq)$	amount of each component is equal
C.	$Na_2C_3H_5OCOOH(COO)_2(aq)$	pH is equal to 7
D.	$Na_2C_3H_5OCOOH(COO)_2(aq)$	amount of each component is equal

Answer: B
Outcome: D1.8k

15. Which of the following pairs of chemical compounds can act as a buffer system?

    A. $HCl(aq)$ and $NaOH(aq)$

    B. $HCl(aq)$ and $H_2SO_4(aq)$

    C. $CH_3COOH(aq)$ and $HCl(aq)$

    D. $CH_3COOH(aq)$ and $NaCH_3COO(aq)$

Answer: D
Outcome: D1.8k

Use the following information to answer question 16.

A 100.00 mL sample of a 0.100 mol/L solution of $H_2CO_3(aq)$ is combined with a 100.00 mL sample of a 0.100 mol/L solution of $NaHCO_3(aq)$ and the following equilibrium system is established.

$$H_2CO_3(aq) + H_2O(l) \rightleftharpoons HCO_3^-(aq) + H_3O^+(aq)$$
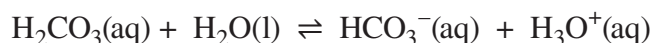
16. Which of the following rows identifies the direction of the shift in equilibrium and the effect on the pH of the system when a small quantity of hydrochloric acid is added to the equilibrium system above?

Row	Direction of Shift	Effect on pH
A.	Toward the products	No change
B.	Toward the products	Decrease
C.	Toward the reactants	No change
D.	Toward the reactants	Decrease

Answer: C
Outcome: D1.3k, D1.8k, D1.3s

Use the following information to answer numerical-response question 5.

A student was asked to investigate a factor that would affect the value of K_a for a weak acid. The student made the following hypothesis.

The value of K_a is dependent upon the initial concentration of the weak acid.

Nine Possible Reagents

1	0.10 mol/L HCl(aq)
2	0.10 mol/L HOCl(aq)
3	0.10 mol/L HClO$_4$(aq)
4	0.20 mol/L HCl(aq)
5	0.20 mol/L HOCl(aq)
6	0.20 mol/L HClO$_4$(aq)
7	0.30 mol/L HCl(aq)
8	0.30 mol/L HOCl(aq)
9	0.30 mol/L HClO$_4$(aq)

Numerical Response

5. The **best** reagents to use to test this hypothesis are numbered _____, _____, and _____.

(Record all **three digits** of your answer **in any order** in the numerical-response section on the answer sheet.)

Answer 258, any order
Outcome: A1.1s

A student titrated an unknown sample of an aqueous acid with aqueous sodium hydroxide. The student graphed the data as shown in the diagram below.

Graph of Titration Data
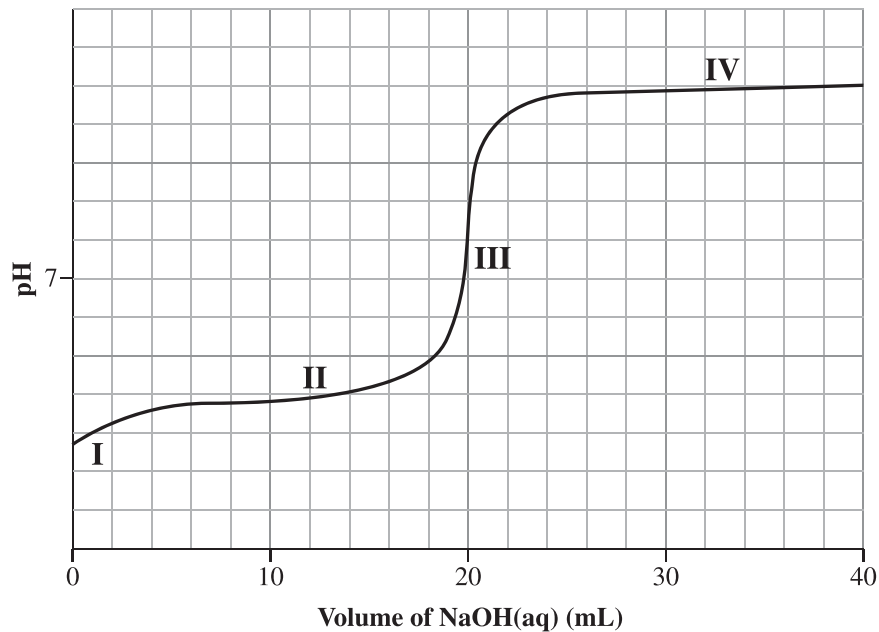
17. *The graph of the student's titration data shows the titration of a* ___***i***___ *acid with a strong base, and on the graph, buffering occurs at* ___***ii***___ .

