AP® CHEMISTRY
2017 SCORING GUIDELINES

Question 1

$$HC_2H_3O_2(aq) + H_2O(l) \rightleftarrows H_3O^+(aq) + C_2H_3O_2^-(aq)$$

The dissociation of ethanoic acid, $HC_2H_3O_2(aq)$, is represented above. A student is given the task of determining the value of K_a for $HC_2H_3O_2(aq)$ using two different experimental procedures.

(a) The student is first asked to prepare 100.0 mL of 0.115 M $HC_2H_3O_2(aq)$ using a 2.000 M standard solution.

(i) Calculate the volume, in mL, of 2.000 M $HC_2H_3O_2(aq)$ the student needs to prepare 100.0 mL of 0.115 M $HC_2H_3O_2(aq)$.

$M_iV_i = M_fV_f$ $V_i = \frac{(0.115\ M)(100.0\ \text{mL})}{2.000\ M} = 5.75\ \text{mL}$	1 point is earned for the correct volume.

(ii) Describe the procedure the student should use to prepare 100.0 mL of 0.115 M $HC_2H_3O_2(aq)$ using appropriate equipment selected from the list below. Assume that the student uses appropriate safety equipment.

- 100 mL beaker
- 100 mL graduated cylinder
- 100 mL volumetric flask
- Eye dropper
- 500 mL wash bottle filled with distilled water
- 2.000 M $HC_2H_3O_2(aq)$ in a 50 mL buret

Use the buret to deliver 5.75 mL of 2.000 M $HC_2H_3O_2$ to the 100 mL volumetric flask. Then add distilled water from the wash bottle to the flask (adding the last few drops with an eyedropper) until the volume of liquid in the flask is at the calibration mark.	1 point is earned for dispensing from the buret. 1 point is earned for diluting the solution to the calibration mark of the volumetric flask.

Question 1 (continued)

(b) Using a pH probe, the student determines that the pH of 0.115 *M* $HC_2H_3O_2(aq)$ is 2.92.

(i) Using the pH value, calculate the value of K_a for $HC_2H_3O_2(aq)$.

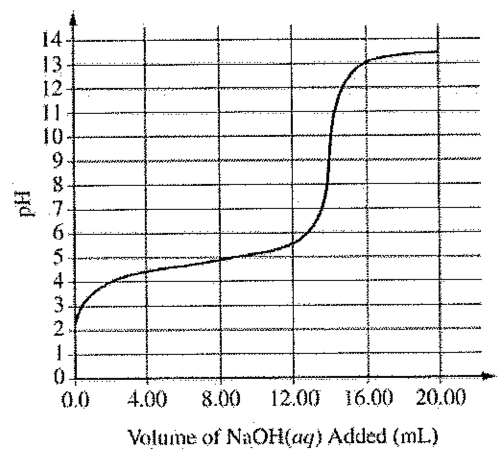
$pH = 2.92 \Rightarrow [H_3O^+] = 10^{-2.92} = 0.0012\ M$ $K_a = \frac{[H_3O^+][C_2H_3O_2^-]}{[HC_2H_3O_2]}$ Since $[H_3O^+] = [C_2H_3O_2^-]$, then $K_a = \frac{(0.0012)(0.0012)}{(0.115 - 0.0012)} = \frac{(0.0012)^2}{(0.114)} = 1.3 \times 10^{-5}$	1 point is earned for correct conversion of pH to $[H_3O^+]$. 1 point is earned for a value of K_a consistent with the student's value of $[H_3O^+]$.

(ii) Calculate the percent dissociation of ethanoic acid in 0.115 *M* $HC_2H_3O_2(aq)$.

Percent dissociation = $\frac{[C_2H_3O_2^-]}{[HC_2H_3O_2]_0} = \frac{0.0012}{0.115} \times 100 = 1.0\%$	1 point is earned for the correct percent dissociation.

In a separate experimental procedure, the student titrates 10.0 mL of the 2.000 *M* $HC_2H_3O_2(aq)$ with an $NaOH(aq)$ solution of unknown concentration. The student monitors the pH during the titration. The following titration curve was created using the experimental data presented in the table.

