Week 7

AP Chemistry

Homework bundle for this week

本周作业合集

exercises.lol

Contents 目录

AP Chemistry Name: ______ Score: ______

1. Which is the strongest intermolecular force?
   - ☐ hydrogen bonding
   - ☐ dipole-dipole
   - ☐ London dispersion
2. Diamond is very hard with a very high melting point. It is a...
   - ☐ covalent-network solid
   - ☐ molecular solid
   - ☐ metallic solid
3. In which state are particles far apart and moving fast and freely?
   - ☐ gas
   - ☐ solid
   - ☐ liquid
4. Find P for 1 mol in 2 L at 300 K ($R = 0.0821$), in atm (1 decimal).

   ______ atm
5. Temperature is a measure of the particles' average...
   - ☐ kinetic energy
   - ☐ mass
   - ☐ charge
6. Real gases deviate most from ideal behaviour at...
   - ☐ high pressure and low temperature
   - ☐ low pressure and high temperature
   - ☐ they never deviate
7. Dissolve 2 mol of solute to make 4 L of solution. The molarity (in M)?

   ______ M
8. With $\varepsilon = 100$, $b = 1$ cm, and $A = 0.5$, the concentration (in M)?

   ______ M

9. All molecules experience London dispersion forces.

☐ True ☐ False

10. During a phase change, the temperature stays constant.

☐ True ☐ False

AP Chemistry

1. **hydrogen bonding**

   Hydrogen bonding (H to N, O, or F) is the strongest of the three.

2. **covalent-network solid**

   One giant lattice of strong covalent bonds makes it hard and high-melting.

3. **gas**

   Gas particles are widely spaced and move freely.

4. **12.3 atm**

   $P = nRT/V = (1)(0.0821)(300)/2 \approx 12.3$ atm.

5. **kinetic energy**

   Temperature tracks the average kinetic energy of the particles.

6. **high pressure and low temperature**

   Crowded (high P) and slow (low T) is where volume and attractions matter.

7. **0.5 M**

   $M = \text{moles/liters} = 2/4 = 0.5$ M.

8. **0.005 M**

   $c = A/(\varepsilon b) = 0.5/(100 \times 1) = 0.005$ M.

9. **True**

   Temporary uneven electron clouds occur in every molecule.

10. **True**

    Added heat breaks attractions instead of raising the temperature.

AP CHEMISTRY • EXERCISE SHEET

3.1 Intermolecular and Interparticle Forces

Name: ______________ Class: __________ Date: ____________ **Total: 10 marks**

KEY WORDS intermolecular forces 分子间作用力 • london dispersion 色散力 • london dispersion forces 伦敦色散力 • hydrogen bonding 氢键 • dipole-dipole 偶极

Objective

Build the skills to answer exam questions on **intermolecular forces** — the attractions between molecules.

You must be able to:

- rank **London dispersion** 色散力, **dipole-dipole** 偶极-偶极, and **hydrogen bonding** 氢键
- predict which force a substance has from its structure
- link stronger forces to higher boiling points

1 Worked examples

Study these first. Each one shows the method for a question type used later — follow the steps and you can do the Practice and Exam-style questions yourself.

■ The three intermolecular forces (IMFs)

- **London dispersion forces (LDF)** — present in **all** molecules; caused by temporary dipoles. Stronger for **larger** molecules (more electrons).
- **Dipole-dipole** — between **polar** molecules.
- **Hydrogen bonding** — a special strong dipole force when H is bonded to **N, O, or F**.

Strength order (roughly): hydrogen bonding > dipole-dipole > LDF (for similar sizes).

■ Predicting the force

CH_4 is nonpolar → only LDF. HCl is polar → dipole-dipole (plus LDF). H_2O has O–H → hydrogen bonding.

■ **IMFs set the boiling point**

Boiling breaks the IMFs between molecules (not the covalent bonds inside them). **Stronger IMFs ⇒ higher boiling point.** Water boils far higher than H_2S because of hydrogen bonding.

■ **Size still matters for LDF**

Among nonpolar molecules, the **larger** one has stronger LDF and a higher boiling point (e.g. Br_2 boils higher than Cl_2).

2 Practice

Now apply the methods above.

2.1 Which intermolecular force is present in **all** molecules? [1]

2.2 Name the strongest IMF in H_2O. [1]

2.3 State the IMF in CH_4. [1]

3 Exam-style questions

3.1 Hydrogen bonding occurs when H is bonded directly to [1]

- **A** C, N, or O
- **B** N, O, or F
- **C** any nonmetal
- **D** a metal

3.2 Compare H_2O and H_2S (both bent, similar size).

(a) State the strongest IMF in each. [2]

(b) Predict which has the higher boiling point, with a reason. [2]

3.3 Explain why Br_2 (a liquid at room temperature) boils higher than Cl_2 (a gas), even though both are nonpolar. [2]

Solutions

2.1 London dispersion forces.

2.2 Hydrogen bonding.

2.3 London dispersion forces only.

3.1 **B** — H bonded to N, O, or F.

3.2 (a) H_2O: hydrogen bonding; H_2S: dipole-dipole. (b) H_2O — its hydrogen bonds are stronger than the dipole-dipole forces in H_2S, so more energy is needed to boil it.

3.3 Br_2 has more electrons than Cl_2, so its London dispersion forces are stronger, giving a higher boiling point.

Question 5

The following information applies to parts A and B.

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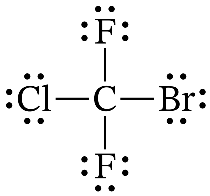
5. The Lewis diagram of $CBrClF_2$ is shown.



Part A

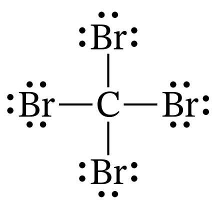
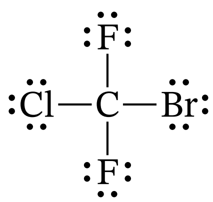
Which of the bonds in $CBrClF_2$ (C−Br, C−Cl, or C−F) is the most polar? **Justify** your answer.

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.

2. Answer the following questions about ascorbic acid (vitamin C).

A. A student combusts a sample of ascorbic acid, $C_xH_yO_x$, to determine its chemical composition. The only products of the reaction are 0.2400 mol of CO_2 and 2.883 g of H_2O.

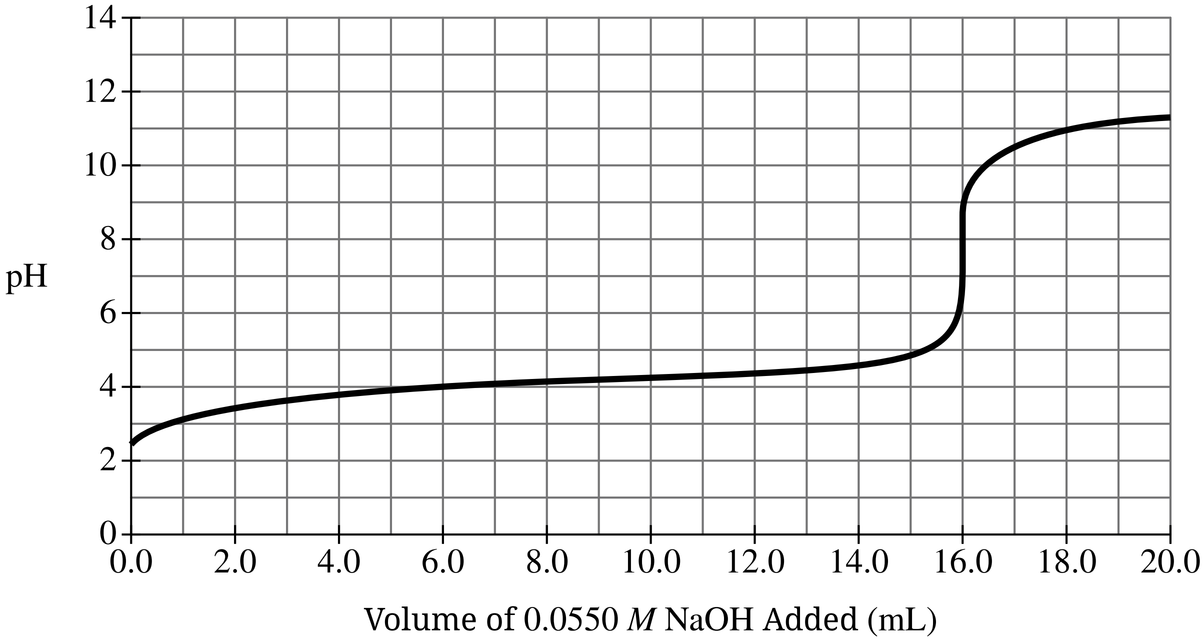
i. Calculate the number of moles of H_2O produced.

ii. The mole ratio of carbon (C) to oxygen (O) is 1:1 in ascorbic acid. Based on this information and your answer to part A (i), determine the empirical formula of ascorbic acid.