The statement above is completed by the information in row

Row	*i*	*ii*
A.	strong	region II only
B.	strong	regions II and IV
C.	weak	region II only
D.	weak	regions II and IV

Answer: C
Outcome: D1.3s

18. If the pH of a solution changes from 2 to 4, then the hydronium ion concentration

    A. is doubled

    B. is halved

    C. increases by a factor of 100

    D. decreases by a factor of 100

Answer: D
Outcome: D2.1k

Numerical Response

6. The hydroxide ion concentration in a solution with a pH of 3.50, expressed in scientific notation, is $a.b \times 10^{-cd}$ mol/L. The values of $a, b, c,$ and d are

_____, _____, _____, and _____.
  a b c d

(Record all **four digits** of your answer in the numerical-response section on the answer sheet.)

Answer: 3211
Outcome: D2.1k

Numerical Response

7. The K_b for the ethanoate ion, $CH_3COO^-(aq)$, expressed in scientific notation, is $a.b \times 10^{-cd}$. The values of $a, b, c,$ and d are _____, _____, _____, and _____.
                a b c d

(Record all **four digits** of your answer in the numerical-response section on the answer sheet.)

Answer: 5610
Outcome: D2.2k

If hydrogen sulfide gas, $H_2S(g)$, is released into the atmosphere, it dissolves in atmospheric water to form aqueous hydrosulfuric acid, $H_2S(aq)$. The ionization of aqueous hydrosulfuric acid can be represented by the following equilibrium equation.

$$H_2S(aq) + H_2O(l) \rightleftharpoons HS^-(aq) + H_3O^+(aq)$$
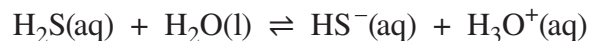
19. *If the concentration of a sample of aqueous hydrosulfuric acid is 0.050 mol/L, then the hydronium ion concentration, $H_3O^+(aq)$, is ____i____ and the pOH of the solution is ____ii____ .*

The statement above is completed by the information in row

Row	*i*	*ii*
A.	5.0×10^{-2} mol/L	1.30
B.	5.0×10^{-2} mol/L	9.82
C.	6.7×10^{-5} mol/L	1.30
D.	6.7×10^{-5} mol/L	9.82

Answer: D
Outcome: D2.1k, D2.2k, D2.3k

Hydrangea flowers are usually white, but can be pink, purple, or blue. The exact colour depends on the concentration of aluminium ions, $Al^{3+}(aq)$, accumulated by the plant. Aluminium occurs naturally in the soil as aluminium hydroxide, $Al(OH)_3(s)$, which dissociates in the water in the soil, as represented by the following equilibrium equation.

Aluminium Hydroxide Equilibrium System

$$Al(OH)_3(s) \rightleftharpoons Al^{3+}(aq) + 3\,OH^-(aq) + \text{energy} \qquad K_c = 4.6 \times 10^{-33}$$
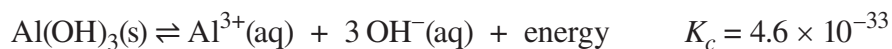
20. *At equilibrium, compared to the rate of the reverse reaction, the rate of the forward reaction is ____i____ and the pH of the solution over time would ____ii____ .*

The statement above is completed by the information in row

Row	i	ii
A.	greater	decrease
B.	greater	remain constant
C.	equal	decrease
D.	equal	remain constant

Answer: D
Outcome: D1.1k

8. The pOH of a solution of aluminium hydroxide was measured to be 4.86. The hydronium ion, $H_3O^+(aq)$, concentration of this solution, expressed in scientific notation, is $a.b \times 10^{-cd}$. The values of a, b, c, and d are _____, _____, _____, and _____.
$$ a b c d$$

(Record all **four digits** of your answer in the numerical-response section on the answer sheet.)