Volume of NaOH(*aq*) Added (mL)	pH
0.00	2.23
2.00	3.99
4.00	4.37
6.00	4.65
8.00	4.90
10.00	5.17
12.00	5.55
14.00	9.35
16.00	13.04
18.00	13.31
20.00	13.46



Question 1 (continued)

(c) Write the balanced net ionic equation for the reaction that occurs when $HC_2H_3O_2(aq)$ and $NaOH(aq)$ are combined.

$HC_2H_3O_2(aq) + OH^-(aq) \rightarrow C_2H_3O_2^-(aq) + H_2O(l)$	1 point is earned for the correct equation.

(d) Calculate the molar concentration of the $NaOH(aq)$ solution.

From the pH curve, the equivalence point occurs at 14.0 mL. $10.0 \text{ mL} \times \frac{2.000 \text{ mol } HC_2H_3O_2}{1000 \text{ mL}} = 0.0200 \text{ mol } HC_2H_3O_2(aq)$	1 point is earned for determining the moles of acid.
$0.0200 \text{ mol } HC_2H_3O_2(aq) \times \frac{1 \text{ mol NaOH}}{1 \text{ mol } HC_2H_3O_2} = 0.0200 \text{ mol NaOH}$ $\frac{0.0200 \text{ mol NaOH}}{0.0140 \text{ L solution}} = 1.43\ M \text{ NaOH}(aq)$	1 point is earned for determining the molar concentration of the base.

(e) Explain how the student can estimate the value of K_a for $HC_2H_3O_2(aq)$ using the titration curve.

At the half-equivalence point (~7.0 mL) the pH of the solution is equal to the pK_a of the acid. The antilog of the negative pH is equal to the value of K_a.	1 point is earned for a correct explanation (numerical explanation not required).

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Question 2

$$H_2O_2(aq) + OCl^-(aq) \rightarrow H_2O(l) + Cl^-(aq) + O_2(g)$$

A student investigates the reaction between $H_2O_2(aq)$ and $NaOCl(aq)$, which is represented by the net-ionic equation shown above.

(a) Is the reaction represented above a redox reaction? Justify your answer.

The reaction <u>is</u> a redox reaction because the oxidation numbers of some atoms changed during the reaction (both oxygen and chlorine undergo changes in oxidation number).	1 point is earned for the correct answer along with a valid justification.

To better understand the reaction, the student looks up thermodynamic data for the reaction. For the reaction represented above, the value of ΔG°_{298} is -197 kJ/mol$_{rxn}$ and the value of ΔS°_{298} is 144 J/(K·mol$_{rxn}$).

(b) Calculate the value of ΔH°_{298} for the reaction in kJ/mol$_{rxn}$.

$\Delta H^\circ = \Delta G^\circ + T\Delta S^\circ$ $= -197\ \text{kJ/mol}_{rxn} + (298\ \text{K})\left(\frac{144\ \text{J}}{\text{K}\cdot\text{mol}_{rxn}}\right)\left(\frac{1\ \text{kJ}}{1000\ \text{J}}\right)$ $= -154\ \text{kJ/mol}_{rxn}$	1 point is earned for the correct calculation of ΔH°.

(c) Does the temperature inside the flask increase, decrease, or remain the same as the reaction proceeds? Justify your answer.

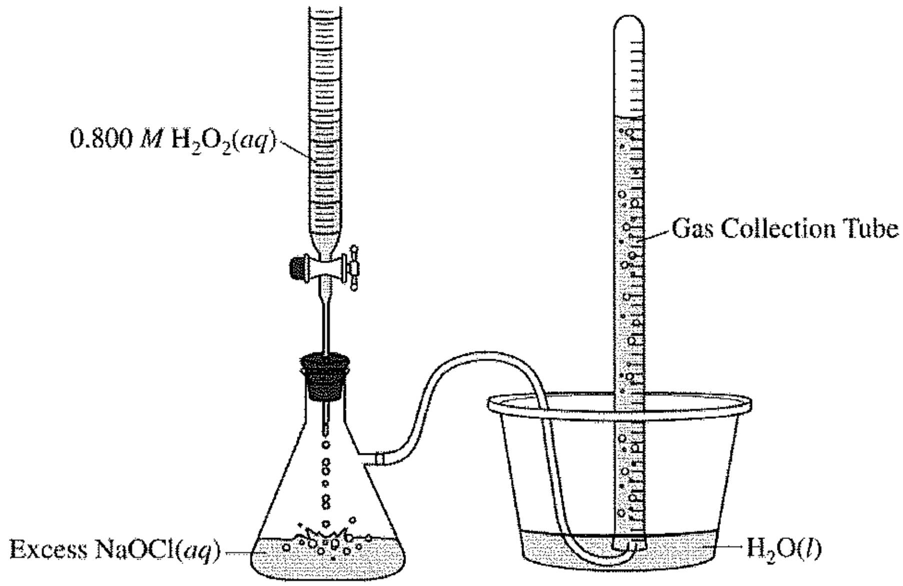
The temperature increases because the reaction is exothermic ($\Delta H^\circ < 0$).	1 point is earned for indicating an increase in temperature with a valid justification.

