2021

AP® CollegeBoard

AP® Chemistry

Scoring Guidelines

Question 1: Long Answer — 10 points

(a) For the correct expression: **1 point**

$$K_a = \frac{[H_3O^+][HCOO^-]}{[HCOOH]}$$

(b) For the correct calculated concentration of H_3O^+: **1 point**

	$HCOOH$	+	H_2O	$\rightleftarrows$	H_3O^+	+	$HCOO^-$
I	0.25				0		0
C	$-x$				$+x$		$+x$
E	$0.25 - x$				x		x

Let $[H_3O^+] = x$, *then* $1.8\times10^{-4} = \dfrac{x^2}{(0.25-x)}$

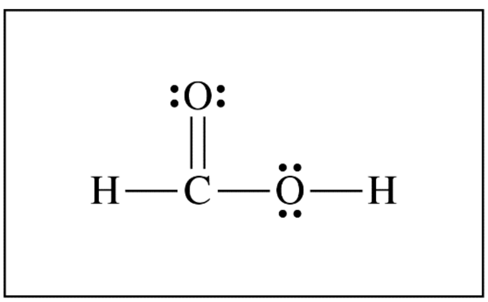
Assume $x << 0.25$, *then* $1.8\times10^{-4} = \dfrac{x^2}{0.25} \Rightarrow x = 0.0067\ M$

For the correct calculated value of pH: **1 point**

$$pH = -\log[H_3O^+] = -\log(0.0067) = 2.17$$

Total for part (b) — 2 points

(c) For the correct diagram: **1 point**



(d) **(i)** For the correct balanced equation (state symbols not required): **1 point**

$$H_2NNH_2(aq) + HCOOH(aq) \rightarrow H_2NNH_3^+(aq) + HCOO^-(aq)$$

(ii) For the correct answer and a valid justification: **1 point**

Acidic. The K_a of $H_2NNH_3^+$ is greater than the K_b of $HCOO^-$, so the production of $H_3O^+(aq)$ occurs to a greater extent than the production of $OH^-(aq)$.

Total for part (d) — 2 points

(e) For the correct answer and a valid justification: **1 point**

Accept one of the following:

- *Yes. The oxidation number of hydrogen changes from +1 in HCOOH to zero in H_2.*
- *Yes. The oxidation number of carbon changes from +2 in HCOOH to +4 in CO_2.*

(f)	For the correct calculated value of the pressure of CO_2 (may be implicit): *24 atm total × 1 atm CO_2 / 2 atm of product = 12 atm CO_2*	**1 point**
	For the correct calculated number of moles of CO_2: $PV = nRT$ $n = \frac{PV}{RT} = \frac{(12\ \text{atm})(4.3\ \text{L})}{(0.08206\ \text{L atm mol}^{-1}\ \text{K}^{-1})(298\ \text{K})} = 2.1\ \text{mol } CO_2$	**1 point**
	Total for part (f)	**2 points**
(g)	For the correct answer and a valid justification: *It would remain the same. In a catalyzed reaction the net amount of catalyst is constant.*	**1 point**
	Total for question 1	**10 points**

Question 2: Long Answer — 10 points

(a) **(i)** For the correct answer: **1 point**

14 protons and 14 neutrons

(ii) For the correct answer: **1 point**

Accept one of the following:

- $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^2$
- $[Ne]\ 3s^2\ 3p^2$

Total for part (a) **2 points**

(b) For a correct explanation: **1 point**

SiH_4 is composed of molecules, for which the only intermolecular forces are London dispersion forces. SiO_2 is a network covalent compound with covalent bonds between silicon and oxygen atoms. London dispersion forces are much weaker than covalent bonds, so SiH_4 boils at a much lower temperature than SiO_2.

(c) For the correct balanced equation (state symbols not required): **1 point**

$$\mathrm{SiH_4}(g) \rightarrow \mathrm{Si}(s) + 2\ \mathrm{H_2}(g)$$

(d) For a correct explanation: **1 point**

The $H_2(g)$ molecules are more highly dispersed than the Si(s) atoms and, therefore, have a higher absolute molar entropy. Silicon is a solid; therefore, its atoms are in fixed positions, are less dispersed, and have a lower absolute molar entropy.