Answer: 7210
Outcome: D2.2k

Use the following information to answer question 21.

Household bleach contains sodium hypochlorite, which is a weak base with a K_b of 2.5×10^{-7}. The ionization of sodium hypochlorite can be represented by the following equilibrium equation.

$$OCl^-(aq) + H_2O(l) \rightleftharpoons HOCl(aq) + OH^-(aq)$$
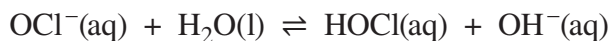
21. The pOH of a 0.012 5 mol/L solution of sodium hypochlorite is

A. 1.90

B. 4.25

C. 8.51

D. 9.75

Answer: B
Outcome: D2.2k

One of the chemicals responsible for the odour of fish is methylamine, $CH_3NH_2(aq)$.
Methylamine is a weak base and reacts with water as represented by the following equation.

$$CH_3NH_2(aq) + H_2O(l) \rightleftharpoons CH_3NH_3{}^+(aq) + OH^-(aq) \qquad K_b = 4.4 \times 10^{-4}$$
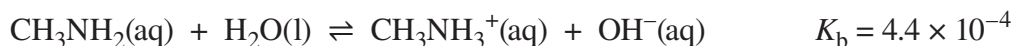
22. Which of the following rows identifies a Brønsted–Lowry base and a conjugate acid–base pair in the equation above?

Row	Brønsted–Lowry Base	Conjugate Acid–Base Pair
A.	$CH_3NH_3{}^+(aq)$	$H_2O(l)$ and $OH^-(aq)$
B.	$CH_3NH_3{}^+(aq)$	$CH_3NH_2(aq)$ and $OH^-(aq)$
C.	$CH_3NH_2(aq)$	$H_2O(l)$ and $OH^-(aq)$
D.	$CH_3NH_2(aq)$	$CH_3NH_2(aq)$ and $OH^-(aq)$

Answer: C
Outcome: D1.5k, D1.7k

23. *The value of the K_a for the conjugate acid of methylamine is* ____***i***____ *, and the conjugate acid is classified as* ____***ii***____ *.*

The statement above is completed by the information in row

Row	i	ii
A.	2.3×10^{-11}	weak and monoprotic
B.	2.3×10^{-11}	strong and polyprotic
C.	4.4×10^{-18}	weak and monoprotic
D.	4.4×10^{-18}	strong and polyprotic

Answer: A
Outcome: D1.6k, D2.2k

24. The $OH^-(aq)$ concentration in a 0.50 mol/L solution of methylamine is

    A. 3.0×10^{-2} mol/L

    B. 1.5×10^{-2} mol/L

    C. 8.8×10^{-4} mol/L

    D. 2.2×10^{-4} mol/L

Answer: B
Outcome: D2.2k

Use the following information to answer numerical-response question 9.

$$CN^-(aq) + H_2O(l) \rightleftharpoons HCN(aq) + OH^-(aq) \qquad\qquad K_b = 1.6 \times 10^{-5}$$

Numerical Response

9. If the pH of a solution of NaCN(aq) is 8.71, then the equilibrium concentration of $CN^-(aq)$, expressed in scientific notation, is $a.b \times 10^{-c}$ mol/L. The values of $a, b,$ and c are _____, _____, and _____.
                                    a b c

(Record all **three digits** of your answer in the numerical-response section on the answer sheet.)

Answer: 166
Outcome: D2.2k, D2.3k

The equilibrium-law expression for an industrial method of producing ethanol is shown below.

$$K_c = \frac{[C_2H_5OH(g)]}{[C_2H_4(g)]\,[H_2O(g)]} \qquad K_c = 300.0$$

At equilibrium, a 5 000 L reaction vessel contains 115 mol of $C_2H_4(g)$ and 110 mol of $H_2O(g)$.