B. Ascorbic acid, $\mathrm{HAsc}(aq)$, acts as a weak acid, as shown in the equation.

$$\mathrm{HAsc}(aq) + \mathrm{H_2O}(l) \rightleftarrows \mathrm{H_3O^+}(aq) + \mathrm{Asc^-}(aq)$$

The following titration curve was produced when a 10.0 mL sample of $\mathrm{HAsc}(aq)$ was titrated using 0.0550 M $\mathrm{NaOH}(aq)$.



i. Calculate the molar concentration of the ascorbic acid solution.

ii. From the titration curve, determine the approximate $\mathrm{p}K_a$ of ascorbic acid.

iii. What is the value of the ratio $\dfrac{[\mathrm{Asc^-}]}{[\mathrm{HAsc}]}$ when the pH of the solution is 4.7?

C. Dehydroascorbic acid (DHAsc) can be produced by reacting ascorbic acid with the triiodide ion, I_3^-, as represented by the following equation.

$$\text{HAsc} + I_3^- \rightarrow \text{DHAsc} + 3\,I^- + 2\,H^+$$

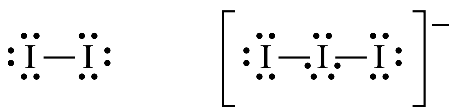
The student runs three trials of the reaction with different initial concentrations of HAsc and I_3^-, producing the following data.

Trial	[HAsc] (M)	$[I_3^-]\,(M)$	Initial Rate of DHAsc Formation (M/s)
1	0.450	1.200	2.457×10^{-4}
2	0.450	0.600	1.229×10^{-4}
3	0.900	1.200	4.914×10^{-4}

i. The rate law for the reaction is $rate = k[\text{HAsc}][I_3^-]$. Explain how the data in the table support the conclusion that the reaction is first order with respect to $[\text{HAsc}]$.

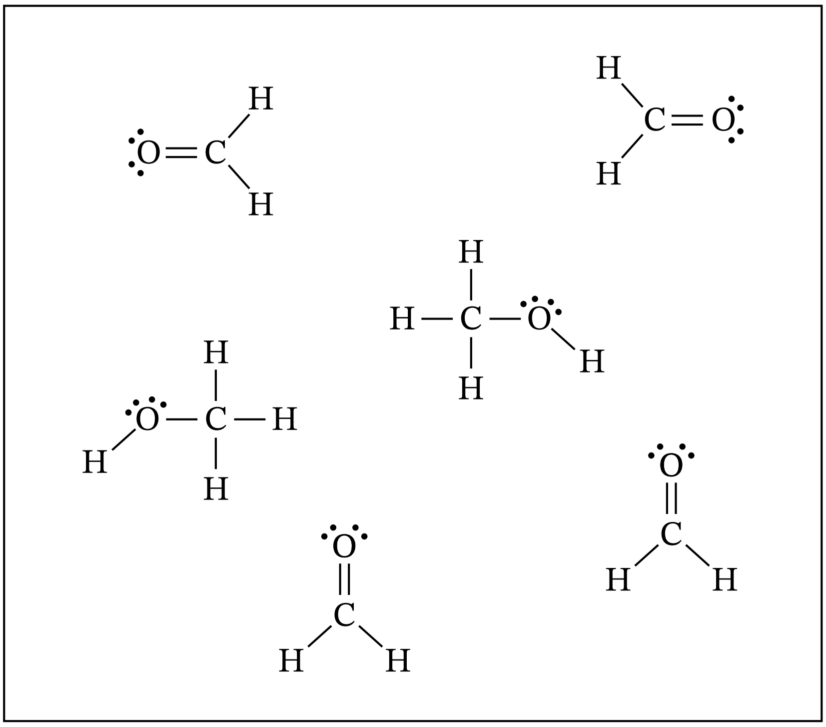
ii. Calculate the value of the rate constant, *k*, for the reaction. Include units with your answer.

D. The triiodide ion, I_3^-, is significantly more soluble in water than elemental iodine, I_2, is. Identify an intermolecular force between I_3^- and water that is **not** present between I_2 and water, which could explain the difference in solubility. Lewis diagrams for I_2 and I_3^- are provided.



I_2 $\quad$ I_3^-

4. A scientist is investigating the properties of a mixture of CH_3OH and H_2CO. The scientist generates the following diagram to represent the mixture.



A. Identify the hybridization of the valence orbitals of the C atom in the H_2CO molecule.

B. In the diagram provided, draw a SINGLE dashed line (----) to represent a strong hydrogen-bonding attraction between one CH_3OH molecule and one H_2CO molecule in the mixture.

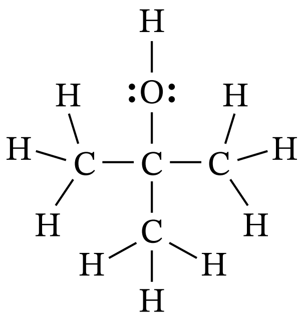
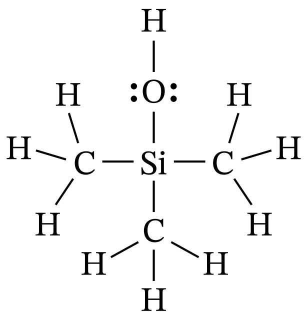
C. The scientist plans to cool a gaseous mixture of CH_3OH and H_2CO to form a liquid mixture and finds data on the two compounds. The data are summarized in the table.

Substance	Melting Point (K)	Boiling Point (K)	Enthalpy of Vaporization (kJ/mol)
CH_3OH	176	338	37.6
H_2CO	181	254	24.2

i. Propose a temperature to which the mixture should be cooled such that CH_3OH and H_2CO will both be liquids.

ii. The scientist analyzes the mixture after it is cooled and determines that 8.59 g of $CH_3OH(l)$ is present. Calculate the amount of thermal energy, in kJ, that was removed to condense the 8.59 g of CH_3OH (molar mass 32.04 g/mol) at its boiling point.

5. Complete Lewis diagrams and some physical properties for compounds X and Y are given.

Compound	X	Y
Lewis diagram		
Molar mass	74.1 g/mol	90.2 g/mol
Boiling point	82°C	98°C

A. Based on VSEPR theory, predict the geometry around the Si atom in compound Y.

B. A student claims that compound Y has a higher boiling point than that of compound X because compound Y has stronger London dispersion forces. Do you agree or disagree? Justify your answer.

C. An equimolar mixture of the two compounds is heated. When the mixture reaches 82°C, which compound will have the higher vapor pressure? Justify your answer.

D. The mixture is heated to 198°C in a sealed, rigid 12.5 L container, at which point both substances are gases and the total pressure in the container is 2.30 atm. Calculate the number of moles of gas particles in the container.

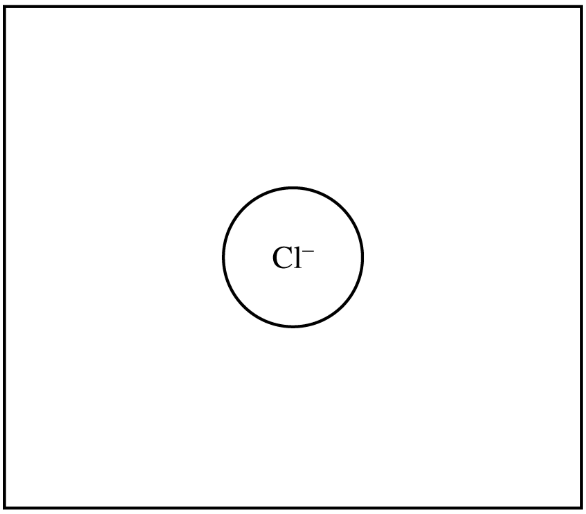
. HCl is a molecular gas as a pure substance but acts as an acid in aqueous solution.

(a) A sample of $HCl(g)$ is stored in a rigid 6.00 L container at 7.45 atm and 296 K.

(i) Calculate the number of moles of $HCl(g)$ in the container.

(ii) The rigid 6.00 L container of $HCl(g)$ is cooled to a temperature of 271 K. Calculate the new pressure, in atm, of the $HCl(g)$.

(b) When HCl ionizes in aqueous solution, $Cl^-(aq)$ ions are formed. In the following box, draw <u>three</u> water molecules with proper orientation around the Cl^- ion. Use  to represent water molecules.



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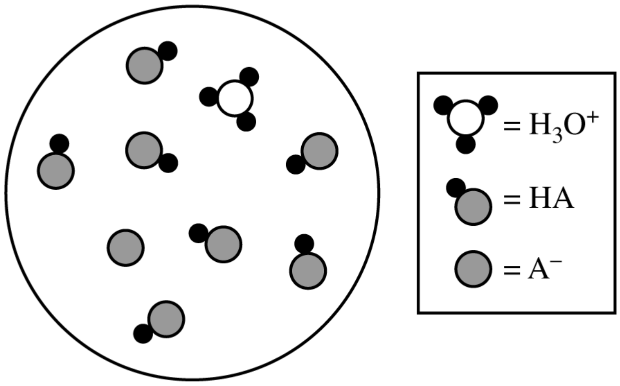
Continue your response to **QUESTION 5** on this page.