(e) For the correct calculated value: **1 point**

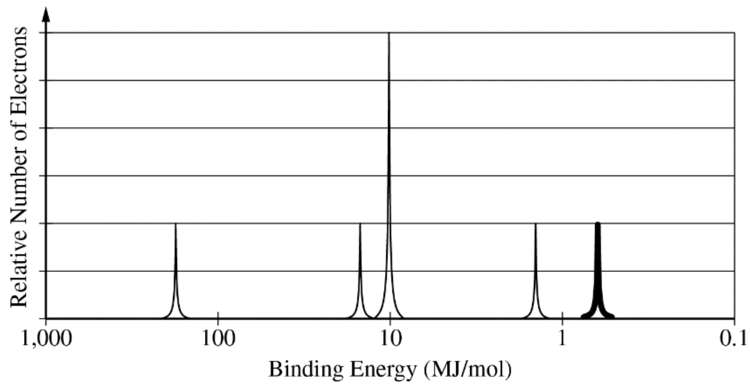
$$\Delta S^\circ_{rxn} = (18 + 2(131)) - 205 = +75\ \mathrm{J/(mol}_{rxn} \cdot \mathrm{K)}$$

(f) For a correct explanation: **1 point**

High temperature is required for the reactant particles to have sufficient thermal energy to overcome the activation energy of the reaction.

(g) For the correct peak height and location: **1 point**

The peak should be drawn to the right of the other peaks, and it should reach the second line above the horizontal axis.



(h) For a correct explanation: **1 point**

The valence electrons of a Ge atom occupy a higher shell (n=4) than those of a Si atom (n=3), so the average distance between the nucleus and the valence electrons is greater in Ge than in Si. This greater separation results in weaker Coulombic attractions between the Ge nucleus and its valence electrons, making them less tightly bound and, therefore, easier to remove compared to those in Si.

(i) For the correct calculated value: **1 point**

$$E = h\nu = h\left(\frac{c}{\lambda}\right) = 6.626\times10^{-34}\ \text{J}\cdot\text{s}\ \left(\frac{2.998\times10^{8}\ \text{m s}^{-1}}{4.00\times10^{-7}\ \text{m}}\right) = 4.97\times10^{-19}\ \text{J}$$

Total for question 2 10 points

Question 3: Long Answer — 10 points

(a)	For the correct balanced equation (state symbols not required): $Ba^{2+}(aq) + SO_4^{2-}(aq) \rightarrow BaSO_4(s)$	**1 point**
(b)	For the correct calculated value of the mass of precipitate (may be implicit): $1.136 \text{ g} - 0.764 \text{ g} = 0.372 \text{ g } BaSO_4$	**1 point**
	For the correct calculated value of the number of moles, consistent with mass of precipitate: $0.372 \text{ g} \times \frac{1 \text{ mol}}{233.39 \text{ g}} = 0.00159 \text{ mol}$	**1 point**
	Total for part (b)	**2 points**
(c)	For the correct calculated value, consistent with part (b): $0.00159 \text{ mol } BaSO_4 \times \frac{1 \text{ mol } CuSO_4}{1 \text{ mol } BaSO_4} = 0.00159 \text{ mol } CuSO_4$ $\frac{0.00159 \text{ mol } CuSO_4}{0.0500 \text{ L}} = 0.0318\ M\ CuSO_4$ *(0.0319 M if decimals are carried)*	**1 point**
(d)	For the correct calculated value: $M_1V_1 = M_2V_2$ $V_1 = \frac{(0.0500\ M)(50.00 \text{ mL})}{(0.1000\ M)} = 25.0 \text{ mL}$	**1 point**
(e)	For a correct technique to measure the volume of solution: *First, measure out the correct volume of 0.1000 M $CuSO_4$ solution with a 25.0 mL volumetric pipet (graduated cylinder or buret is acceptable).*	**1 point**
	For a correct technique to dilute the solution to the final volume: *Transfer the 25.0 mL of solution to a 50.00 mL volumetric flask and dilute the solution with water up to the 50.00 mL mark.*	**1 point**
	Total for part (e)	**2 points**
(f)	For the correct value (between 0.032 *M* and 0.038 *M*): Accept one of the following: • $y = mx = \frac{0.63}{0.1000}x = 6.3x$ $x = \frac{y}{6.3} = \frac{0.219\ M}{6.3} = 0.035\ M$ • *Estimated value from the graph within the specified range.*	**1 point**