25. Under these conditions, the equilibrium concentration of $C_2H_5OH(g)$ is

A. 1.69×10^{-6} mol/L

B. 1.52×10^{-1} mol/L

C. 7.50×10^{1} mol/L

D. 5.92×10^{5} mol/L

Answer: B
Outcome: D2.3k

A technician injected $PCl_3(g)$ and $NH_3(g)$ into a 1.00 L reaction vessel, closed the vessel, and allowed the reaction to reach equilibrium, as represented by the following equation.

$$PCl_3(g) + 3\,NH_3(g) \rightleftharpoons P(NH_2)_3(g) + 3\,HCl(g) + energy$$

The technician then changed the reaction conditions and allowed a new equilibrium to be established. The graph below represents both the establishment of the original equilibrium and the changes to the equilibrium system.

Equilibrium System
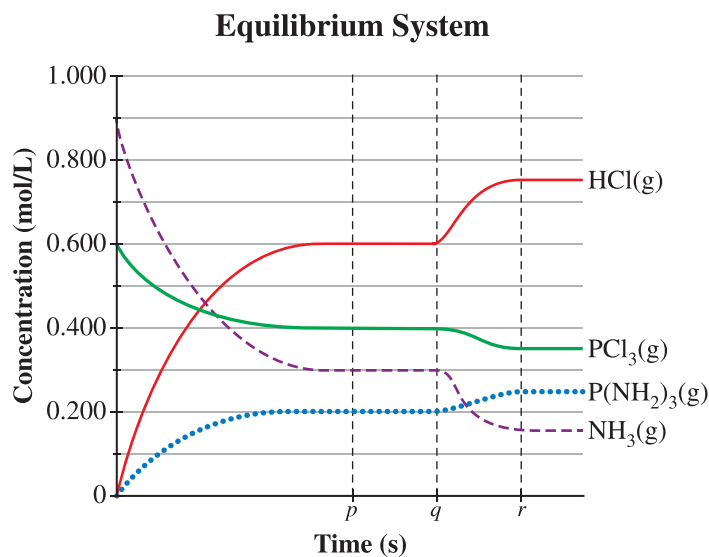
Numerical Response

10. The value of the equilibrium constant at time p on the graph is _____ .

(Record your **three-digit answer** in the numerical-response section on the answer sheet.)

Answer: 4.00
Outcome: D2.3k, D2.3s

26. *The change in the reaction conditions represented by time q on the graph is the result of ____i____ , and the value of the new equilibrium constant at time r will ____ii____ .*

The statement above is completed by the information in row

Row	i	ii
A.	increasing the temperature of the system	increase
B.	increasing the temperature of the system	decrease
C.	decreasing the temperature of the system	increase
D.	decreasing the temperature of the system	decrease

Answer: C
Outcome: D1.3k, D1.3s, D2.3s

Use the following information to answer numerical-response question 11.

Methane gas, $CH_4(g)$, can be produced in a laboratory by reacting carbon disulfide, $CS_2(g)$, and hydrogen gas, $H_2(g)$, as represented by the following equation.

$$CS_2(g) + 4 H_2(g) \rightleftharpoons CH_4(g) + 2 H_2S(g)$$
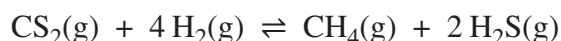
Initially, at a temperature of 90 °C, 0.18 mol/L $CS_2(g)$ and 0.31 mol/L $H_2(g)$ are present in a closed container. When equilibrium is established, 0.13 mol/L $CS_2(g)$ is present.

Numerical Response

11. The concentration of hydrogen gas present in the container at equilibrium
is _____ mol/L.

(Record your **three-digit answer** in the numerical-response section on the answer sheet.)