Acid (HA)	Anion (A^-)	K_a Value
HNO_2	NO_2^-	5.6×10^{-4}
HCl	Cl^-	2.0×10^7
$HClO_4$	ClO_4^-	1.6×10^{15}

The K_a values for three acids are shown in the preceding table.

(c) The following particulate diagram represents the ionization of one of the acids in the data table. Water molecules have been omitted for clarity. Which acid (HNO_2, HCl, or $HClO_4$) is represented in the diagram? Justify your answer using the information in the table.



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. Answer the following questions related to $HBr(l)$ and $HF(l)$.

(a) In the following table, list all of the types of intermolecular forces present in pure samples of $HBr(l)$ and $HF(l)$.

Liquid	$HBr(l)$	$HF(l)$
Intermolecular forces present		

(b) The enthalpy of vaporization, ΔH°_{vap}, for each liquid is provided in the following table.

Liquid	$HBr(l)$	$HF(l)$
ΔH°_{vap}	17.3 kJ / mol	25.2 kJ / mol

(i) Based on the types and relative strengths of intermolecular forces, explain why ΔH°_{vap} of $HF(l)$ is greater than that of $HBr(l)$.

(ii) Calculate the amount of thermal energy, in kJ, required to vaporize 6.85 g of $HF(l)$.

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Continue your response to **QUESTION 6** on this page.

(c) Based on the arrangement of electrons in the Br and F atoms, explain why the bond length in an HBr molecule is greater than that in an HF molecule.

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CHEMISTRY

SECTION II

Time—1 hour and 45 minutes

7 Questions

YOU MAY USE YOUR CALCULATOR FOR THIS SECTION.

irections: Questions 1–3 are long free-response questions that require about 23 minutes each to answer and are vorth 10 points each. Questions 4–7 are short free-response questions that require about 9 minutes each to answer nd are worth 4 points each.

'or each question, show your work for each part in the space provided after that part. Examples and equations may e included in your responses where appropriate. For calculations, clearly show the method used and the steps ıvolved in arriving at your answers. You must show your work to receive credit for your answer. Pay attention to ignificant figures.

. A student reacts 0.300 g of methyl salicylate ($C_8H_8O_3$) with a stoichiometric amount of a strong base. This product is then acidified to produce salicylic acid crystals ($HC_7H_5O_3$).

(a) For every 1 mole of $C_8H_8O_3$ (molar mass 152.15 g/mol) reactant used, 1 mole of salicylic acid crystals ($HC_7H_5O_3$, molar mass 138.12 g/mol) is produced. Calculate the maximum mass, in grams, of $HC_7H_5O_3$ that could be produced in this reaction.

GO ON TO THE NEXT PAGE.

Continue your response to **QUESTION 1** on this page.

As part of the experimental procedure to purify the $HC_7H_5O_3$ crystals after the reaction is complete, the crystals are filtered from the reaction mixture, rinsed with distilled water, and dried. Some physical properties of $HC_7H_5O_3$ are given in the following table.

Properties of Salicylic Acid ($HC_7H_5O_3$)	
Melting point	159°C
Solubility in H_2O at 25°C	2.2 g/L
Specific heat capacity	1.17 J/(g·°C)
Heat of fusion	27.1 kJ/mol

(b) The student's experiment results in an 87% yield of dry $HC_7H_5O_3$. The student suggests that some of the $HC_7H_5O_3$ crystals dissolved in the distilled water during the rinsing step. Is the student's claim consistent with the calculated percent yield value? Justify your answer.

(c) Given the physical properties in the table, calculate the quantity of heat that must be absorbed to increase the temperature of a 0.105 g sample of dry $HC_7H_5O_3$ (molar mass 138.12 g / mol) crystals from 25°C to the melting point of 159°C and melt the crystals completely.

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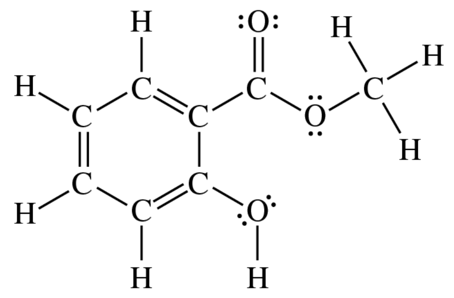
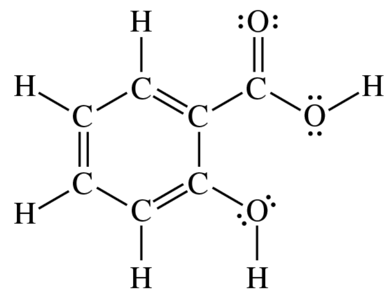
Continue your response to **QUESTION 1** on this page.

The structures and melting points for methyl salicylate and salicylic acid are shown.



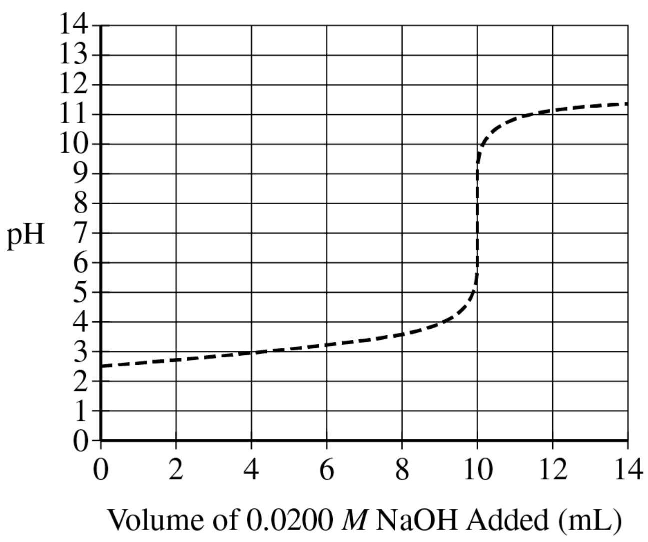
Methyl Salicylate
Melting Point: –9°C



Salicylic Acid
Melting Point: 159°C

(d) The same three types of intermolecular forces (London dispersion forces, dipole-dipole interactions, and hydrogen bonding) exist among molecules of each substance. Explain why the melting point of salicylic acid is higher than that of methyl salicylate.

The student titrates 20.0 mL of 0.0100 M $HC_7H_5O_3(aq)$ with 0.0200 M NaOH, using a probe to monitor the pH of the solution. The data are plotted producing the following titration curve.



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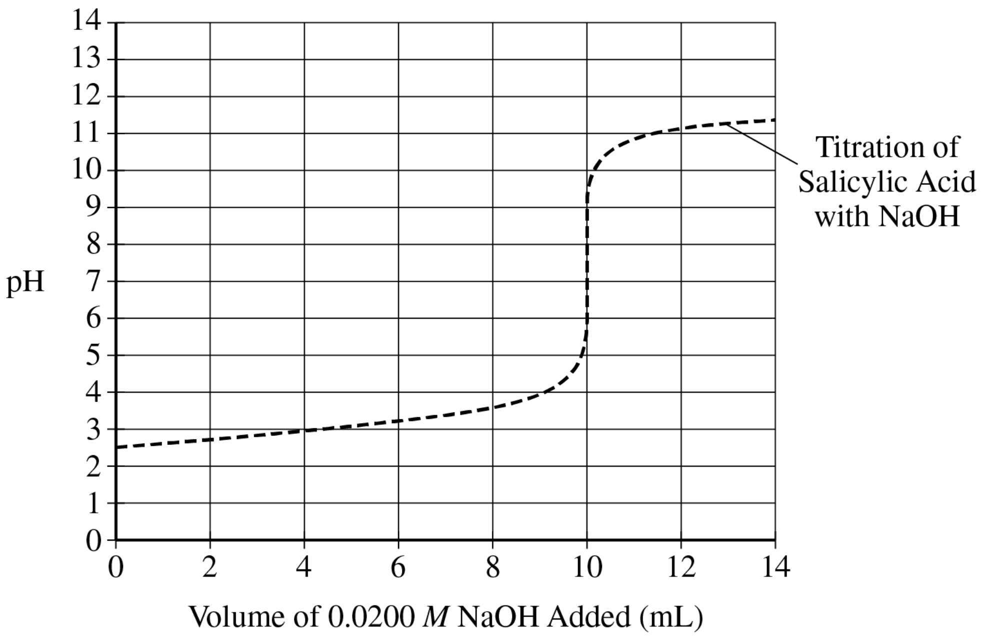
Continue your response to **QUESTION 1** on this page.

(e) Using the information in the graph, estimate the pK_a of $HC_7H_5O_3$. ______________

(f) When the pH of the titration mixture is 4.00, is there a higher concentration of the weak acid, $HC_7H_5O_3$, or its conjugate base, $C_7H_5O_3^-$, in the flask? Justify your answer.

(g) The student researches benzoic acid ($HC_7H_5O_2$) and finds that it has similar properties to salicylic acid ($HC_7H_5O_3$). The K_a for benzoic acid is 6.3×10^{-5}. Calculate the value of pK_a for benzoic acid.