(g)	For the correct answer: *The concentration will be <u>less than</u> that determined in part (f).*	**1 point**
	For a valid justification: *The additional water will decrease the concentration of $CuSO_4$ in the cuvette. Therefore, there will be a decrease in absorbance (according to the Beer-Lambert law). This dilution results in a lower estimated concentration of $CuSO_4$.*	**1 point**
	Total for part (g)	**2 points**
	Total for question 3	**10 points**

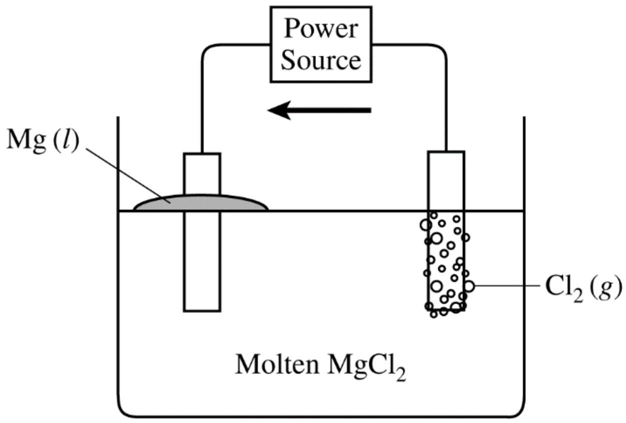
Question 4: Short Answer — 4 points

(a)	For the correct calculated value with units: $q = mc\Delta T = (15.0\text{ g})(0.72\text{ J/(g}\cdot{}^{\circ}\text{C}))(39.7{}^{\circ}\text{C} - 22.0{}^{\circ}\text{C}) = 190\text{ J}$	**1 point**
(b)	For the correct calculated value of the moles of reaction, consistent with part (a) (may be implicit): $q_{sys} = -q_{surr}$ $-190\text{ J} \times \dfrac{1\text{ kJ}}{1000\text{ J}} \times \dfrac{1\text{ mol}_{rxn}}{-1650\text{ kJ}} = 0.00012\text{ mol}_{rxn}$	**1 point**
	For the correct calculated value of the mass of iron: $0.00012\text{ mol}_{rxn} \times \dfrac{4\text{ mol Fe}}{1\text{ mol}_{rxn}} \times \dfrac{55.85\text{ g Fe}}{1\text{ mol Fe}} = 0.027\text{ g Fe}$ *(0.026 g if decimals are carried)*	**1 point**
	Total for part (b)	**2 points**
(c)	For the correct answer and a valid justification: *Greater than. A greater mass of iron provides a greater number of moles of reaction, which would transfer a greater quantity of thermal energy to the same mass of sand and therefore lead to a greater maximum temperature.*	**1 point**
	Total for question 4	**4 points**

Question 5: Short Answer — 4 points

(a) For the correct answer: **1 point**

Electron flow should be indicated only in a counter-clockwise direction in the external circuit, from the Cl_2 anode to the Mg cathode.



(b) For the correct answer and calculated value: **1 point**

No, because 2.0 V is less than 3.73 V, which is the minimum voltage needed for electrolysis to occur.

$$E^\circ_{cell} = -2.37\text{ V} + (-1.36\text{ V}) = -3.73\text{ V}$$

(c) For the correct calculated value of moles of electrons (may be implicit): **1 point**

$$2.00\text{ g Mg} \times \frac{1\text{ mol Mg}}{24.30\text{ g Mg}} \times \frac{2\text{ mol } e^-}{1\text{ mol Mg}} = 0.165\text{ mol } e^-$$

For the correct calculated number of seconds: **1 point**

$$0.165\text{ mol } e^- \times \frac{96{,}485\text{ C}}{1\text{ mol } e^-} \times \frac{1\text{ s}}{5.00\text{ C}} = 3180\text{ s}$$