Answer: 0.11
Outcome: D2.3k, D2.3s

Toluene, $C_7H_8(g)$, is an important organic solvent and can be produced as represented by the following equilibrium equation.

$$C_7H_{14}(g) + energy \rightleftharpoons C_7H_8(g) + 3H_2(g)$$
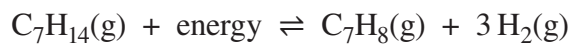
A technician placed 3.00 mol of $C_7H_{14}(g)$ into an empty 1.00 L flask. The flask was then stoppered and allowed to reach equilibrium. At equilibrium, 1.20 mol of $H_2(g)$ was present in the flask.

27. The value of the equilibrium constant is

    A.   0.185

    B.   0.266

    C.   0.798

    D.   1.15

Answer: B
Outcome: D2.3k, D2.3s

A technician added $CS_2(g)$, $H_2(g)$, $CH_4(g)$, and $H_2S(g)$ to an empty 1.00 L container at 960 °C and allowed the contents of the container to reach equilibrium, as represented by the following equation.

$$CS_2(g) + 4 H_2(g) \rightleftharpoons CH_4(g) + 2 H_2S(g)$$
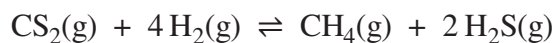
The technician records the following data.

	$CS_2(g)$	$H_2(g)$	$CH_4(g)$	$H_2S(g)$
Initial concentration (mol/L)	2.00	4.00	2.00	4.00
Equilibrium concentration (mol/L)	1.25	?		?

28. *The equilibrium concentration of $H_2(g)$ is ____i____ mol/L, and the equilibrium concentration of $H_2S(g)$ is ____ii____ mol/L.*

The statement above is completed by the information in row

Row	i	ii
A.	3.25	2.50
B.	3.25	5.50
C.	1.00	2.50
D.	1.00	5.50

Answer: D
Outcome: D2.3k, D2.3s

A student observes a system at equilibrium between a silver nitrate solution and copper solid. The net ionic equation for this equilibrium is shown below.

$$2\,Ag^+(aq) \;+\; Cu(s) \;\rightleftharpoons\; 2\,Ag(s) \;+\; Cu^{2+}(aq) \;+\; 54.1\;kJ$$
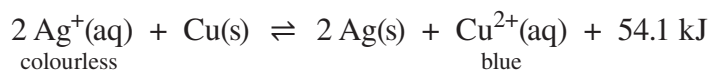<div style="text-align:center">colourless   blue</div>

Materials Involved in Shifting Equilibrium	Direction of Equilibrium Shift	Qualitative Observation After Shift in Equilibrium
1 Hot plate	5 Toward products	7 Solution turns lighter blue
2 Ice water bath	6 Toward reactants	8 Solution turns darker blue
3 Concentrated NaCl(aq)		
4 Concentrated AgNO₃(aq)		

Numerical Response

12. Using the numbers above, choose **one material** that would result in a shift in equilibrium and match it with the direction of the equilibrium shift and with a qualitative observation that would confirm this shift. (There is more than one correct answer.)

Number: _____\ \ _____\ \ _____

      Material   **Direction of** **Qualitative**
      chosen   **equilibrium**   **observation**
             shift

(Record all **three digits** of your answer in the numerical-response section on the answer sheet.)

Answer: 167, 258, 367, 458
Outcome: D1.3k, D1.1s

Multi-unit Scenarios

Use the following information to answer question 1 and numerical-response question 1.

Volcanoes on Io, one of Jupiter's moons, emit hydrogen sulfide gas, $H_2S(g)$, and sulfur dioxide gas, $SO_2(g)$. The gases can react as represented by the following equilibrium equation.

$$16\ H_2S(g)\ +\ 8\ SO_2(g)\ \rightleftharpoons\ 16\ H_2O(g)\ +\ 3\ S_8(g)\ +\ 332.2\ kJ$$

1. The enthalpy diagram that could represent the reaction above is

A.

E_p **(kJ)**

16 $H_2S(g)$ + 8 $SO_2(g)$

ΔH is negative

16 $H_2O(g)$ + 3 $S_8(g)$

Reaction progress

B.