(d) Calculate the value of the equilibrium constant, K, for the reaction at 298 K.

$\Delta G^\circ = -RT \ln K$ $K = e^{\frac{-\Delta G^\circ}{RT}} = e^{\frac{-(-197{,}000\ \text{J/mol})}{(8.314\ \text{J/(mol·K)})(298\ \text{K})}} = e^{79.5} = 3 \times 10^{34}$	1 point is earned for the correct value of K with evidence of calculation.

The student decides to produce 40.0 mL of $O_2(g)$ at a pressure of 0.988 atm and a temperature of 298 K using the reaction represented above. The student uses the equipment shown below. The student sets up a 250 mL Erlenmeyer flask fitted with a one-hole stopper. The flask is connected to a 50 mL gas-collection tube that initially is completely filled with water.

Question 2 (continued)

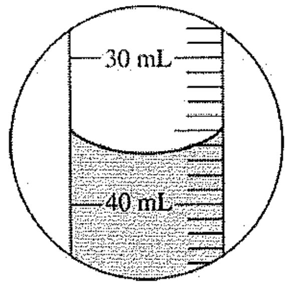


(e) Calculate the volume of 0.800 *M* $H_2O_2(aq)$ that the student should add to excess NaOCl(*aq*) to produce 40.0 mL of $O_2(g)$ at 0.988 atm and 298 K.

$PV = nRT$ $n = \frac{PV}{RT} = \frac{(0.988\text{ atm})(0.0400\text{ L})}{(0.08206\text{ L atm mol}^{-1}\text{ K}^{-1})(298\text{ K})} = 0.00162\text{ mol }O_2$	1 point is earned for calculating the number of moles of O_2 needed.
$0.00162\text{ mol }O_2 \times \frac{1\text{ mol }H_2O_2}{1\text{ mol }O_2} = 0.00162\text{ mol }H_2O_2$ needed $0.00162\text{ mol }H_2O_2 \times \frac{\text{L}}{0.800\text{ mol }H_2O_2} = 0.00202\text{ L}$	1 point is earned for calculating the volume of H_2O_2 solution that should be added.

Question 2 (continued)

(f) The student added the amount of $H_2O_2(aq)$ calculated in part (e) to excess $NaOCl(aq)$. However, instead of producing 40.0 mL of $O_2(g)$, the volume indicated in the diagram below was produced.



(i) Based on the diagram above, what volume of gas was produced?

36.5 mL (values within ± 0.4 of 36.5 are acceptable)	1 point is earned for the correct reading of the meniscus level to **three** significant figures.

(ii) Assuming that all the gas in the tube is $O_2(g)$, calculate the percent yield of $O_2(g)$.

$\text{percent yield} = \dfrac{\text{actual yield}}{\text{theoretical yield}} = \dfrac{36.5\text{ mL}}{40.0\text{ mL}} \times 100 = 91.3\%$	1 point is earned for the correct percent yield.

(iii) Is the assumption that all the gas in the tube is $O_2(g)$ correct? Explain.

No, the gas also contains water vapor and air that was originally in the flask.	1 point is earned for the correct answer with a valid explanation. (Only **one** of the two extra gases is required for the point.)

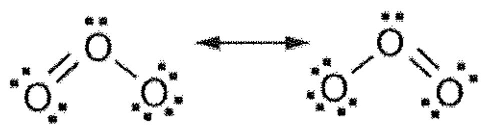
(g) To account for the percent yield being less than 100 percent, the student claims that the reaction reached equilibrium before the expected amount of $O_2(g)$ was produced. Considering your answer to part (d) above, do you agree or disagree with the student's claim? Justify your answer.

Disagree. The very large value of K implies that the reaction goes essentially to completion, so essentially all of the H_2O_2 reacts to form O_2.	1 point is earned for an appropriate conclusion and valid justification based on the value of K in part (d).

