2026

AP® Chemistry

Free-Response Questions

CHEMISTRY
SECTION II
TIME – 1 HOUR AND 45 MINUTES

Directions:

Section II has 7 questions and lasts 1 hour and 45 minutes.

You may use the available paper for scratch work and planning, but only work written in the free-response booklet will be scored. Any work done on scratch paper will not be scored. Place your answers in the space provided for each part in the booklet (e.g., Part A, Part B, Part C). Label sub-parts (e.g., i., ii., iii.) as needed. Use a pencil or a pen with black or dark blue ink to write your responses.

For each question, show your work for each part in the space provided for that part in the free-response booklet. Examples and equations may be included in your responses where appropriate. For calculations, clearly show the method used and the steps involved in arriving at your answers. You must show your work to receive credit for your answer. Pay attention to significant figures.

A calculator is allowed in this section. You may use a handheld four-function, scientific, or graphing calculator, or the calculator available in this application. Reference information, including a periodic table and lists of equations and constants, can be used throughout the exam. A digital version is available in this application.

You may pace yourself as you answer the questions in this section, or you may use these optional timing recommendations:

Questions 1 through 3 are long free-response questions. It is suggested that you spend about 23 minutes on each of those questions. Questions 4 through 7 are short free-response questions. It is suggested that you spend about 9 minutes on each of those questions.

You can go back and forth between questions in this section until time expires. The clock will turn red when 5 minutes remain—**the proctor will not give you any time updates or warnings.**

Note: This exam was originally administered digitally. It is presented here in a format optimized for teacher and student use in the classroom.

During the AP Exam administration, students have access to reference information. To see the reference information for this course, please visit AP Central:
https://apcentral.collegeboard.org/exam-administration-ordering-scores/administering-exams/subject-specific/reference-information

Question 1

1. A student performs a calorimetry experiment with KCl.

Part A

Consider the K^+ ion in KCl.

i. **Write** the complete ground-state electron configuration for the potassium ion, K^+.

ii. Which has the larger radius, the K^+ ion or the K atom? **Explain** your reasoning using principles of atomic structure.

The following information applies to parts B, C, D, and E.

A student performs an experiment to determine the enthalpy of solution, ΔH_{soln}, of KCl. The student places water in a calorimeter, measures the initial temperature, adds KCl(*s*), and stirs until the KCl dissolves completely. The temperature is continuously monitored during the experiment. Data from the experiment are given in the following table.

Mass of water	97.5 g
Mass of KCl(*s*)	6.80 g
Initial temperature of water	24.5°C
Final temperature of solution	21.1°C

Part B

Describe how the student can use the temperature readings during the experiment to determine when the dissolution is complete.

Part C

Use the data in the table to do the following.

i. **Calculate** the magnitude of the thermal energy, *q*, in joules, transferred during the dissolution. Show the work that leads to your answer. (Assume that the solution has a specific heat capacity of 3.95 J/(g·°C).)

ii. **Calculate** the value of the molar enthalpy of solution, ΔH_{soln}, in kJ/mol, for KCl given that 0.0912 mol of KCl dissolved. Show the work that leads to your answer. Include the sign with your answer.

Part D

The calorimeter is not perfectly insulated. Would this cause the magnitude of ΔH_{soln} calculated in part C (ii) to be greater than, less than, or equal to the accepted value? **Justify** your answer.

Part E

The student performs a second experiment using the same mass of water but 6.80 g of RbCl(*s*) instead of 6.80 g of KCl(*s*). The magnitude of the molar enthalpy of solution, ΔH_{soln}, of RbCl is approximately equal to that of KCl.

Is the magnitude of ΔT in the RbCl experiment greater than, less than, or equal to that in the KCl experiment? **Justify** your answer. (Assume that the specific heat capacities of the solutions are equal.)

Part F

RbCl has a K_{sp} of 57 at 20°C.

i. **Write** the net ionic equation for the dissolution of RbCl in pure water.

ii. **Calculate** the molar solubility of RbCl in a saturated solution at 20°C. Show the work that leads to your answer.

iii. A second saturated solution is prepared by dissolving RbCl(*s*) in 1.0 *M* KCl(*aq*) at 20°C instead of in pure water. Will the molar solubility of RbCl in 1.0 *M* KCl(*aq*) be greater than, less than, or equal to the molar solubility calculated in part F (ii)? **Justify** your answer.