E_p **(kJ)**

16 $H_2O(g)$ + 3 $S_8(g)$

ΔH is negative

16 $H_2S(g)$ + 8 $SO_2(g)$

Reaction progress

C.

E_p **(kJ)**

16 $H_2O(g)$ + 3 $S_8(g)$

ΔH is positive

16 $H_2S(g)$ + 8 $SO_2(g)$

Reaction progress

D.

E_p **(kJ)**

16 $H_2S(g)$ + 8 $SO_2(g)$

ΔH is positive

16 $H_2O(g)$ + 3 $S_8(g)$

Reaction progress
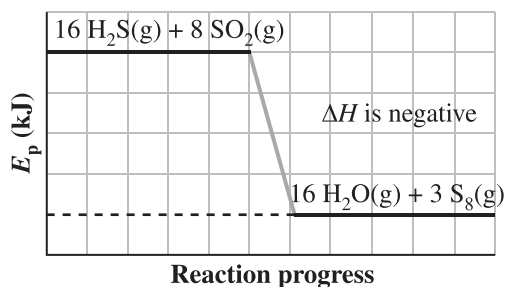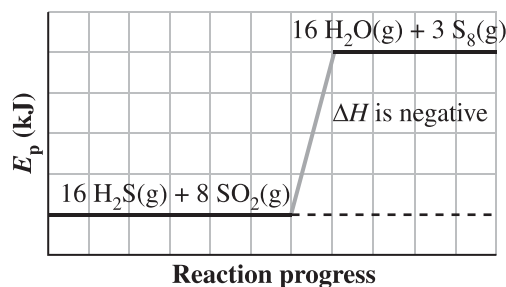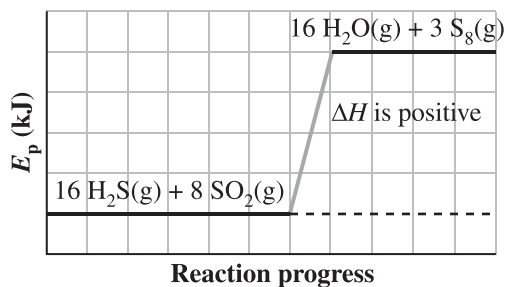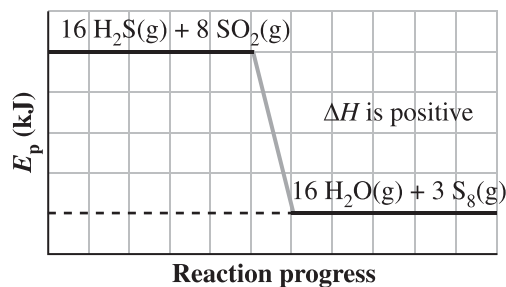
Answer: A
Outcome: A2.3k, A2.3s

1. The oxidation number of sulfur in

$H_2S(g)$ is +/– _____ (Record in the **first** column)

$SO_2(g)$ is +/– _____ (Record in the **second** column)

$S_8(g)$ is +/– _____ (Record in the **third** column)

(Record your answer in the numerical-response section on the answer sheet.)

Answer: 240
Outcome: B1.2k

Use the following information to answer questions 2 to 7 and numerical-response question 2.

Most automobile engines are cooled by a mixture of antifreeze and water. Antifreezes are added to the water to prevent the cooling system in an engine from freezing in cold weather. Many compounds can be used for this purpose.

Compounds Used as an Antifreeze

Compound	1	2	3	4
Common name	wood alcohol	ethylene glycol	glycerol	propylene glycol
IUPAC name	methanol	ethane-1,2-diol	propane-1,2,3-triol	propane-1,2-diol
Specific heat capacity (J/g•°C)	2.52	2.40	2.41	2.50
Viscosity (relative to water, water = 1.00)	0.64	17.8	648	52
Density (g/mL)	0.79	1.11	1.26	1.04

2. If a 1.25 kg sample of pure antifreeze was heated by 16.5 °C when 52.0 kJ of energy was added, then the sample is **most likely** to be