Question 3

Answer the following questions about ozone.

(a) The O_3 molecule has a central oxygen atom bonded to two outer oxygen atoms that are not bonded to one another. In the box below, draw the Lewis electron-dot diagram of the O_3 molecule. Include all valid resonance structures.

	1 point is earned for a diagram that includes all 18 valence electrons and obeys the octet rule. 1 point is earned for showing correct application of resonance.

(b) Based on the diagram you drew in part (a), what is the shape of the ozone molecule?

The ozone molecule has a bent shape.	1 point is earned for the shape based on student's Lewis diagram.

Ozone decomposes according to the reaction represented below.

$$2\ O_3(g) \rightarrow 3\ O_2(g) \qquad \Delta H° = -285\ \text{kJ/mol}_{rxn}$$

(c) The bond enthalpy of the oxygen-oxygen bond in O_2 is 498 kJ/mol. Based on the enthalpy of the reaction represented above, what is the average bond enthalpy, in kJ/mol, of an oxygen-oxygen bond in O_3 ?

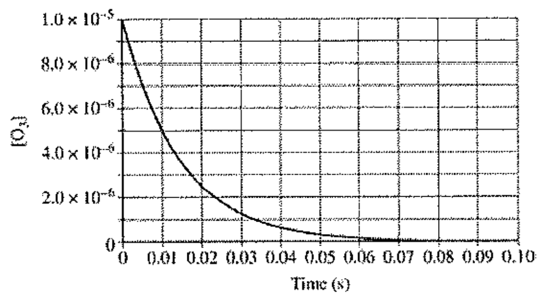
$\Delta H° = \Sigma$ (bond enthalpies)$_{reactants}$ − Σ (bond enthalpies)$_{products}$ Four equivalent bonds are broken in two O_3 molecules. Three oxygen-oxygen bonds are formed in three O_2 molecules. Let x = the bond enthalpy in ozone, therefore $4x - 3(498\ \text{kJ/mol}) = -285\ \text{kJ/mol}_{rxn}$ $x = 302$ kJ/mol	1 point is earned for the correct determination of the number of bonds broken in the reactants and the number of bonds formed in the products. 1 point is earned for the calculation of the energy of the bonds in O_3 consistent with bond counting, the bond energy of O_2, and the $\Delta H°_{rxn}$.

Ozone can oxidize $HSO_3^-(aq)$, as represented by the equation below.

$$HSO_3^-(aq) + O_3(aq) \rightarrow HSO_4^-(aq) + O_2(g)$$

Question 3 (continued)

A solution is prepared in which the initial concentration of $HSO_3^-(aq)$ (6.4×10^{-4} *M*) is much larger than that of $O_3(aq)$ (1.0×10^{-5} *M*). The concentration of $O_3(aq)$ is monitored as the reaction proceeds, and the data are plotted in the graph below.



(d) The data are consistent with the following rate law: rate = $k_1\,[O_3]$.

(i) Based on the graph on the previous page, determine the half-life of the reaction.

Half-life = 0.010 s	1 point is earned for the correct answer.

(ii) Determine the value of the rate constant, k_1, for the rate law. Include units with your answer.

$t_{1/2} = \frac{0.693}{k_1} \Rightarrow k_1 = \frac{0.693}{t_{1/2}} = \frac{0.693}{0.010\text{ s}} = 69\text{ s}^{-1}$	1 point is earned for the correct value. 1 point is earned for the correct unit.

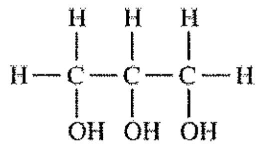
(iii) Considering the relative concentrations of the reactants, briefly explain why the data in the graph are also consistent with the following rate law: rate = $k_2[O_3][HSO_3^-]$.

The data are consistent with rate = $k_2[O_3][HSO_3^-]$ because $[HSO_3^-]$ remains essentially constant during the experiment. ($[HSO_3^-]$ can be contained in the rate constant k_1.)	1 point is earned for a correct explanation.

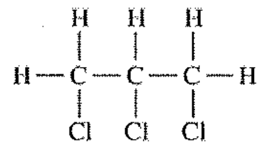
(iv) Briefly describe an experiment that could provide evidence to support the rate law given in part (d)(iii).

