AP® CollegeBoard

2020 Exam Sample Questions

AP® CHEMISTRY

Sample Question 1

Time allotted: 25 minutes (plus 5 minutes to submit)

Common additives to drinking water include elemental chlorine, chloride ions, and phosphate ions. Recently, reports of elevated lead levels in drinking water have been reported in cities with pipes that contain lead, $Pb(s)$. When $Cl_2(aq)$ flows through a metal pipe containing $Pb(s)$, some of the lead atoms oxidize, losing two electrons each, and aqueous chloride ions form.

(a) Write a balanced, net-ionic equation for the reaction between $Pb(s)$, and $Cl_2(aq)$.

Dissolution reactions and K_{sp} values for two lead compounds are given in the following table.

Dissolution Reaction	K_{sp}
$PbCl_2(s) \rightleftarrows Pb^{2+}(aq) + 2\ Cl^-(aq)$	1.6×10^{-5}
$Pb_3(PO_4)_2(s) \rightleftarrows 3\ Pb^{2+}(aq) + 2\ PO_4^{3-}(aq)$	1.08×10^{-53}

(b) Write the K_{sp} expression for the dissolution of $Pb_3(PO_4)_2(s)$ in water.

(c) Calculate the molar solubility of $Pb_3(PO_4)_2(s)$.

(d) Using the table of K_{sp} values above, explain why the addition of $PO_4^{3-}(aq)$ is more effective at reducing $[Pb^{2+}]$ in drinking water than $Cl^-(aq)$.

(e) Cities try to maintain a maximum dissolved lead concentration of $[Pb^{2+}] = 1.0 \times 10^{-9}\ M$. If a sample of water has $[Pb^{2+}] = 1.0 \times 10^{-9}\ M$ and enough phosphate is added such that $[PO_4^{3-}] = 3.0 \times 10^{-5}\ M$, would the concentration of $Pb^{2+}(aq)$ increase, decrease, or remain the same? Justify your answer with a comparison of Q and K_{sp}.

(f) Higher concentrations of $Pb^{2+}(aq)$ are found in pipes carrying hot water than in pipes carrying cold water. Is this observation consistent with a negative enthalpy of dissolution, ΔH_{soln}? Justify your answer with regards to LeChâtelier's principle.

A student researches the properties of the phosphate ion and finds the following Lewis electron-dot diagrams and table of bond lengths:

Diagram 1

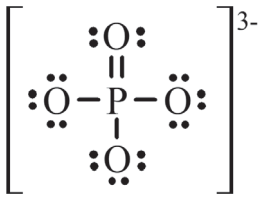
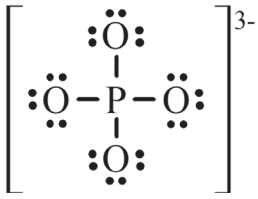


Diagram 2

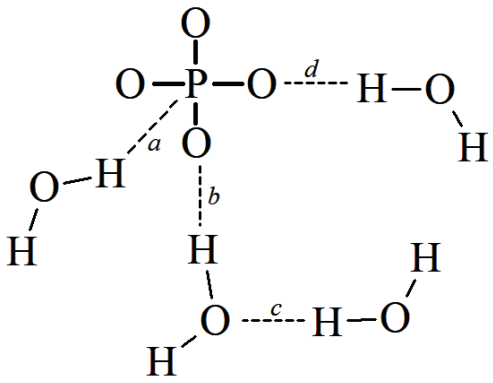


Bond type	Bond length (pm)
P–O	163
P=O	150

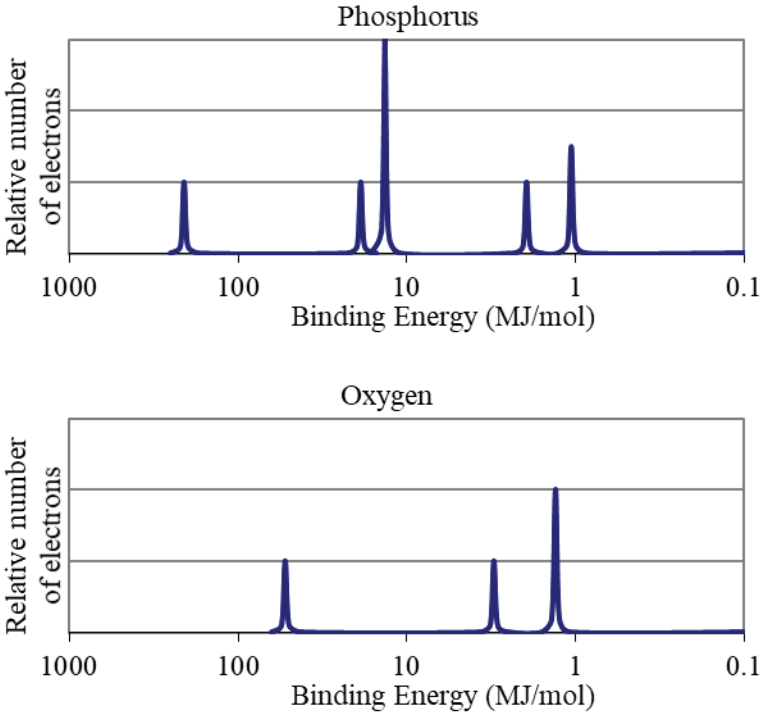
(g) Using diagram 1, the student claims that the bond angles are 90°. Do you agree or disagree with the student's claim? Justify your answer in terms of VSEPR theory.

(h) The student also finds that all four P—O bonds in phosphate have a bond length of 162.5 pm. Which diagram is consistent with this finding? Justify your answer.