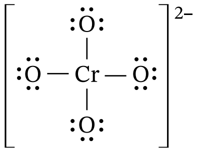
Question 2: Version J

2. Answer the following questions about the chromate ion, CrO_4^{2-}, and the dichromate ion, $Cr_2O_7^{2-}$.

Part A

The bonds between chromium and oxygen in CrO_4^{2-} can be represented as covalent bonds. One possible Lewis diagram for the CrO_4^{2-} ion is shown in Figure 1.

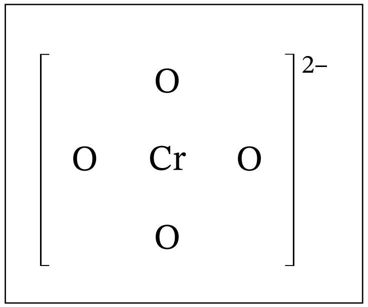
Figure 1



i. Based on VSEPR theory, **predict** the molecular geometry of the CrO_4^{2-} ion.

ii. On Figure 2, **draw** a complete Lewis diagram for a resonance structure of CrO_4^{2-} that results in a formal charge of zero on two of the O atoms and a formal charge of −1 on the other two O atoms. Your diagram should contain the same number of valence electrons as in Figure 1.

Figure 2



Part B

When reacted with a strong acid like $HNO_3(aq)$, $CrO_4^{2-}(aq)$ can be converted to $Cr_2O_7^{2-}(aq)$ and $H_2O(l)$ in a reversible reaction.

i. **Write** a balanced net ionic equation for the reaction between $CrO_4^{2-}(aq)$ and a strong acid.

ii. Is the reaction a redox reaction? **Justify** your answer based on the oxidation number of Cr.

The following information applies to parts C and D.

In acidic solutions, $Cr_2O_7^{2-}(aq)$ reacts to form $CrO_3(aq)$ according to Equation 1.

$$\text{Equation 1: } Cr_2O_7^{2-}(aq) + 2\ H_3O^+(aq) \rightarrow 2\ CrO_3(aq) + 3\ H_2O(l)$$

$CrO_3(aq)$ can be electrolyzed to plate objects with a thin layer of chromium metal according to Equation 2.

$$\text{Equation 2: } CrO_3(aq) + 6\ H^+(aq) + 6\ e^- \rightarrow Cr(s) + 3\ H_2O(l) \qquad E^\circ = -1.32\ \text{V}$$

Part C

Is the reaction represented by Equation 2 thermodynamically favorable or unfavorable under standard conditions? **Justify** your answer with a calculation of ΔG°. Show the work that leads to your answer.

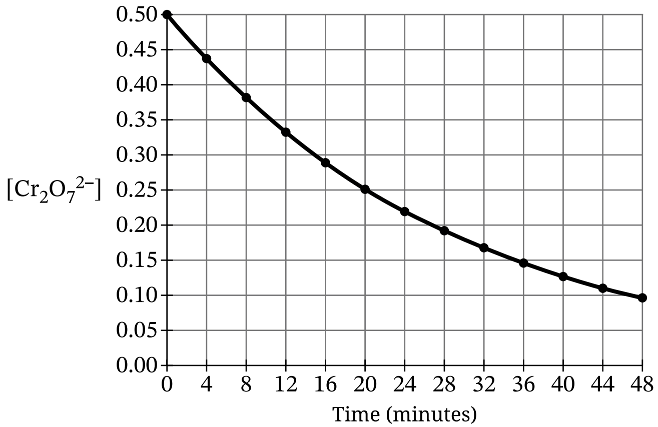
Part D

Calculate the number of grams of $Cr(s)$ that could be plated onto the surface of a steel rod when 15.0 A of current is applied for 3250 seconds. Show the work that leads to your answer.

Part E

In a separate experiment, an iron wire is placed directly in a solution of $0.50\ M\ Cr_2O_7^{2-}(aq)$ with $pH = 1.99$. The concentration of $Cr_2O_7^{2-}(aq)$ remaining is recorded over time, and the results are presented in Figure 3.

Figure 3

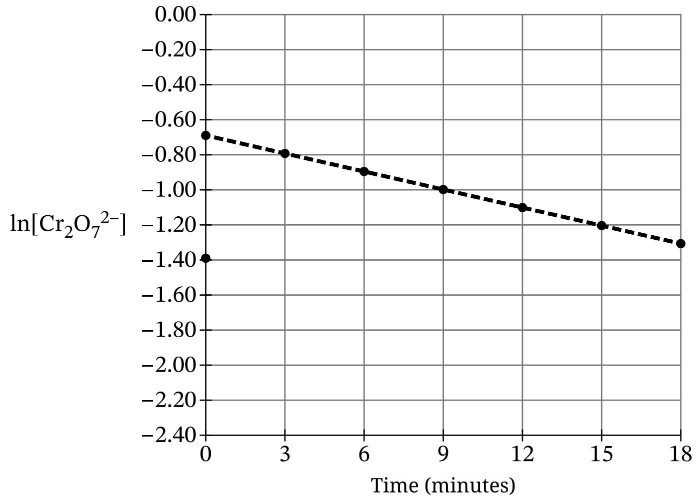


Explain how the data in Figure 3 support the conclusion that the reaction is first order with respect to $Cr_2O_7^{2-}$.