Repeat the experiment with a different initial concentration of HSO_3^-. (If the change in the rate of the reaction is directly proportional to the change in $[HSO_3^-]$, then the reaction is first order with respect to HSO_3^-.)	1 point is earned for describing a valid experiment.

Question 4



Glycerol
Boiling point 290°C



Trichloropropane
Boiling point 157°C

The structural formulas of glycerol and trichloropropane are given above. Both compounds are liquids at 25°C.

(a) For each compound, identify all types of intermolecular forces present in the liquid. Explain why glycerol has the higher boiling point in terms of the relative strengths of the intermolecular forces.

Each substance has intermolecular London dispersion forces and dipole-dipole forces. Glycerol also has hydrogen bonding. The presence of hydrogen bonding in glycerol results in the total intermolecular forces in glycerol being stronger than the total intermolecular forces in trichloropropane.	1 point is earned for identifying the IMFs in <u>each</u> liquid. 1 point is earned for a correct explanation.

(b) Glycerol (molar mass 92.09 g/mol) has been suggested for use as an alternative fuel. The enthalpy of combustion, ΔH°_{comb}, of glycerol is −1654 kJ/mol. What mass of glycerol would need to be combusted to heat 500.0 g of water from 20.0°C to 100.0°C ? (The specific heat capacity of water is 4.184 J/(g·°C). Assume that all the heat released by the combustion reaction is absorbed by the water.)

$q_{H_2O} = mc\Delta T = (500.0\text{ g}) \times (4.184\text{ J/(g·°C)}) \times (100.0°\text{C} - 20.0°\text{C})$ $= 167{,}000\text{ J} = 167\text{ kJ}$ $-q_{H_2O} = q_{comb}$ $-167\text{ kJ} \times \frac{1\text{ mol glycerol}}{-1654\text{ kJ}} \times \frac{92.09\text{ g glycerol}}{1\text{ mol glycerol}} = 9.30\text{ g glycerol}$	1 point is earned for a correct calculation of q. 1 point is earned for the correct mass of glycerol.

Question 5

Overall reaction: $Pb(s) + PbO_2(s) + 2\ H^+(aq) + 2\ HSO_4^-(aq) \rightarrow 2\ PbSO_4(s) + 2\ H_2O(l)$

Cathode half-cell reaction: $PbO_2(s) + 3\ H^+(aq) + HSO_4^-(aq) + 2\ e^- \rightarrow PbSO_4(s) + 2\ H_2O(l)$

The equations above represent reactions associated with the operation of a lead storage battery. The first is the overall reaction that occurs as the battery produces an electrical current, and the second is the half-reaction that occurs at the cathode.

(a) Determine the oxidation number of sulfur in the overall reaction.

+6	1 point is earned for the correct answer.

(b) Write the equation for the half-reaction that occurs at the anode as the battery operates.

$Pb(s) + HSO_4^-(aq) \rightarrow PbSO_4(s) + H^+(aq) + 2\ e^-$	1 point is earned for a correct equation.

After the battery has operated for some time, it can be recharged by applying a current to reverse the overall reaction.

(c) Calculate the time, in seconds, needed to regenerate 100. g of Pb(*s*) in the battery by applying a current of 5.00 amp.

$100.\ \text{g Pb} \times \frac{1\ \text{mol Pb}}{207.2\ \text{g}} = 0.483\ \text{mol Pb}$ $0.483\ \text{mol Pb} \times \frac{2\ \text{mol}\ e^-}{1\ \text{mol Pb}} = 0.966\ \text{mol}\ e^-$	1 point is earned for the correct number of moles of electrons (may be implicit).
$0.966\ \text{mol}\ e^- \times \frac{96{,}485\ \text{C}}{1\ \text{mol}\ e^-} = 93{,}200\ \text{C}$ $I = \frac{q}{t} \Rightarrow t = \frac{q}{I}$ $\frac{93{,}200\ \text{C}}{5.00\ \text{amp}} \times \frac{1\ \text{amp}}{1\ \text{C/s}} = 18{,}600\ \text{s}$	1 point is earned for the correct time based on the moles of electrons.

Question 6

Answer the following questions about the solubility of $AgCl(s)$. The value of K_{sp} for $AgCl(s)$ is 1.8×10^{-10}.

(a) Calculate the value of $[Ag^+]$ in a saturated solution of $AgCl$ in distilled water.