   A. methanol

   B. ethane-1,2-diol

   C. propane-1,2-diol

   D. propane-1,2,3-triol

   Answer: A
   Outcome: A1.1k, A1.3s

3. The two compounds that belong to the same homologous series are numbered

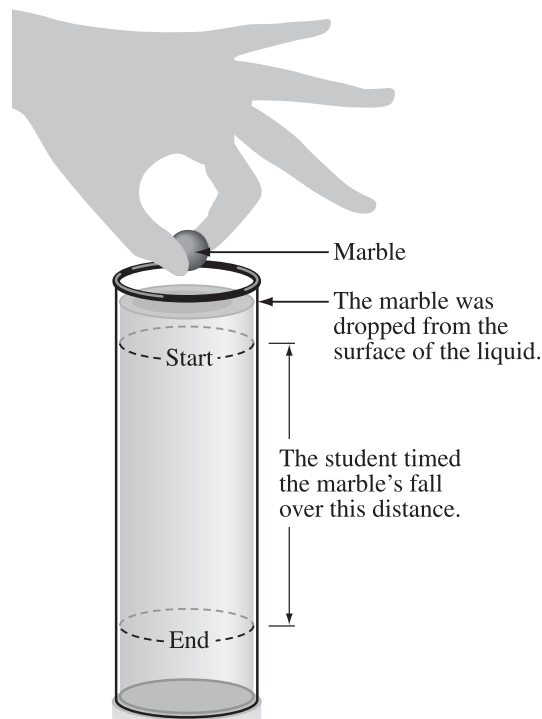   **A.** 1 and 2

    B. 2 and 3

    C. 2 and 4

    D. 3 and 4

Answer: C
Outcome: C1.6k

A student took a 25.0 mL sample of Compound 1 and poured it into a tube, as illustrated in the diagram. They measured the time it took for the marble to fall the distance indicated in the diagram and repeated this procedure for each remaining compound, with identical equipment, and with all measurements made at the same temperature.

Marble

The marble was dropped from the surface of the liquid.

Start

The student timed the marble's fall over this distance.

End

Variables

1 Number of carbon atoms

2 Number of hydroxyl groups

3 Density of the liquid

4 Viscosity of the liquid

5 Volume of the liquid

6 Time for the marble to travel the distance

7 Distance the marble travelled

8 Temperature of the liquid

Numerical Response

2. In the experiment described above,

the responding variable is numbered _____ (Record in the **first** column)

one controlled variable is numbered _____ (Record in the **second** column)

another controlled variable is numbered _____ (Record in the **third** column)

and a third controlled variable is numbered _____ (Record in the **fourth** column)

(Record your answer in the numerical-response section on the answer sheet.)

Answer: 6578, 6587, 6785, 6758, 6857, 6875
Outcome: C1.1s

If ethylene glycol, $C_2H_6O_2$(aq), is ingested, enzymes in the body convert it to glycolic acid, $C_2H_4O_3$(aq), as represented by the following **unbalanced** incomplete half-reaction.

<div align="center">

HO⌒OH $\xrightarrow{\text{enzymes}}$ HO⌒C(=O)OH

$C_2H_6O_2$(aq)   **$C_2H_4O_3$(aq)**

</div>
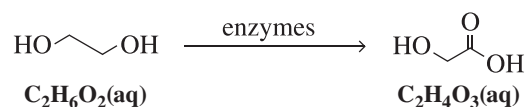
The buildup of glycolic acid ($K_a = 1.5 \times 10^{-4}$) causes acidosis, a serious medical condition.

4. The oxidation number of carbon in ethylene glycol is

    A.   –2

    B.   –1

    C.   +1

    D.   +2

Answer: B
Outcome: B1.2k

5. *If the half-reaction above is balanced in an acidic solution, the H^+(aq) will appear on the side of the equation with the* ___i___ *and will have a coefficient of* ___ii___ .

The statement above is completed by the information in row

Row	i	ii
A.	reactants	2
B.	reactants	4
C.	products	2
D.	products	4

Answer: D
Outcome: B1.7k

Use the following additional information to answer question 6 and 7.