The following information applies to parts F and G.

The student creates a plot of $\ln\left[Cr_2O_7^{2-}\right]$ versus time for a trial with an initial concentration of $0.50\ M\ Cr_2O_7^{2-}(aq)$, as shown in Figure 4.

Figure 4



Part F

Calculate the value of the rate constant, k, for the reaction. Report your answer in units of min^{-1}. Show the work that leads to your answer.

Part G

The student then runs a second trial of the experiment under identical conditions but uses an initial concentration of $0.25\ M\ Cr_2O_7^{2-}(aq)$ instead of $0.50\ M\ Cr_2O_7^{2-}(aq)$. On Figure 4, carefully **draw** the plot of $\ln\left[Cr_2O_7^{2-}\right]$ versus time that would be expected for the second experiment. The point at time zero has already been plotted.

Question 3: Version J

The following information applies to all parts.

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3. Nitrous acid, HNO_2, is a weak acid that ionizes according to Equation 1.

$$\text{Equation 1: } HNO_2(aq) + H_2O(l) \rightleftarrows NO_2^-(aq) + H_3O^+(aq) \quad K_a = 5.6\times10^{-4} \text{ at } 298 \text{ K}$$

Part A

Identify a conjugate acid-base pair in the equation. Be sure to clearly label which is the acid and which is the base.

Part B

A solution of $HNO_2(aq)$ with an initial concentration of $0.125\ M$ has a pH of 2.09.

i. **Calculate** the value of $[H_3O^+]$ in the solution. Show the work that leads to your answer.

ii. **Calculate** $[HNO_2]$ at equilibrium. Show the work that leads to your answer.

Part C

In an experiment, the solution of $0.125\ M$ $HNO_2(aq)$ is heated to 333 K. The new equilibrium concentrations are determined to be $[HNO_2] = 0.114\ M$, $[NO_2^-] = 0.0109\ M$, and $[H_3O^+] = 0.0109\ M$.

i. **Calculate** the value of K_a for HNO_2 at 333 K. Show the work that leads to your answer.

ii. Is the reaction represented by Equation 1 endothermic or exothermic? **Justify** your answer by comparing K_a values at 298 K and 333 K.

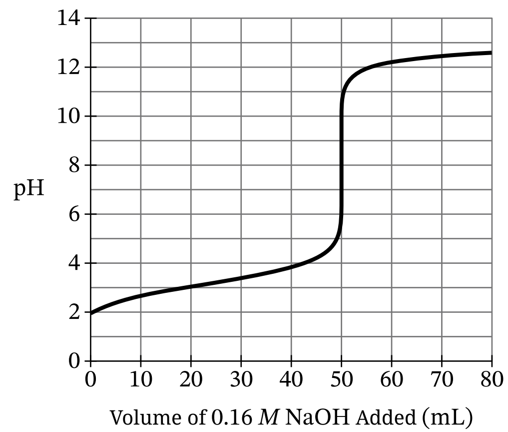
The following information applies to parts D, E, and F.

In a second experiment, a student is given a bottle containing HNO_2 with an unknown molarity. To determine the concentration of the $HNO_2(aq)$ in the bottle, the student titrates 35.0 mL of the $HNO_2(aq)$ with $0.16\ M$ $NaOH(aq)$ at 298 K, which reacts according to Equation 2.

$$\text{Equation 2: } HNO_2(aq) + OH^-(aq) \rightarrow NO_2^-(aq) + H_2O(l)$$

The results of the titration are summarized in Figure 1.

Figure 1



Part D

Using Figure 1, **identify** the pH at the equivalence point.

Part E

Using Figure 1, **calculate** the molarity $HNO_2(aq)$ of in the bottle. Show the work that leads to your answer.

Part F

Draw an X on Figure 1 to represent a point in the titration where $[HNO_2] > [NO_2^-]$ in the reaction mixture.