(h) The student performs a second titration, this time titrating 20.0 mL of a 0.0100 M benzoic acid solution with 0.0200 M NaOH. Sketch the curve that would result from this titration of benzoic acid on the following graph, which already shows the original curve from the titration of 20.0 mL of 0.0100 M salicylic acid. The initial pH of the benzoic acid solution is 3.11.



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. Answer the following questions about the compounds NH_2Cl and NCl_3. The Lewis electron-dot diagrams of the two compounds are shown.

(a) Calculate the number of moles of NH_2Cl (molar mass 51.48 g/mol) present in 1.0 L of a solution in which the concentration of NH_2Cl is 0.0016 g/L.

(b) NH_2Cl is highly soluble in water, whereas NCl_3 is nearly insoluble. Explain this observation in terms of the types and relative strengths of the intermolecular forces between each of the solutes and water.

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Continue your response to **QUESTION 4** on this page.

(c) The value of $\Delta H^\circ_{vaporization}$ for $NCl_3(l)$ is 32.9 kJ/mol. Calculate the amount of energy required to vaporize a 15.0 g sample of NCl_3 (molar mass 120.36 g/mol).

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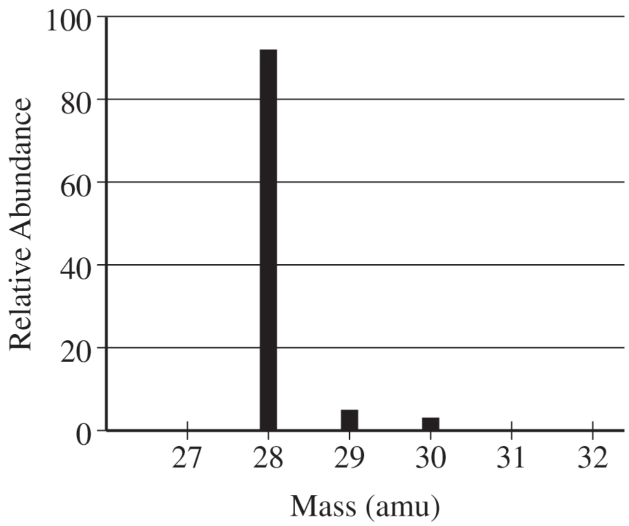
2. Answer the following questions about the element Si and some of its compounds.

(a) The mass spectrum of a pure sample of Si is shown below.



(i) How many protons and how many neutrons are in the nucleus of an atom of the most abundant isotope of Si ?

(ii) Write the ground-state electron configuration of Si.

Two compounds that contain Si are SiO_2 and SiH_4.

(b) At 161 K, SiH_4 boils but SiO_2 remains as a solid. Using principles of interparticle forces, explain the difference in boiling points.

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At high temperatures, SiH_4 decomposes to form solid silicon and hydrogen gas.

(c) Write a balanced equation for the reaction.

A table of absolute entropies of some substances is given below.

Substance	$S°$ (J/(mol · K))
$H_2(g)$	131
$Si(s)$	18
$SiH_4(g)$	205

(d) Explain why the absolute molar entropy of $Si(s)$ is less than that of $H_2(g)$.

(e) Calculate the value, in J/(mol· K), of $\Delta S°$ for the reaction.

(f) The reaction is thermodynamically favorable at all temperatures. Explain why the reaction occurs only at high temperatures.

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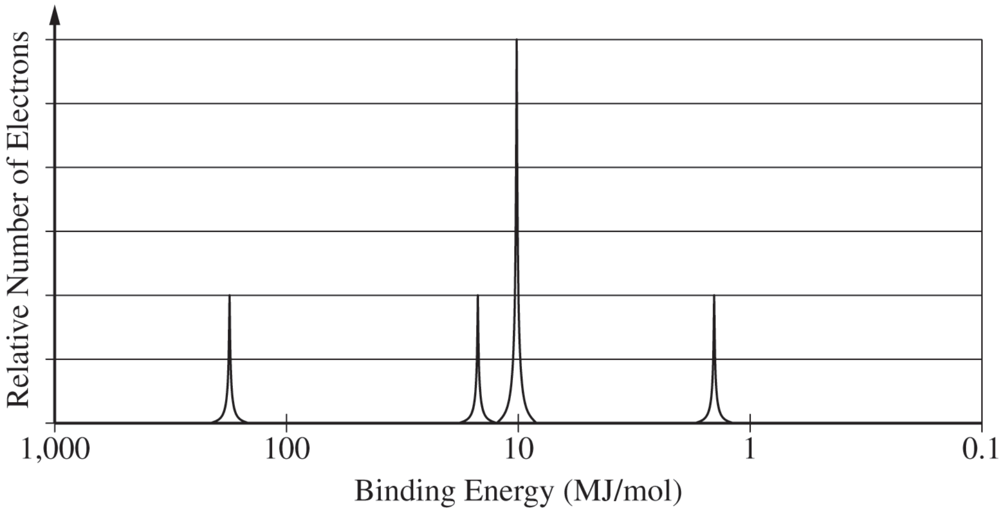
(g) A partial photoelectron spectrum of pure Si is shown below. On the spectrum, draw the missing peak that corresponds to the electrons in the $3p$ sublevel.



(h) Using principles of atomic structure, explain why the first ionization energy of Ge is lower than that of Si.

(i) A single photon with a wavelength of 4.00×10^{-7} m is absorbed by the Si sample. Calculate the energy of the photon in joules.

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CHEMISTRY

Section II

Time—1 hour and 45 minutes

7 Questions

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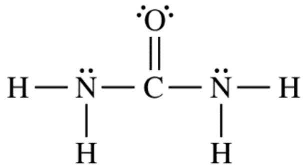
Directions: Questions 1–3 are long free-response questions that require about 23 minutes each to answer and are worth 10 points each. Questions 4–7 are short free-response questions that require about 9 minutes each to answer and are worth 4 points each.

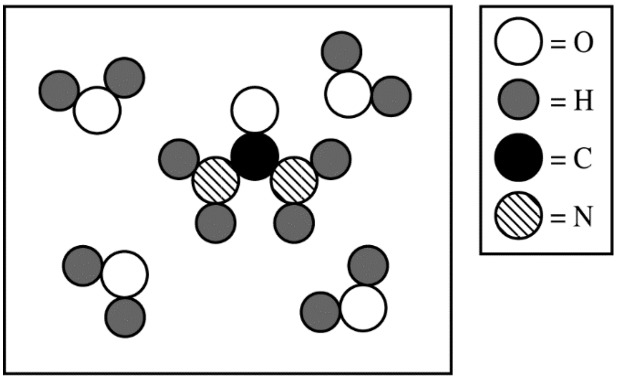
Write your response in the space provided following each question. Examples and equations may be included in your responses where appropriate. For calculations, clearly show the method used and the steps involved in arriving at your answers. You must show your work to receive credit for your answer.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



1. The compound urea, H_2NCONH_2, is widely used in chemical fertilizers. The complete Lewis electron-dot diagram for the urea molecule is shown above.

   (a) Identify the hybridization of the valence orbitals of the carbon atom in the urea molecule.

   (b) Urea has a high solubility in water, due in part to its ability to form hydrogen bonds. A urea molecule and four water molecules are represented in the box below. Draw ONE dashed line (----) to indicate a possible location of a hydrogen bond between a water molecule and the urea molecule.

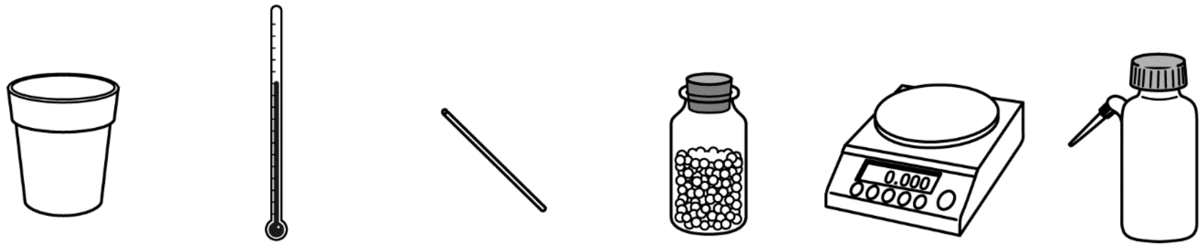


$$H_2NCONH_2(s) \rightleftarrows H_2NCONH_2(aq)$$

The dissolution of urea is represented by the equation above. A student determines that 5.39 grams of H_2NCONH_2 (molar mass 60.06 g/mol) can dissolve in water to make 5.00 mL of a saturated solution at 20.°C.

(c) Calculate the concentration of urea, in mol/L, in the saturated solution at 20.°C.

(d) The student also determines that the concentration of urea in a saturated solution at 25°C is 19.8 *M*. Based on this information, is the dissolution of urea endothermic or exothermic? Justify your answer in terms of Le Chatelier's principle.



Polystyrene Cup   Thermometer   Stirring Rod   Bottle of Urea   Balance   Distilled Water

(e) The equipment shown above is provided so that the student can determine the value of the molar heat of solution for urea. Knowing that the specific heat of the solution is 4.18 J/(g·°C), list the specific measurements that are required to be made during the experiment.