> The glycolic acid produced can react with the $H_2PO_4^-(aq)/HPO_4^{2-}(aq)$ buffer that is present in cellular fluid.

6. Which of the following rows identifies the Brønsted–Lowry base that will first react with the glycolic acid and the extent of that reaction?

Row	Brønsted–Lowry Base	Extent of the Reaction
A.	$H_2PO_4^-(aq)$	<50%
B.	$H_2PO_4^-(aq)$	>50%
C.	$HPO_4^{2-}(aq)$	<50%
D.	$HPO_4^{2-}(aq)$	>50%

Answer: D
Outcome: D1.5k, D1.6k

Use the following additional information to answer question 7.

> During acidosis, the pH of the blood may change from 7.40 to 7.25.

7. Which of the following rows identifies the $[OH^-(aq)]$ at a pH of 7.25 and compares it to the $[OH^-(aq)]$ at a pH of 7.40?

Row	$[OH^-(aq)]$ at pH of 7.25	Compared to $[OH^-(aq)]$ at pH of 7.40
A.	1.8×10^{-7}	Less at a pH of 7.25
B.	1.8×10^{-7}	Greater at a pH of 7.25
C.	5.6×10^{-8}	Less at a pH of 7.25
D.	5.6×10^{-8}	Greater at a pH of 7.25

Answer: A
Outcome: D2.1k, D2.2k

Use the following information to answer questions 8 to 11 and numerical-response question 3.

Sorbic acid, C_5H_7COOH(aq), is used as a preservative in wine as it inhibits the growth of fungi and bacteria. Its structure can be represented by the following line diagram.

$K_a = 1.7 \times 10^{-5}$
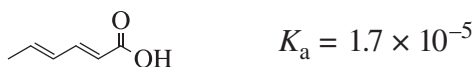
8. Which of the following rows identifies a classification and a functional group for sorbic acid?

Row	Classification	Functional Group
A.	Aromatic	Ester linkage
B.	Aromatic	Carboxyl
C.	Aliphatic	Ester linkage
D.	Aliphatic	Carboxyl

Answer: D
Outcome: C1.3k, C1.4k, C1.3s

9. *Sorbic acid can react with excess Br_2(l) in _____i_____ and the number of different inorganic products produced is _____ii_____ .*

The statement above is completed by the information in row

Row	*i*	*ii*
A.	an addition reaction	two
B.	an addition reaction	zero
C.	a substitution reaction	two
D.	a substitution reaction	zero

Answer: B
outcome: C2.2k

10. The pH of a 0.020 mol/L solution of sorbic acid is

    A.   6.47

    B.   4.77

    C.   3.23

    D.   1.70

Answer: C
Outcome: D2.2k

Numerical Response

3. The value of K_b for the sorbate ion is $a.b \times 10^{-cd}$. The values of a, b, c, and d are

_____, _____, _____, and _____.
  a b c d

(Record all **four digits** of your answer in the numerical-response section on the answer sheet.)

Answer: 5910
Outcome: D2.2k

Use the following additional information to answer question 11.

Sorbic acid can react with the bicarbonate ion that is also present in wine. The reaction can be represented by the following equilibrium equation.

$$C_5H_7COOH(aq) + HCO_3^-(aq) \rightleftharpoons C_5H_7COO^-(aq) + H_2CO_3(aq)$$
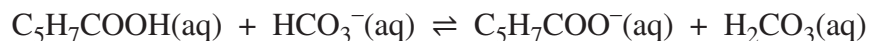
11. Which of the following rows identifies the extent of reaction and a conjugate acid–base pair?

Row	Extent of Reaction	Conjugate Acid–Base Pair
A.	Reactants Favoured	$HCO_3^-(aq)$, $C_5H_7COO^-(aq)$
B.	Reactants Favoured	$C_5H_7COOH(aq)$, $C_5H_7COO^-(aq)$
C.	Products Favoured	$HCO_3^-(aq)$, $C_5H_7COO^-(aq)$
D.	Products Favoured	$C_5H_7COOH(aq)$, $C_5H_7COO^-(aq)$

Answer: D
Outcome: D1.6k, D1.7k