Part G

Equilibrium constants at 298 K are shown in Table 1 for the acid ionization reaction represented by Equation 1, K_a; the autoionization of water, K_w; and the neutralization reaction represented by Equation 2, K_2.

Table 1

Chemical Equation	Equilibrium Constant
$HNO_2(aq) + H_2O(l) \rightleftarrows NO_2^-(aq) + H_3O^+(aq)$	$K_a = 5.6 \times 10^{-4}$
$H_2O(l) + H_2O(l) \rightleftarrows H_3O^+(aq) + OH^-(aq)$	$K_w = 1.0 \times 10^{-14}$
$HNO_2(aq) + OH^-(aq) \rightarrow NO_2^-(aq) + H_2O(l)$	$K_2 = \ ?$

Calculate the value of K_2 for Equation 2 at 298 K. Show the work that leads to your answer.

Part H

The student decides to repeat the experiment, this time using an indicator, and has access to the indicators in Table 2.

Table 2

Indicator Name	Acid Color	pH Range of Color Change	Base Color
Methyl orange	Red	3.1–4.4	Yellow
Thymol blue	Yellow	8.0–9.6	Blue
Clayton yellow	Yellow	12.2–13.2	Orange

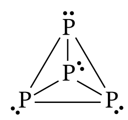
The student conducts a second titration by adding two drops of methyl orange indicator to 35.0 mL of the $HNO_2(aq)$ solution and titrating the solution with 0.16 M $NaOH(aq)$ until a color change from red to yellow occurs.

The student claims that methyl orange was the best choice for the indicator. Do you agree or disagree? **Justify** your answer.

Question 4

4. White phosphorus, $P_4(g)$, can decompose into $P_2(g)$ at elevated temperatures. A balanced chemical equation, K_p expression, and Lewis diagrams for the chemical species involved in the reaction are given.

$$P_4(g) \rightleftarrows 2\,P_2(g) \qquad K_p = \frac{(P_{P_2})^2}{P_{P_4}} = \ ?$$

Compound	P_4	P_2
Lewis diagram		$:P{\equiv}P:$

Part A

The average bond length in P_4 molecules is 221 pm, whereas the average bond length in P_2 molecules is 189 pm. **Explain** why the average bond length in P_4 is greater than the average bond length in P_2.

Part B

A sample of $P_4(s)$ is placed in a sealed rigid container and heated to 1600. K, at which point the initial partial pressure of $P_4(g)$ is 0.470 atm. Some of the $P_4(g)$ decomposes into $P_2(g)$ as the system reaches equilibrium. At equilibrium, the partial pressure of $P_2(g)$ is determined to be 0.630 atm.

Calculate the value of the equilibrium constant, K_p, for the reaction at 1600. K. Show the work that leads to your answer.

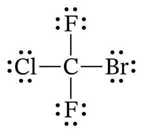
Part C

The reaction is thermodynamically favorable under standard conditions only at temperatures above 1500 K. A student claims that the reaction must be endothermic because it is favorable only at high temperatures. Do you agree or disagree? **Justify** your answer using ΔS°_{rxn} and ΔG°_{rxn}.

Question 5

The following information applies to parts A and B.

5. The Lewis diagram of $CBrClF_2$ is shown.



Part A

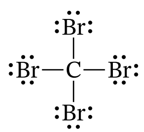
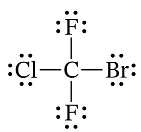
Which of the bonds in $CBrClF_2$ (C−Br, C−Cl, or C−F) is the most polar? **Justify** your answer.

Part B

In a molecule of $CBrClF_2$, the F−C−F bond angle is 106.8° and the Br−C−Cl bond angle is 112.3°. **Explain** the difference in bond angles using principles of atomic structure and VSEPR theory.

Part C

Lewis diagrams and boiling points for CBr_4 and $CBrClF_2$ are given in the following table.

Formula	CBr_4	$CBrClF_2$
Lewis diagram		
Boiling point	463 K	269 K

i. Clearly **identify** all the intermolecular forces in pure $CBr_4(l)$ and in pure $CBrClF_2(l)$.