	$S°$ (J/(mol·K))
$H_2NCONH_2(s)$	104.6
$H_2NCONH_2(aq)$	?

(f) The entropy change for the dissolution of urea, ΔS°_{soln} , is 70.1 J/(mol·K) at 25°C. Using the information in the table above, calculate the absolute molar entropy, $S°$, of aqueous urea.

(g) Using particle-level reasoning, explain why ΔS°_{soln} is positive for the dissolution of urea in water.

(h) The student claims that $\Delta S°$ for the process contributes to the thermodynamic favorability of the dissolution of urea at 25°C. Use the thermodynamic information above to support the student's claim.

2. Answer the following questions relating to the chemistry of the halogens.

   (a) The molecular formulas of diatomic bromine, chlorine, fluorine, and iodine are written below. Circle the formula of the molecule that has the longest bond length. Justify your choice in terms of atomic structure.

   Br_2 Cl_2 F_2 I_2

A chemistry teacher wants to prepare Br_2. The teacher has access to the following three reagents: $NaBr(aq)$, $Cl_2(g)$, and $I_2(s)$.

Half-Reaction	$E°$ at 25°C (V)
$Br_2 + 2\,e^- \rightarrow 2\,Br^-$	1.07
$Cl_2 + 2\,e^- \rightarrow 2\,Cl^-$	1.36
$I_2 + 2\,e^- \rightarrow 2\,I^-$	0.53

   (b) Using the data in the table above, write the balanced equation for the thermodynamically favorable reaction that will produce Br_2 when the teacher combines two of the reagents. Justify that the reaction is thermodynamically favorable by calculating the value of $E°$ for the reaction.

Br_2 and Cl_2 can react to form the compound $BrCl$.

   (c) The boiling point of Br_2 is 332 K, whereas the boiling point of $BrCl$ is 278 K. Explain this difference in boiling point in terms of all the intermolecular forces present between molecules of <u>each</u> substance.

The compound $BrCl$ can decompose into Br_2 and Cl_2, as represented by the balanced chemical equation below.

$$2\,BrCl(g) \rightleftarrows Br_2(g) + Cl_2(g) \qquad \Delta H° = 1.6\ \text{kJ/mol}_{rxn}$$

A 0.100 mole sample of pure $BrCl(g)$ is placed in a previously evacuated, rigid 2.00 L container at 298 K. Eventually the system reaches equilibrium according to the equation above.

   (d) Calculate the pressure in the container before equilibrium is established.

   (e) Write the expression for the equilibrium constant, K_{eq}, for the decomposition of $BrCl$.

After the system has reached equilibrium, 42 percent of the original $BrCl$ sample has decomposed.

   (f) Determine the value of K_{eq} for the decomposition reaction of $BrCl$ at 298 K.

   (g) Calculate the bond energy of the Br-Cl bond, in kJ/mol, using $\Delta H°$ for the reaction (1.6 kJ/mol$_{rxn}$) and the information in the following table.

Bond	Bond Energy (kJ/mol)
Br – Br	193
Cl – Cl	243
Br – Cl	?

Sulfur atom =  Carbon atom =  Oxygen atom = 

Compound	Molecular Structure	Boiling Point at 1 atm (K)
CS_2		319
COS		223

4. The table above gives the molecular structures and boiling points for the compounds CS_2 and COS.

(a) In terms of the types and relative strengths of all the intermolecular forces in each compound, explain why the boiling point of $CS_2(l)$ is higher than that of $COS(l)$.

(b) A 10.0 g sample of $CS_2(l)$ is put in an evacuated 5.0 L rigid container. The container is sealed and heated to 325 K, at which temperature all of the $CS_2(l)$ has vaporized. What is the pressure in the container once all of the $CS_2(l)$ has vaporized?

AP CHEMISTRY • EXERCISE SHEET

3.2 Properties of Solids

Name: ______ Class: ______ Date: ______ **Total: 11 marks**

KEY WORDS molecular 分子晶体 • covalent-network 共价网络 • solution 溶液 • intermolecular forces 分子间作用力

Objective

Build the skills to answer exam questions on the **properties of solids** — linking structure to behavior.

You must be able to:

- classify a solid as **ionic**, **molecular 分子晶体**, **covalent-network 共价网络**, or **metallic**
- predict melting point, hardness, and conductivity from the type
- match a substance to its solid type

1 Worked examples

Study these first. Each one shows the method for a question type used later — follow the steps and you can do the Practice and Exam-style questions yourself.

The four solid types

type	particles	held by	example
ionic	ions	ionic bonds	NaCl
molecular	molecules	IMFs	ice, $CO_2(s)$
covalent network	atoms	covalent bonds	diamond, SiO_2
metallic	cations + e^- sea	metallic bonds	copper

Melting point

Melting point tracks the strength of what must be broken: **covalent network** and **ionic** are very high; **metallic** varies; **molecular** is low (only weak IMFs break).

Conductivity

- **Metallic** — conducts (mobile electrons).
- **Ionic** — conducts only molten/dissolved.
- **Molecular / covalent network** — usually insulators (graphite is the exception).

■ **Hardness**

Covalent-network solids (diamond) are the hardest; molecular solids are soft.

2 Practice

Now apply the methods above.

2.1 Classify diamond as a solid type. [1]

2.2 Which solid type has the lowest melting points, and why? [2]

2.3 Name a solid type that conducts electricity when solid. [1]

3 Exam-style questions

3.1 A solid that is very hard, has a very high melting point, and does not conduct is most likely [1]

- **A** molecular
- **B** metallic
- **C** covalent network
- **D** ionic

3.2 A substance melts at 801°C, does not conduct as a solid, but conducts when molten.

(a) Identify the solid type. [1]

(b) Explain the conductivity behavior. [2]

3.3 Solid CO_2 (dry ice) melts (sublimes) at a very low temperature, while SiO_2 melts above 1600°C. Explain the difference in terms of what is broken on melting. [3]

Solutions

2.1 Covalent network.

2.2 Molecular — only weak intermolecular forces need to be overcome.

2.3 Metallic.

3.1 **C** — hard, very high melting, non-conducting fits a covalent-network solid.

3.2 (a) Ionic. (b) In the solid the ions are fixed; when molten the ions are free to move and carry charge.

3.3 Melting dry ice (CO_2) breaks only weak **intermolecular** forces between molecules; melting SiO_2 breaks strong **covalent bonds** throughout the network, which needs far more energy, hence the much higher temperature.

CHEMISTRY
Section II
7 Questions
Time—90 minutes

YOU MAY USE YOUR CALCULATOR FOR THIS SECTION.

Directions: Questions 1–3 are long free-response questions that require about 20 minutes each to answer and are worth 10 points each. Questions 4–7 are short free-response questions that require about 7 minutes each to answer and are worth 4 points each.

Write your response in the space provided following each question. 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.

Mass of KI tablet	0.425 g
Mass of thoroughly dried filter paper	1.462 g
Mass of filter paper + precipitate after first drying	1.775 g
Mass of filter paper + precipitate after second drying	1.699 g
Mass of filter paper + precipitate after third drying	1.698 g

1. A student is given the task of determining the I^- content of tablets that contain KI and an inert, water-soluble sugar as a filler. A tablet is dissolved in 50.0 mL of distilled water, and an excess of 0.20 M $Pb(NO_3)_2(aq)$ is added to the solution. A yellow precipitate forms, which is then filtered, washed, and dried. The data from the experiment are shown in the table above.

   (a) For the chemical reaction that occurs when the precipitate forms,

   (i) write a balanced, net-ionic equation for the reaction, and

   (ii) explain why the reaction is best represented by a net-ionic equation.

   (b) Explain the purpose of drying and weighing the filter paper with the precipitate three times.

   (c) In the filtrate solution, is $[K^+]$ greater than, less than, or equal to $[NO_3^-]$? Justify your answer.

   (d) Calculate the number of moles of precipitate that is produced in the experiment.

   (e) Calculate the mass percent of I^- in the tablet.

   (f) In another trial, the student dissolves a tablet in 55.0 mL of water instead of 50.0 mL of water. Predict whether the experimentally determined mass percent of I^- will be greater than, less than, or equal to the amount calculated in part (e). Justify your answer.

(g) A student in another lab also wants to determine the I^- content of a KI tablet but does not have access to $Pb(NO_3)_2$. However, the student does have access to 0.20 M $AgNO_3$, which reacts with $I^-(aq)$ to produce $AgI(s)$. The value of K_{sp} for AgI is 8.5×10^{-17}.

(i) Will the substitution of $AgNO_3$ for $Pb(NO_3)_2$ result in the precipitation of the I^- ion from solution? Justify your answer.

(ii) The student only has access to one KI tablet and a balance that can measure to the nearest 0.01 g. Will the student be able to determine the mass of AgI produced to three significant figures? Justify your answer.

AP CHEMISTRY • EXERCISE SHEET

3.3 Solids, Liquids, and Gases

Name: ____________ Class: ________ Date: _________ **Total: 10 marks**

KEY WORDS heating curve 加热曲线 • intermolecular forces 分子间作用力 • solution 溶液

Objective

Build the skills to answer exam questions on **solids, liquids, and gases** — the particle picture of the three states.