(i) The student generates the following particulate diagram of an aqueous solution containing phosphate ions. The student uses dashed lines to show hydrogen bonding and omits lone pairs of electrons for clarity. Identify the letter corresponding to an incorrect hydrogen bonding interaction in the student's diagram, and indicate how the diagram should be changed to be correct.



The complete photoelectron spectra of phosphorus and of oxygen are given in the following diagrams.



(j) The student notices that the rightmost peak of O is taller than the rightmost peak of P. The student claims that this is because O has fewer occupied electron shells, which means that the valence electrons are closer to the nucleus and experience greater attraction. Do you agree or disagree with the student's claim? Justify your answer based on the data and principles of atomic structure.

Sample Question 2

Time allotted: 15 minutes (plus 5 minutes to submit)

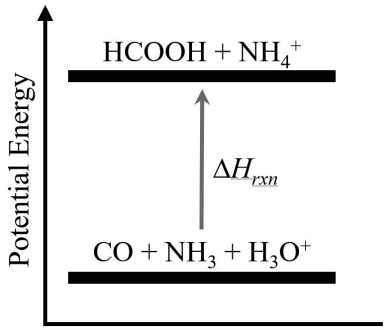
Methanoic acid, $HCOOH(aq)$, is a monoprotic acid that can be synthesized by the reaction between CO and NH_3 in the presence of hydronium ions. A proposed mechanism for the reaction consists of the three elementary steps shown below.

Step 1:	$CH_3OH + CO \rightarrow HCO_2CH_3$	*slow*
Step 2:	$HCO_2CH_3 + NH_3 \rightarrow HCONH_2 + CH_3OH$	*fast*
Step 3:	$HCONH_2 + H_3O^+ \rightarrow HCOOH + NH_4^+$	*fast*
Overall reaction:	$CO + NH_3 + H_3O^+ \rightarrow HCOOH + NH_4^+$	$\Delta H_{rxn} = -81\ \text{kJ/mol}_{rxn}$

(a) Write the chemical formula of a species that behaves as a catalyst in the mechanism.

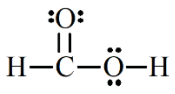
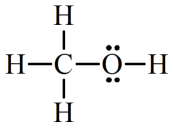
(b) According to the proposed mechanism, if additional NH_3 is added to the reaction mixture, will the rate of the overall reaction increase, decrease, or remain the same? Justify your answer.

A student generates the following potential energy diagram for the overall reaction.



(c) Is the student's diagram consistent with the enthalpy of the overall reaction? Justify your answer.

At the end of the reaction, $HCOOH$ is separated from CH_3OH by distillation. The chemical structures and vapor pressures at $50\,°C$ for the two substances are given below.

Substance	$HCOOH$	CH_3OH
Structure		
Vapor Pressure at $50\,°C$	17.3 kPa	55.6 kPa

(d) Identify the types of intermolecular forces in $HCOOH$ and CH_3OH.

(e) When an equimolar mixture of the two compounds is heated to $50\,°C$ in the distillation, the vapor phase contains a higher mole fraction of CH_3OH molecules. Explain this result in terms of the types and relative strengths of intermolecular forces in both substances.

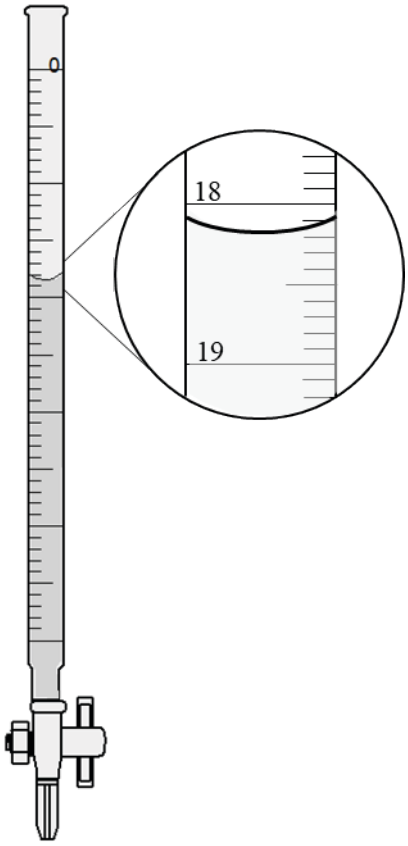
$$HCOOH(aq) + NaOH(aq) \rightarrow NaHCOO(aq) + H_2O(l)$$

The student uses $NaOH(aq)$ to titrate a methanoic acid solution of unknown concentration. A balanced chemical equation for the reaction appears above. The student places 20.00 mL of the $HCOOH$ solution into a flask and uses a buret filled with $0.300\ M$ $NaOH$ to deliver just enough $NaOH(aq)$ to reach the endpoint. The incomplete data from the student's three trials are summarized in the following table.

Trial	Volume of $HCOOH$	Initial Buret Reading	Final Buret Reading	Volume of $NaOH$ Dispensed
1	20.00 mL	10.94 mL	27.61 mL	16.67 mL
2	20.00 mL	27.61 mL	48.84 mL	?
3	20.00 mL	1.12 mL	?	?

(f) Calculate the molarity of $HCOOH$ from the student's data for Trial 1.

(g) The final buret reading for Trial 3 is shown in the experimental setup below. What should the student report as the volume of $NaOH(aq)$ dispensed for Trial 3 in the data table? Clearly show the final reading from the buret and the calculation of the volume dispensed.



(h) The student calculates a value of $[HCOOH(aq)]$ for Trial 2 that is significantly higher than the value for the other two trials. The student claims that the reason for the higher calculated concentration is that water remained in the flask to which the $HCOOH(aq)$ was added, which meant more $NaOH(aq)$ was needed to reach the endpoint. Do you agree or disagree with the student's claim? Justify your answer.