2025

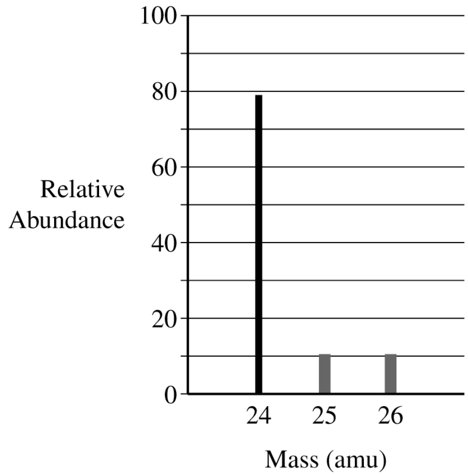
AP® Chemistry

Scoring Guidelines

Question 1: Long Answer — 10 points

A (i) For the correct plotted lines: **Point 01**

The abundance for the two lines should be between 10 and 11.



(ii) For the correct answer: **Point 02**

Magnesium-26 has one more neutron than magnesium-25 does.

B (i) For a correct explanation: **Point 03**

The charge on the sodium ion is less than the charge on the magnesium ion. A smaller charge results in a weaker Coulombic attraction between Na^{+} *and water.*

(ii) For a correct explanation: **Point 04**

The Na^{+} *ion is larger than the* Mg^{2+} *ion, so the distance between the* Na^{+} *and the oxygen on the water molecule will be greater. As distance increases, Coulombic attraction decreases.*

C For the correct calculated value: **Point 05**

$$\text{pOH} = -\log(2.80 \times 10^{-4}) = 3.553$$

$$\text{pH} = 14 - \text{pOH} = 14 - 3.553 = 10.447$$

D For the correct calculated value: **Point 06**

$$M_1V_1 = M_2V_2$$

$$M_2 = \frac{(1.85 \times 10^{-3}\,M)(0.03500\text{ L})}{(0.03500\text{ L} + 0.05000\text{ L})} = 7.62 \times 10^{-4}\,M$$

E	(i) For the correct expression: $K_{sp} = [Mg^{2+}][OH^-]^2$	**Point 07**
	(ii) For the correct calculated value, consistent with part D and part E (i): $Q = [Mg^{2+}][OH^-]^2 = (7.62 \times 10^{-4})(1.65 \times 10^{-4})^2 = 2.07 \times 10^{-11}$	**Point 08**
	(iii) For the correct prediction and justification, consistent with part E (ii). Examples of acceptable responses may include the following: • *$Q > K_{sp}$, so a precipitate will form.* • *The concentration of the ions in solution (represented by Q) is greater than that of a saturated solution, so a precipitate will form.*	**Point 09**
F	For the correct answer and justification: *Decrease. The H^+ from $HNO_3(aq)$ will react with OH^-, decreasing $[OH^-]$ and causing $Q < K_{sp}$. As a result, more $Mg(OH)_2(s)$ will dissolve until equilibrium is reestablished, resulting in less $Mg(OH)_2(s)$.*	**Point 10**

Question 2: Long Answer — 10 points

A (i) For the correct calculated value: **Point 01**

$$2.883 \text{ g } H_2O \times \frac{1 \text{ mol } H_2O}{18.02 \text{ g } H_2O} = 0.1600 \text{ mol } H_2O$$

(ii) For the correct calculated number of moles of H (may be implicit): **Point 02**

$$0.1600 \text{ mol } H_2O \times \frac{2 \text{ mol H}}{1 \text{ mol } H_2O} = 0.3200 \text{ mol H}$$

For the correct empirical formula. **Point 03**

Examples of acceptable responses may include the following:

- $x : y : z$ = (moles of C):(moles of H):(moles of O)

  $x : y : z = 0.2400 : 0.3200 : 0.2400 = 3 : 4 : 3$

  Therefore, the empirical formula of ascorbic acid is $C_3H_4O_3$.

- $0.2400 \text{ mol } CO_2 \times \frac{1 \text{ mol C}}{1 \text{ mol } CO_2} = 0.2400 \text{ mol C}$

  $\frac{0.3200 \text{ mol H}}{0.2400 \text{ mol C}} = \frac{4 \text{ H}}{3 \text{ C}}$

  Given that the ratio of C:O *is* 1:1, *the empirical formula of ascorbic acid is* $C_3H_4O_3$.