$CBr_4(l)$:

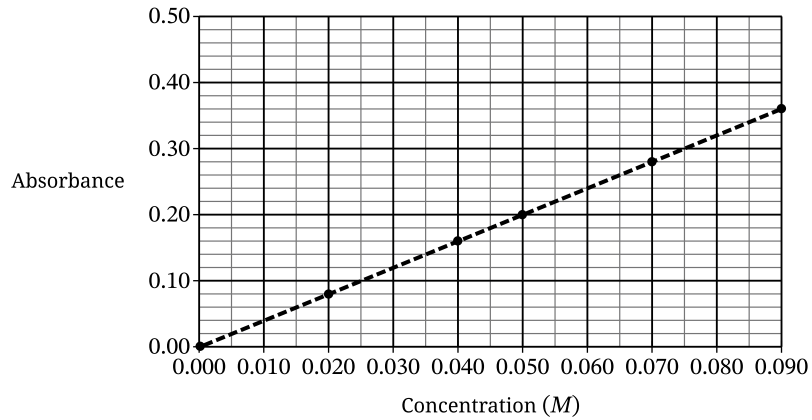
$CBrClF_2(l)$:

ii. In terms of the relative strengths of all the intermolecular forces, **explain** why pure $CBr_4(l)$ has a higher boiling point than pure $CBrClF_2(l)$ does.

Question 6: Version J

6. A student performs a spectrophotometry experiment with $V^{2+}(aq)$ solutions and produces the calibration curve shown in Figure 1 by measuring the absorbance of several solutions of known concentration.

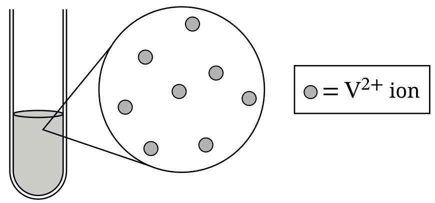
Figure 1



Part A

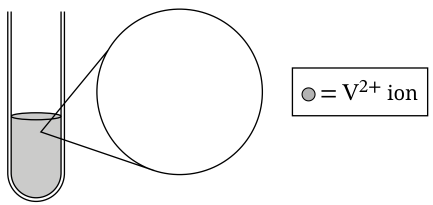
The student measures an absorbance of 0.32 for a $V^{2+}(aq)$ solution. The concentration of V^{2+} ions in the solution is represented by the particle diagram in the circle in Figure 2. In the circle in Figure 3, **draw** the correct number of V^{2+} ions to represent the concentration of a solution with an absorbance of 0.08. (Water molecules have been omitted for clarity. Assume that each particle diagram represents the same volume.)

Figure 2



Absorbance = 0.32

Figure 3



Absorbance = 0.08

Part B

The student measures the absorbance of a different $V^{2+}(aq)$ solution with an unknown molarity, but the absorbance is higher than 0.36 (the upper limit of the graph). The student then transfers 3.00 mL of this $V^{2+}(aq)$ solution to a 25.0 mL volumetric flask, dilutes to the mark on the flask with distilled water, and measures the absorbance of the diluted solution.

i. The absorbance of the diluted solution is 0.22. **Determine** the molarity of $V^{2+}(aq)$ in the diluted solution.

ii. **Determine** the molarity of $V^{2+}(aq)$ in the original, undiluted solution. Show the work that leads to your answer.

Part C

The concentration of $V^{2+}(aq)$ calculated in part B (ii) is lower than the actual concentration of the undiluted solution. The student claims that the calculated concentration is too low because during the dilution step, the final level of the solution was higher than the mark on the volumetric flask. Do you agree or disagree? **Justify** your answer.

Question 7

The following information applies to parts A and B.

7. Sodium metal reacts with oxygen gas according to Equation 1.

$$\text{Equation 1: } 4\,Na(s) + O_2(g) \rightarrow 2\,Na_2O(s) \qquad \Delta H^{\circ}_{rxn} = -828\ \text{kJ/mol}_{rxn}$$

Standard enthalpies of formation are provided in Table 1.

Table 1

Substance	ΔH°_f (kJ/mol)
$Na(s)$	0
$O_2(g)$	0
$Na_2O(s)$	?

Part A

Based on the information given, **calculate** the value of ΔH°_f for $Na_2O(s)$. Show the work that leads to your answer.

Part B

An 18.4 g sample of $Na(s)$ reacts with 12.8 g of $O_2(g)$ according to Equation 1. **Calculate** the total amount of heat, in kilojoules, released during this process. Show the work that leads to your answer.

Part C

Lattice enthalpy can be defined as the energy required to separate an ionic crystal into gaseous ions. $Rb_2O\,(s)$ and $Na_2O\,(s)$ have similar crystal structures, and their lattice enthalpies are given in Table 2.

Table 2

Compound	Lattice Enthalpy (kJ/mol)
$Na_2O\,(s)$	2481
$Rb_2O\,(s)$	2163

Using Coulomb's law, **explain** why the lattice enthalpy of $Rb_2O\,(s)$ is smaller than that of $Na_2O\,(s)$.

STOP

END OF EXAM