Total for part (c) 2 points

Total for question 5 4 points

Question 6: Short Answer — 4 points

(a) For a correct description: **1 point**

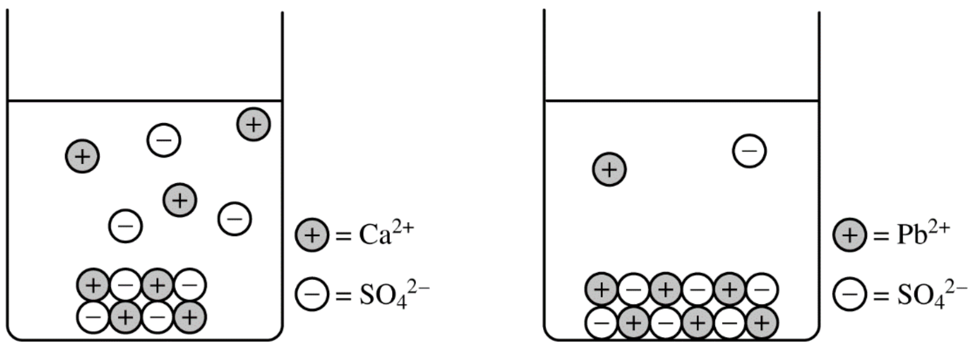
Ionic solids do not have free-moving ions that are required to carry an electric current. Therefore, there is no conduction of electricity.

(b) For the correct answer and a valid justification: **1 point**

$CaSO_4$. The greater electrical conductivity of the $CaSO_4$ solution relative to the $PbSO_4$ solution implies a higher concentration of ions, which comes from the dissolution (dissociation) of $CaSO_4$ to a greater extent.

(c) For a correct drawing that shows an equal number of cations and anions: **1 point**

The drawing shows solid $PbSO_4$ at the bottom of the beaker (similar to the solid shown for $CaSO_4$) and fewer dissociated Pb^{2+} and SO_4^{2-} ions in the solution.



Higher Conductivity Solution

Lower Conductivity Solution

(d) For a correct explanation: **1 point**

The additional precipitate is $CaSO_4$ that forms in response to the increased $[SO_4^{2-}]$ in solution. According to Le Chatelier's principle ($Q > K_{sp}$), the introduction of SO_4^{2-} as a common ion shifts the equilibrium towards the formation of more $CaSO_4(s)$.

Total for question 6 — 4 points

Question 7: Short Answer — 4 points

(a) For the correct calculated value: **1 point**

Accept one of the following:

- $0.325 \text{ mol } O_2 \times \dfrac{32.00 \text{ g } O_2}{1 \text{ mol } O_2} = 10.4 \text{ g } O_2$

  $D = \dfrac{m}{V} = \dfrac{10.4 \text{ g}}{7.95 \text{ L}} = 1.31 \text{ g/L}$

- $D = \dfrac{m}{V} = \dfrac{P(MM)}{RT} = \dfrac{(1.0 \text{ atm})(32.00 \text{ g/mol})}{(0.08206 \frac{\text{L}\cdot\text{atm}}{\text{mol}\cdot\text{K}})(298 \text{ K})} = 1.31 \text{ g/L}$

(b) For the correct answer and a valid justification: **1 point**

Accept one of the following:

- *No, the density of the gas remains constant because P, R, and T remain constant AND the mass and volume of O_2 decrease proportionately.*
- *A mathematical justification is shown below.*

$$D = \frac{m}{V} = \frac{n \text{ moles of } O_2 \times \text{molar mass of } O_2}{\frac{nRT}{P}} = \frac{P \times (\text{molar mass of } O_2)}{RT}$$

(c) For a valid explanation: **1 point**

Accept one of the following:

- *As the gas cools, the average kinetic energy (speed) of the O_2 molecules decreases. The molecules rebound with less energy when they collide with each other and the walls of the container. The spacing between particles decreases, causing the volume occupied by the gas to decrease.*
- *As the gas cools, the average kinetic energy (speed) of the O_2 molecules decreases. The molecules rebound with less energy when they collide with each other and the walls of the container. The only way for the molecules to maintain a constant rate of collisions with the walls of the container (maintaining a pressure of 1.00 atm) is for the volume of the gas to decrease.*

(d) For a valid explanation: **1 point**

The ideal gas law assumes that gas particles do not experience interparticle attractions. As a real gas cools further, the intermolecular forces have greater effect as the average speed of the molecules decreases, resulting in inelastic collisions. To maintain a gas pressure of 1.00 atm, the volume must decrease to accommodate more collisions with less energy.

Total for question 7 — 4 points