B (i) For the correct calculated value: **Point 04**

$$0.0160 \text{ L NaOH} \times \frac{0.0550 \text{ mol NaOH}}{1 \text{ L NaOH}} \times \frac{1 \text{ mol HAsc}}{1 \text{ mol NaOH}} = 8.80 \times 10^{-4} \text{ mol HAsc}$$

$$\frac{8.80 \times 10^{-4} \text{ mol HAsc}}{0.0100 \text{ L}} = 0.0880\ M \text{ HAsc}$$

(ii) For the correct pK_a: **Point 05**

4.1 (*acceptable range:* 4.0 – 4.3)

(iii) For the correct ratio, consistent with part B (ii): **Point 06**

Using the Henderson-Hasselbalch equation:

$$pH = pK_a + \log\left(\frac{[Asc^-]}{[HAsc]}\right)$$

$$4.7 = 4.1 + \log\left(\frac{[Asc^-]}{[HAsc]}\right)$$

$$\frac{[Asc^-]}{[HAsc]} = 10^{0.6} = 4.0$$

C (i) For a correct explanation. **Point 07**

Examples of acceptable responses may include the following:

- $\frac{4.914 \times 10^{-4}}{2.457 \times 10^{-4}} = \left(\frac{0.900}{0.450}\right)^{a}$, thus $a = 1$
- *Comparing trials 1 and 3, the rate doubles when the concentration of ascorbic acid is doubled and the triiodide ion concentration is constant, indicating that the process is first order with respect to ascorbic acid.*

(ii) For the correct calculated value: **Point 08**

$rate = k[\text{HAsc}][\text{I}_3^{\,-}]$

Using trial 1 data:

$$k = \frac{rate}{[\text{HAsc}][\text{I}_3^{\,-}]} = \frac{2.457 \times 10^{-4}\ M/\text{s}}{(0.450\ M)(1.200\ M)} = 4.55 \times 10^{-4} M^{-1}\ \text{s}^{-1}$$

For the correct units: **Point 09**

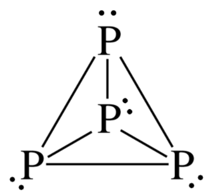
$M^{-1}\ \text{s}^{-1}$

D For the correct answer: **Point 10**

Ion-dipole attractions are present between $\text{I}_3^{\,-}$ *ions and water but not between* I_2 *molecules and water.*

Question 3: Long Answer — 10 points

A For the correct diagram: **Point 01**



B (i) For a correct explanation: **Point 02**

Because gas particles are more dispersed (have more microstates) than solids, the entropy decreases as the reactants (which include a gas) convert to the solid product.

(ii) For the correct answer and a valid justification: **Point 03**

Yes. Given that $\Delta G^\circ_{rxn} = \Delta H^\circ_{rxn} - T\Delta S^\circ_{rxn}$, *the reaction must have* $\Delta G^\circ_{rxn} < 0$ *to be favorable. Because the reaction is exothermic,* $\Delta H^\circ_{rxn} < 0$ *and enthalpy contributes to favorability.* $\Delta S^\circ_{rxn} < 0$, *so entropy does not contribute to favorability.*

C (i) For the correct calculated value reported with the correct number of significant figures: **Point 04**

$q = mc\Delta T = (100.1\text{ g})(4.18\text{ J/(g}\cdot{}^\circ\text{C)})(22.38^\circ\text{C} - 22.00^\circ\text{C})$

$q = 160\text{ J} = 0.16\text{ kJ}$

(ii) For the correct calculated value, consistent with part C (i): **Point 05**

$q_{rxn} = -q_{surr} = -0.16\text{ kJ}$

$$\Delta H^\circ_{rxn} = \frac{-0.16\text{ kJ}}{0.100\text{ g }P_4O_{10}} \times \frac{283.9\text{ g }P_4O_{10}}{1\text{ mol }P_4O_{10}} \times \frac{1\text{ mol }P_4O_{10}}{1\text{ mol}_{rxn}} = -450\text{ kJ/mol}_{rxn}$$

For the correct sign: **Point 06**

-450 kJ/mol_{rxn}

D For the correct answer and a valid justification: **Point 07**

Less than. If less P_4O_{10} *is present, less thermal energy will be transferred to the water during the reaction, causing the temperature increase to be less than it was with* 0.100 g *of* P_4O_{10}.