You must be able to:

- describe particle arrangement, motion, and spacing in each state
- explain state changes in terms of energy and IMFs
- read a **heating curve** 加热曲线

1 Worked examples

Study these first. Each one shows the method for a question type used later — follow the steps and you can do the Practice and Exam-style questions yourself.

■ The three states

- **Solid** — particles packed close in a fixed arrangement, vibrating in place.
- **Liquid** — particles close but free to move past each other.
- **Gas** — particles far apart, moving fast and randomly, filling the container.

■ State changes and energy

Adding energy loosens the particles: solid → liquid (melting) → gas (boiling). Energy goes into **overcoming IMFs**, not raising temperature, during a change of state.

■ The heating curve

On a temperature-vs-time graph of steady heating, the **flat plateaus** are the melting and boiling points: temperature stays constant while the state changes (energy breaks IMFs). The sloped parts warm a single state.

■ Which state at a temperature

Compare the temperature to the melting and boiling points. Below the melting point → solid; between → liquid; above the boiling point → gas.

2 Practice

Now apply the methods above.

2.1 In which state are particles far apart and fast-moving? [1]

2.2 On a heating curve, what is happening during a flat plateau? [1]

2.3 A substance melts at 0°C and boils at 100°C. State its state at 50°C. [1]

3 Exam-style questions

3.1 During boiling, the energy added is used to [1]

- **A** raise the temperature
- **B** overcome intermolecular forces
- **C** break covalent bonds
- **D** create new atoms

3.2 A heating curve for a pure substance shows two flat plateaus.

(a) What do the two plateaus represent? [2]

(b) Why does the temperature stay constant during each? [2]

3.3 Explain, in terms of particle spacing and forces, why gases are much easier to compress than liquids. [2]

Solutions

2.1 Gas.

2.2 A change of state (melting or boiling) at constant temperature.

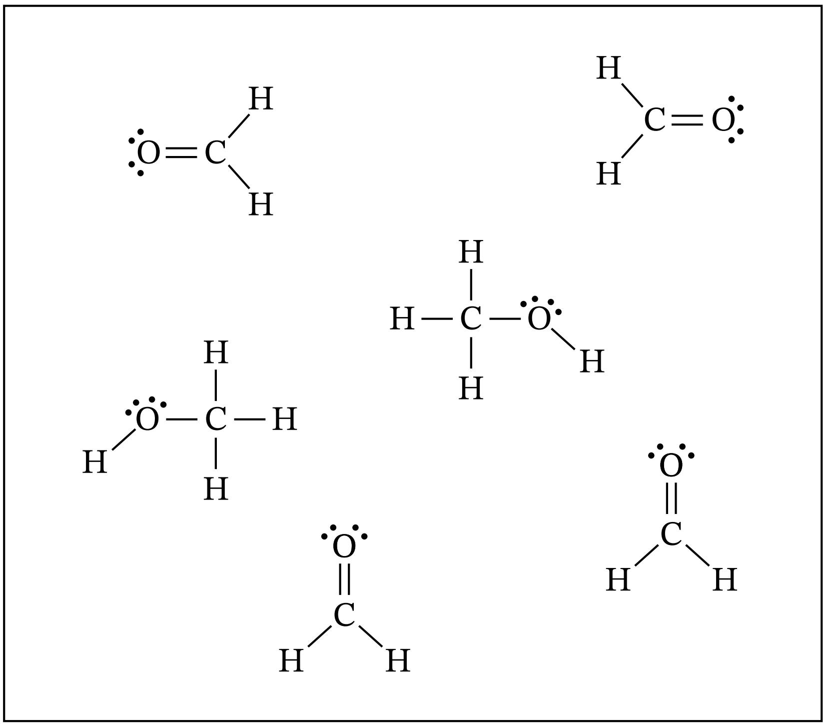
2.3 Liquid.

3.1 B — energy overcomes the intermolecular forces to separate the particles.

3.2 (a) The melting point and the boiling point. (b) The added energy goes into overcoming intermolecular forces (changing state), not into raising the kinetic energy/temperature.

3.3 In a gas the particles are far apart with large empty spaces and negligible forces, so they can be pushed closer; in a liquid the particles are already touching, leaving little room to compress.

4. A scientist is investigating the properties of a mixture of CH_3OH and H_2CO. The scientist generates the following diagram to represent the mixture.



A. Identify the hybridization of the valence orbitals of the C atom in the H_2CO molecule.

B. In the diagram provided, draw a SINGLE dashed line (----) to represent a strong hydrogen-bonding attraction between one CH_3OH molecule and one H_2CO molecule in the mixture.

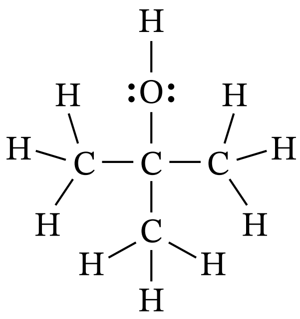
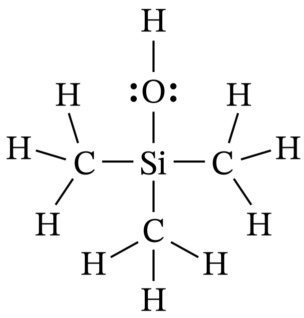
C. The scientist plans to cool a gaseous mixture of CH_3OH and H_2CO to form a liquid mixture and finds data on the two compounds. The data are summarized in the table.

Substance	Melting Point (K)	Boiling Point (K)	Enthalpy of Vaporization (kJ/mol)
CH_3OH	176	338	37.6
H_2CO	181	254	24.2

i. Propose a temperature to which the mixture should be cooled such that CH_3OH and H_2CO will both be liquids.

ii. The scientist analyzes the mixture after it is cooled and determines that 8.59 g of $CH_3OH(l)$ is present. Calculate the amount of thermal energy, in kJ, that was removed to condense the 8.59 g of CH_3OH (molar mass 32.04 g/mol) at its boiling point.

5. Complete Lewis diagrams and some physical properties for compounds X and Y are given.

Compound	X	Y
Lewis diagram		
Molar mass	74.1 g/mol	90.2 g/mol
Boiling point	82°C	98°C

A. Based on VSEPR theory, predict the geometry around the Si atom in compound Y.

B. A student claims that compound Y has a higher boiling point than that of compound X because compound Y has stronger London dispersion forces. Do you agree or disagree? Justify your answer.

C. An equimolar mixture of the two compounds is heated. When the mixture reaches 82°C, which compound will have the higher vapor pressure? Justify your answer.

D. The mixture is heated to 198°C in a sealed, rigid 12.5 L container, at which point both substances are gases and the total pressure in the container is 2.30 atm. Calculate the number of moles of gas particles in the container.

AP CHEMISTRY • EXERCISE SHEET

3.4 The Ideal Gas Law

Name: ______________ Class: __________ Date: ____________ **Total: 14 marks**

KEY WORDS kelvin 开尔文 • solution 溶液

Objective

Build the skills to answer exam questions on the **ideal gas law** $PV = nRT$.

You must be able to:

- use $PV = nRT$ with $R = 0.08206$ L atm mol^{-1}K^{-1}
- convert temperature to **kelvin** 开尔文 and match units
- combine states with $\dfrac{P_1V_1}{T_1} = \dfrac{P_2V_2}{T_2}$

1 Worked examples

Study these first. Each one shows the method for a question type used later — follow the steps and you can do the Practice and Exam-style questions yourself.

The ideal gas law

$$PV = nRT.$$

Use consistent units: P in atm, V in L, n in mol, T in **kelvin** ($T_K = T_C + 273$), with $R = 0.08206$ L atm mol^{-1}K^{-1}.

A worked calculation

Find the volume of 2.0 mol of gas at 1.0 atm and 300 K:

$$V = \frac{nRT}{P} = \frac{(2.0)(0.08206)(300)}{1.0} = 49.2 \text{ L}.$$

Always convert to kelvin

A temperature in °C must become K first. 25°C = 298 K. Forgetting this is a common lost mark.

The combined gas law

When n is fixed and conditions change,

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}.$$

Solve for the unknown, keeping temperatures in kelvin.

2 Practice

Now apply the methods above.

2.1 Convert 27°C to kelvin. [1]

2.2 Find n for a gas with $P = 2.0$ atm, $V = 10.0$ L, $T = 300$ K. [3]

2.3 A gas at 1.0 atm and 2.0 L is compressed to 0.5 L at constant T. Find the new pressure. [2]

3 Exam-style questions

3.1 In $PV = nRT$, the temperature must be in [1]

- **A** °C
- **B** kelvin
- **C** °F
- **D** any unit

3.2 A 5.0 L container holds 0.25 mol of gas at 350 K.

(a) Find the pressure in atm. [3]

(b) State what happens to the pressure if the temperature is doubled at constant volume. [1]

3.3 A balloon has volume 2.0 L at 300 K. Find its volume at 360 K if the pressure is unchanged. [3]

Solutions

2.1 $27 + 273 = 300$ K.