$K_{sp} = [Ag^+][Cl^-]$ Let $x = [Ag^+] = [Cl^-]$ Then $1.8 \times 10^{-10} = (x)(x) \Rightarrow x = \sqrt{1.8 \times 10^{-10}}$ $x = [Ag^+] = 1.3 \times 10^{-5}\ M$	1 point is earned for the correct K_{sp} expression and indication that the two ions have equal concentrations. 1 point is earned for correct calculation of the value of $[Ag^+]$.

(b) The concentration of $Cl^-(aq)$ in seawater is $0.54\ M$.

(i) Calculate the molar solubility of $AgCl(s)$ in seawater.

$1.8 \times 10^{-10} = [Ag^+] \times (0.54) \Rightarrow [Ag^+] = 3.3 \times 10^{-10}\ M$	1 point is earned for the correct answer with supporting work.

(ii) Explain why $AgCl(s)$ is less soluble in seawater than in distilled water.

An increased $[Cl^-]$ will decrease the solubility of $AgCl(s)$ since the K_{sp} is a product of the $[Ag^+]$ and $[Cl^-]$. (This is an example of the common ion effect.)	1 point is earned for a correct explanation.

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Question 7

A new element with atomic number 116 was discovered in 2000. In 2012 it was named livermorium, Lv. Although Lv is radioactive and short-lived, its chemical properties and reactivity should follow periodic trends.

(a) Write the electron configuration for the valence electrons of Lv in the ground state.

$7s^2\ 7p^4$	1 point is earned for the correct configuration.

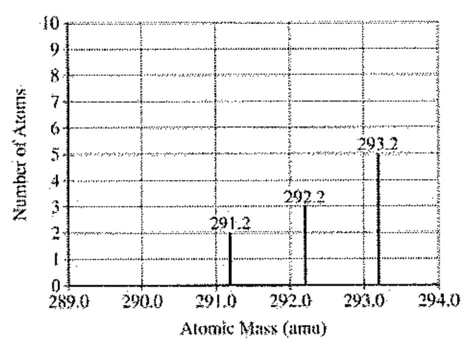
(b) According to periodic properties, what would be the most likely formula for the product obtained when Lv reacts with $H_2(g)$?

LvH_2 (or H_2Lv)	1 point is earned for the correct formula.

(c) The first ionization energy of polonium, Po, is 812 kJ/mol. Is the first ionization energy of Lv expected to be greater than, less than, or equal to that of Po? Justify your answer in terms of Coulomb's law.

Less than that of Po. The two atoms have comparable effective nuclear charges, but the valence electrons in Lv would be at a greater distance from the nucleus than those in Po. By Coulomb's law, the attractive force between the valence electrons and the nucleus decreases by the inverse square of the distance between them.	1 point is earned for a correct prediction <u>with</u> a valid justification.

(d) Shown below is a hypothetical mass spectrum for a sample of Lv containing 10 atoms.



Using the information in the graph, determine the average atomic mass of Lv in the sample to four significant figures.

Average atomic mass $= \frac{2}{10}(291.2) + \frac{3}{10}(292.2) + \frac{5}{10}(293.2) = 292.5$ amu	1 point is earned for the correct average atomic mass.

2017 AP Chemistry Scoring Worksheet

Section I: Multiple Choice

__________ × 1.0000 = ______________

Number Correct (out of 50) — Weighted Section I Score (Do not round)

Section II: Free Response

Question 1 ________ (out of 10) × 1.0869 = ________ (Do not round)

Question 2 ________ (out of 10) × 1.0869 = ________ (Do not round)

Question 3 ________ (out of 10) × 1.0869 = ________ (Do not round)

Question 4 ________ (out of 4) × 1.0869 = ________ (Do not round)

Question 5 ________ (out of 4) × 1.0869 = ________ (Do not round)

Question 6 ________ (out of 4) × 1.0869 = ________ (Do not round)

Question 7 ________ (out of 4) × 1.0869 = ________ (Do not round)

Sum = ________

Weighted Section II Score (Do not round)

Composite Score

__________ + __________ = __________

Weighted Section I Score + Weighted Section II Score = Composite Score (Round to nearest whole number)

AP Score Conversion Chart
Chemistry

Composite Score Range	AP Score
79-100	5
64-78	4
44-63	3
28-43	2
0-27	1