E	For the correct calculated value: *Using Hess's law:* $\Delta H^\circ_{f,\ PCl_5(g)} = \frac{1}{4}\Delta H^\circ_1 + \Delta H^\circ_2$ $\Delta H^\circ_{f,\ PCl_5(g)} = \frac{1}{4}(-1148) + (-88) = -375\ \text{kJ/mol}$	**Point 08**
F	(i) For the correct calculated value: $K_p = \frac{P_{PCl_5}}{(P_{PCl_3})(P_{Cl_2})} = \frac{4.00}{(2.00)(6.00)} = \frac{1}{3} = 0.333$	**Point 09**
	(ii) For the correct answer and a valid justification: *Decrease. The negative value of ΔH°_2 indicates that the reaction is exothermic. Because exothermic reactions favor reactant formation at higher temperature, the value of K_p decreases.*	**Point 10**

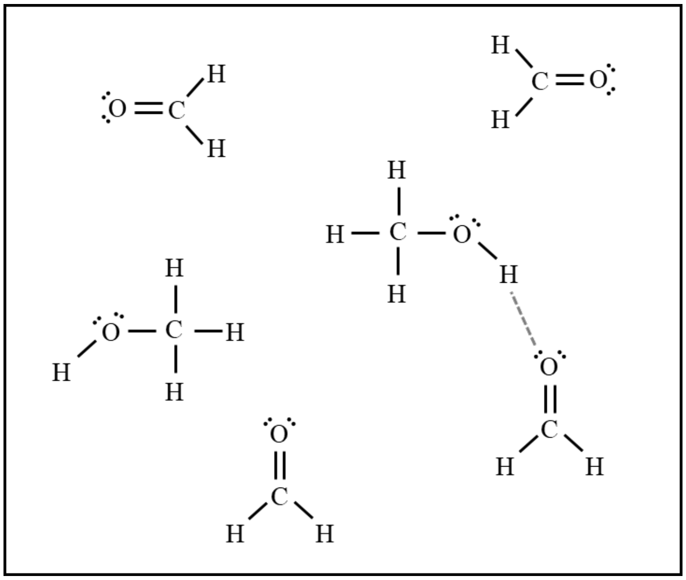
Question 4: Short Answer — 4 points

A For the correct answer: **Point 01**

sp^2

B For a correct diagram: **Point 02**

The diagram should show a dashed line between the O *atom in one* H_2CO *molecule and the* H *atom in the* –OH *group of one* CH_3OH *molecule. See example response below.*



C (i) For a correct proposal: **Point 03**

The proposed temperature should be in the range 181 K – 254 K .

(ii) For the correct calculated value: **Point 04**

$$8.59 \text{ g } CH_3OH \times \frac{1 \text{ mol } CH_3OH}{32.04 \text{ g } CH_3OH} \times \frac{-37.6 \text{ kJ}}{1 \text{ mol } CH_3OH} = -10.1 \text{ kJ}$$, *so* 10.1 kJ *are removed.*

Question 5: Short Answer — 4 points

A	For the correct answer: *Tetrahedral*	**Point 01**
B	For the correct answer and a valid justification: *Agree. Compound* Y *has a larger, more polarizable electron cloud because the* Si *atom has more occupied electron shells than the* C *atom, giving compound* Y *stronger London dispersion forces and a higher boiling point than compound* X.	**Point 02**
C	For the correct answer and a valid justification. Examples of acceptable responses may include the following: • *Compound* X. *Compound* X *has weaker intermolecular forces than compound* Y*, so molecules of* X *are more likely to be in the gas phase at* 82°C *and would therefore have a higher vapor pressure.* • *Compound* X. *At* 82°C*, compound* X *has reached its boiling point, but compound* Y *has not. Therefore, the proportion of* X *molecules in the vapor phase would be much greater than that of compound* Y*, giving compound* X *the higher vapor pressure.*	**Point 03**
D	For the correct calculated value: $PV = nRT$ $n = \frac{PV}{RT} = \frac{(2.30 \text{ atm})(12.5 \text{ L})}{(0.08206 \frac{\text{L}\cdot\text{atm}}{\text{K}\cdot\text{mol}})(471\text{K})} = 0.744 \text{ mol}$	**Point 04**