2.2 $n = \dfrac{PV}{RT} = \dfrac{(2.0)(10.0)}{(0.08206)(300)} = 0.81$ mol.

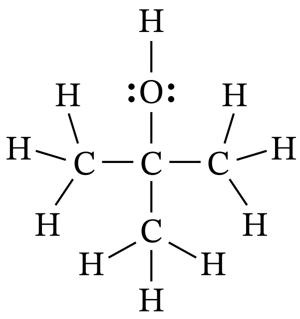
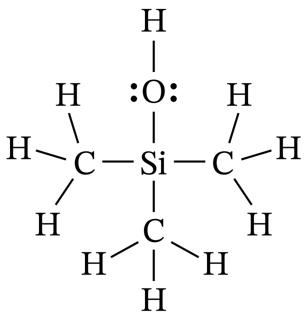
2.3 $P_2 = \dfrac{P_1V_1}{V_2} = \dfrac{(1.0)(2.0)}{0.5} = 4.0$ atm.

3.1 **B** — kelvin.

3.2 (a) $P = \dfrac{nRT}{V} = \dfrac{(0.25)(0.08206)(350)}{5.0} = 1.44$ atm. (b) The pressure doubles.

3.3 $\dfrac{V_1}{T_1} = \dfrac{V_2}{T_2}$; $V_2 = 2.0 \times \dfrac{360}{300} = 2.4$ L.

5. Complete Lewis diagrams and some physical properties for compounds X and Y are given.

Compound	X	Y
Lewis diagram		
Molar mass	74.1 g/mol	90.2 g/mol
Boiling point	82°C	98°C

A. Based on VSEPR theory, predict the geometry around the Si atom in compound Y.

B. A student claims that compound Y has a higher boiling point than that of compound X because compound Y has stronger London dispersion forces. Do you agree or disagree? Justify your answer.

C. An equimolar mixture of the two compounds is heated. When the mixture reaches 82°C, which compound will have the higher vapor pressure? Justify your answer.

D. The mixture is heated to 198°C in a sealed, rigid 12.5 L container, at which point both substances are gases and the total pressure in the container is 2.30 atm. Calculate the number of moles of gas particles in the container.

2. A chemical reaction between maleic acid ($H_2C_4H_2O_4$) and sodium bicarbonate ($NaHCO_3$) occurs in the presence of water to produce carbon dioxide and sodium maleate ($Na_2C_4H_2O_4$), as represented by the following equation.

$$H_2C_4H_2O_4(aq) + 2\,NaHCO_3(aq) \rightarrow 2\,CO_2(g) + 2\,H_2O(l) + Na_2C_4H_2O_4(aq)$$

(a) A student combines equal masses of $H_2C_4H_2O_4(s)$ chunks and $NaHCO_3(s)$ chunks with sufficient water at 20.0°C. The student determines that 0.0114 mol of $CO_2(g)$ is produced after the reaction goes to completion.

(i) Calculate the number of grams of $CO_2(g)$ produced.

(ii) The $CO_2(g)$ produced from the reaction at 20.0°C was collected and found to have a pressure of 1.25 atm. Calculate the volume of $CO_2(g)$, in liters.

(b) The student performs a second experiment that is identical to the first except that the student grinds the chunks of $H_2C_4H_2O_4(s)$ and $NaHCO_3(s)$ into powder before combining the powder with water.

(i) What happens to the surface area of the reactants when the student grinds the chunks into powder?

(ii) The rate-determining step for the overall reaction is the dissolving of the solids. Would the time required for the dissolving of the solids in the second experiment be longer than, shorter than, or the same as the time required in the first experiment? Justify your answer based on the collisions between particles.

GO ON TO THE NEXT PAGE.

Continue your response to **QUESTION 2** on this page.

(iii) When the reaction is complete, will the volume of $CO_2(g)$ at the end of the second experiment be greater than, less than, or equal to the volume at the end of the first experiment? Justify your answer.

The student conducts additional trials of the experiment and produces the following data table.

Trial	Mass of $H_2C_4H_2O_4$ (grams)	Mass of $NaHCO_3$ (grams)	Moles of CO_2 Produced (mol)
3	1.543	1.251	0.01489
4	1.543	1.686	0.02007

(c) Based on the student's data, identify the limiting reactant in trial 3. Justify your answer.

(d) The reaction has a value of $\Delta S°$ greater than zero. Using particle-level reasoning, explain why the entropy increases as the reaction progresses.

GO ON TO THE NEXT PAGE.

Continue your response to **QUESTION 2** on this page.

The student notices that the temperature of the reaction mixture decreases as the reaction takes place and correctly determines that the reaction is endothermic.

(e) The student claims that the reaction is thermodynamically favorable at all temperatures because $\Delta S^\circ_{rxn} > 0$ and the reaction is endothermic. Do you agree or disagree with the student's claim? Justify your answer.

Next, the student investigates the acid-base behavior of maleic acid. The student notes that maleic acid is a diprotic acid. The two acid dissociation processes that occur are represented by the following equations.

$$H_2C_4H_2O_4 + H_2O \rightleftarrows HC_4H_2O_4^- + H_3O^+ \qquad K_{a_1} = 1.5 \times 10^{-2}$$

$$HC_4H_2O_4^- + H_2O \rightleftarrows C_4H_2O_4^{2-} + H_3O^+ \qquad K_{a_2} = 8.5 \times 10^{-7}$$

(f) Calculate the pK_{a_2} value for the $HC_4H_2O_4^-$ ion.

(g) A buffer solution with a pH of 7.00 is prepared using $C_4H_2O_4^{2-}$ and $HC_4H_2O_4^-$. Calculate the ratio $\dfrac{[C_4H_2O_4^{2-}]}{[HC_4H_2O_4^-]}$ in this solution.

GO ON TO THE NEXT PAGE.

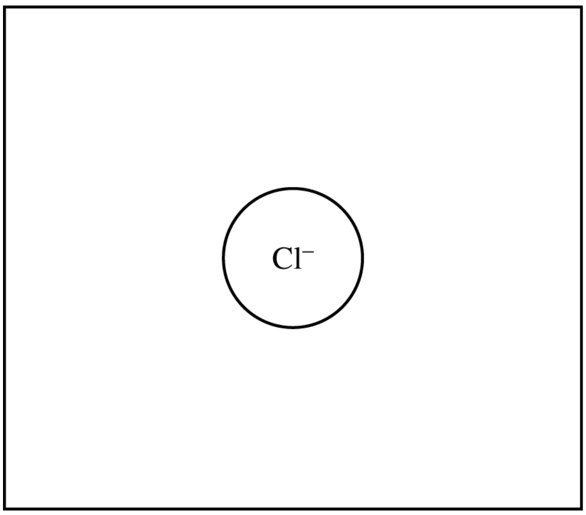
. HCl is a molecular gas as a pure substance but acts as an acid in aqueous solution.

(a) A sample of $HCl(g)$ is stored in a rigid 6.00 L container at 7.45 atm and 296 K.

(i) Calculate the number of moles of $HCl(g)$ in the container.

(ii) The rigid 6.00 L container of $HCl(g)$ is cooled to a temperature of 271 K. Calculate the new pressure, in atm, of the $HCl(g)$.

(b) When HCl ionizes in aqueous solution, $Cl^{-}(aq)$ ions are formed. In the following box, draw three water molecules with proper orientation around the Cl^{-} ion. Use  to represent water molecules.



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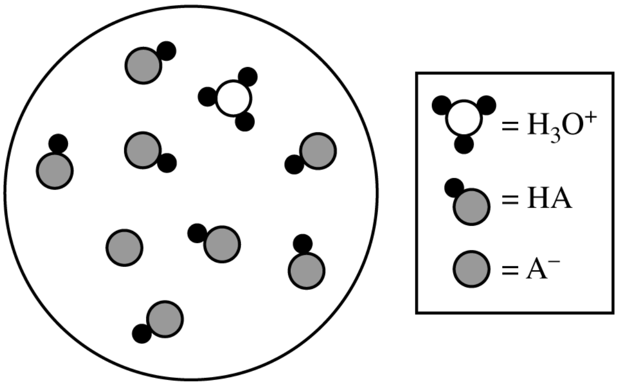
Continue your response to **QUESTION 5** on this page.

Acid (HA)	Anion (A^-)	K_a Value
HNO_2	NO_2^-	5.6×10^{-4}
HCl	Cl^-	2.0×10^{7}
$HClO_4$	ClO_4^-	1.6×10^{15}

The K_a values for three acids are shown in the preceding table.

(c) The following particulate diagram represents the ionization of one of the acids in the data table. Water molecules have been omitted for clarity. Which acid (HNO_2, HCl, or $HClO_4$) is represented in the diagram? Justify your answer using the information in the table.



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$$CH_3OH(g) \rightleftarrows CO(g) + 2\ H_2(g) \qquad \Delta H° = 90.0\ \text{kJ/mol}_{rxn}$$

. Methanol vapor decomposes to form carbon monoxide gas and hydrogen gas at high temperatures in the presence of a platinum catalyst, as represented by the balanced chemical equation given.