Question 6: Short Answer — 4 points

A For the correct equation (state symbols not required): **Point 01**

$Al(s) \rightarrow Al^{3+}(aq) + 3\,e^-$

B For the correct balanced net ionic equation (state symbols not required): **Point 02**

$2\,Al(s) + 3\,Zn^{2+}(aq) \rightarrow 2\,Al^{3+}(aq) + 3\,Zn(s)$

C For the correct answer and a valid justification that correctly compares the masses of Al and Zn based on their molar masses and the stoichiometry of the balanced equation. **Point 03**

Examples of acceptable responses may include the following:

- Zn *experiences a greater change in mass. Assuming the entire* Al *anode reacts:*

  $$50.0\text{ g Al} \times \frac{1\text{ mol Al}}{26.98\text{ g Al}} \times \frac{3\text{ mol Zn}}{2\text{ mol Al}} \times \frac{65.38\text{ g Zn}}{1\text{ mol Zn}} = 182\text{ g Zn}$$

- Zn *experiences a greater change in mass.*

  $$1\text{ mol}_{rxn} \times \frac{3\text{ mol Zn}}{1\text{ mol}_{rxn}} \times \frac{65.38\text{ g Zn}}{1\text{ mol Zn}} = 196.1\text{ g Zn}$$

  $$1\text{ mol}_{rxn} \times \frac{2\text{ mol Al}}{1\text{ mol}_{rxn}} \times \frac{26.98\text{ g Al}}{1\text{ mol Al}} = 53.96\text{ g Al}$$

  Thus, for however many moles of reaction that proceed, the mass of Zn *produced will be greater than the mass of* Al *consumed.*

- Zn *experiences a greater change in mass. As the reaction proceeds, three moles of* Zn *are used for every two moles of* Al. *Thus, for every* 196 g *of* Zn *that are produced,* 54 g *of* Al *are consumed.*

D For the correct calculated value. **Point 04**

Examples of acceptable responses may include the following:

- $E^\circ_{cell} = 1.50\text{ V} + 0.76\text{ V} = 2.26\text{ V}$

- $Au^{3+}(aq) + 3\,e^- \rightarrow Au(s) \qquad +1.50\text{ V}$

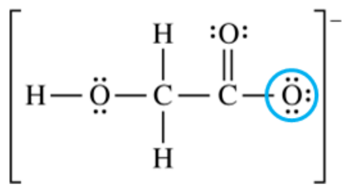
  $Zn(s) \rightarrow Zn^{2+}(aq) + 2\,e^- \qquad +0.76\text{ V}$

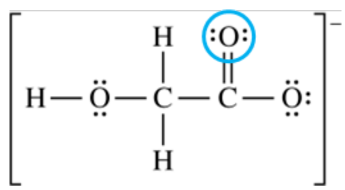
  $E^\circ_{cell} = 2.26\text{ V}$

Question 7: Short Answer — 4 points

A For a correct circled atom. **Point 01**

Accept one of the following:

- 

- 

(Because of resonance, the two C−O *bonds on the right are equivalent.)*

B (i) For the correct calculated value: **Point 02**

$$K_b = \frac{[HC_2H_3O_3][OH^-]}{[C_2H_3O_3^-]} = \frac{(1.3\times10^{-5})(1.3\times10^{-5})}{(2.5-1.3\times10^{-5})} \approx \frac{(1.3\times10^{-5})^2}{(2.5)} = 6.8\times10^{-11}$$

(ii) For the correct calculated value, consistent with part B (i): **Point 03**

$$K_a = \frac{K_w}{K_b} = \frac{1.0\times10^{-14}}{6.8\times10^{-11}} = 1.5\times10^{-4}$$

C For the correct answer and a valid justification: **Point 04**

Agree. H_3O^+ *is consumed in step 1 and regenerated in step 2, which is consistent with the behavior of a catalyst.*