(a) Are the hydrogen atoms oxidized or are they reduced in the forward reaction? Justify your answer in terms of oxidation numbers.

(b) In the following box, draw the complete Lewis electron-dot diagram for the carbon monoxide molecule in which every atom obeys the octet rule. Show all bonding and nonbonding valence electrons.

C O

(c) The values of the standard molar entropies of the compounds involved in the reaction are given in the following table.

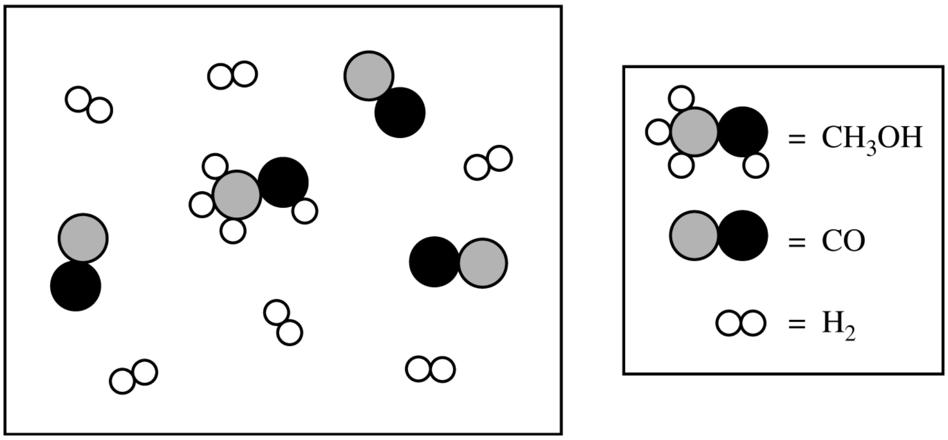
Substance	$S°$ (J/(K·mol))
$CH_3OH(g)$	240.
$CO(g)$	198
$H_2(g)$	131

(i) Use the data in the table to calculate the value of the standard entropy change, $\Delta S°$, in J/(K·mol$_{rxn}$), for the reaction.

GO ON TO THE NEXT PAGE.

(ii) Calculate the value of $\Delta G°$, in kJ/mol$_{rxn}$, for the reaction at 375 K. Assume that $\Delta H°$ and $\Delta S°$ are independent of temperature.

The following particle-level diagram shows a representative sample of the equilibrium mixture represented by the equation given.



(d) Use information from the particle diagram to calculate the partial pressure of CO at equilibrium when the total pressure of the equilibrium mixture is 12.0 atm.

(e) Write the expression for the equilibrium constant, K_p, for the reaction.

GO ON TO THE NEXT PAGE.

Continue your response to **QUESTION 2** on this page.

$$CH_3OH(g) \rightleftarrows CO(g) + 2\ H_2(g)$$

The reaction system represented by the equation is allowed to achieve equilibrium at a different temperature. The following table gives the partial pressure of each species in the equilibrium mixture.

Substance	Partial Pressure at Different Temperature
$CH_3OH(g)$	2.7 atm
$CO(g)$	4.2 atm
$H_2(g)$	8.4 atm

(f) Use the information in the table to calculate the value of the equilibrium constant, K_p, at the new temperature.

(g) The volume of the container is rapidly doubled with no change in temperature. As equilibrium is re-established, does the number of moles of $CH_3OH(g)$ increase, decrease, or remain the same? Justify your answer by comparing the value of the reaction quotient, Q, with the value of the equilibrium constant, K_p.

GO ON TO THE NEXT PAGE.

CHEMISTRY

SECTION II

Time—1 hour and 45 minutes

7 Questions

YOU MAY USE YOUR CALCULATOR FOR THIS SECTION.

Directions: Questions 1–3 are long free-response questions that require about 23 minutes each to answer and are worth 10 points each. Questions 4–7 are short free-response questions that require about 9 minutes each to answer and are worth 4 points each.

For each question, show your work for each part in the space provided after that part. 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.

$$\mathrm{HCOOH}(aq) + \mathrm{H_2O}(l) \rightleftarrows \mathrm{H_3O^+}(aq) + \mathrm{HCOO^-}(aq) \qquad K_a = 1.8 \times 10^{-4}$$

1. Methanoic acid, HCOOH, ionizes according to the equation above.

(a) Write the expression for the equilibrium constant, K_a, for the reaction.

(b) Calculate the pH of a 0.25 M solution of HCOOH.

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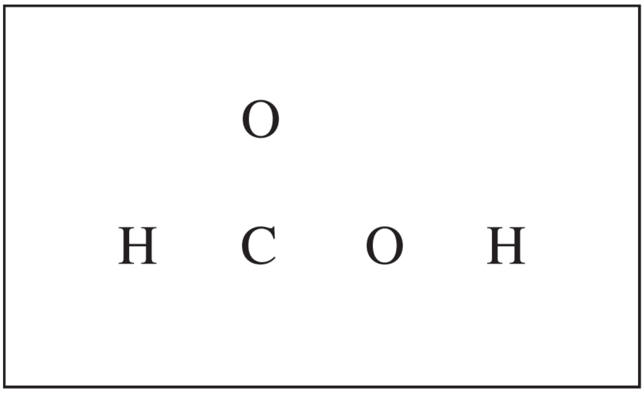
(c) In the box below, complete the Lewis electron-dot diagram for HCOOH. Show all bonding and nonbonding valence electrons.



$$H_2NNH_2(aq) + H_2O(l) \rightleftarrows H_2NNH_3^{+}(aq) + OH^{-}(aq) \qquad K_b = 1.3 \times 10^{-6}$$

(d) In aqueous solution, the compound H_2NNH_2 reacts according to the equation above. A 50.0 mL sample of 0.25 M $H_2NNH_2(aq)$ is combined with a 50.0 mL sample of 0.25 M HCOOH(aq).

(i) Write the balanced net ionic equation for the reaction that occurs when H_2NNH_2 is combined with HCOOH.

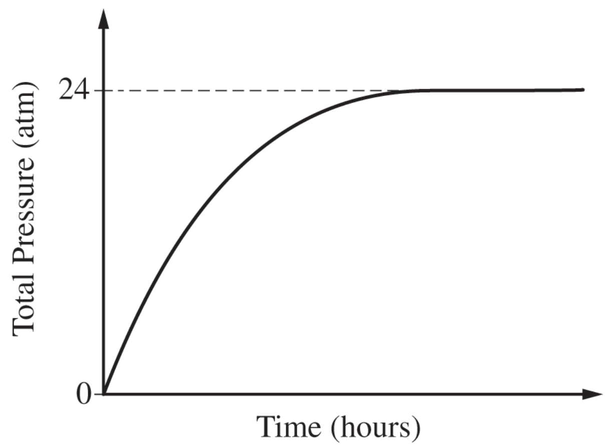
(ii) Is the resulting solution acidic, basic, or neutral? Justify your answer.

GO ON TO THE NEXT PAGE.

When a catalyst is added to a solution of $HCOOH(aq)$, the reaction represented by the following equation occurs.

$$HCOOH(aq) \rightarrow H_2(g) + CO_2(g)$$

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

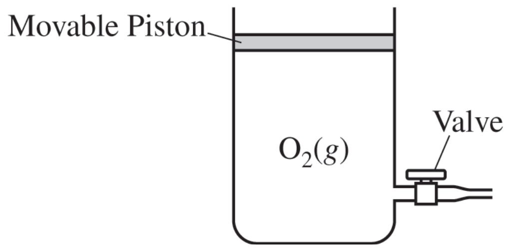


(f) The reaction occurs in a rigid 4.3 L vessel at 25°C, and the total pressure is monitored, as shown in the graph above. The vessel originally did not contain any gas. Calculate the number of moles of $CO_2(g)$ produced in the reaction. (Assume that the amount of $CO_2(g)$ dissolved in the solution is negligible.)

(g) After the reaction has proceeded for several minutes, does the amount of catalyst increase, decrease, or remain the same? Justify your answer.

GO ON TO THE NEXT PAGE.

Begin your response to **QUESTION 7** on this page.



7. A student investigates gas behavior using a rigid cylinder with a movable piston of negligible mass, as shown in the diagram above. The cylinder contains 0.325 mol of $O_2(g)$.

(a) The cylinder has a volume of 7.95 L at 25°C and 1.00 atm. Calculate the density of the $O_2(g)$, in g/L, under these conditions.

(b) Attempting to change the density of the $O_2(g)$, the student opens the valve on the side of the cylinder, pushes down on the piston to release some of the gas, and closes the valve again. The temperature of the gas remains constant at 25°C. Will this action change the density of the gas remaining in the cylinder? Justify your answer.

GO ON TO THE NEXT PAGE.

(c) The student tries to change the density of the $O_2(g)$ by cooling the cylinder to $-55°C$, which causes the volume of the gas to decrease. Using principles of kinetic molecular theory, explain why the volume of the $O_2(g)$ decreases when the temperature decreases to $-55°C$.

(d) The student further cools the cylinder to $-180°C$ and observes that the measured volume of the $O_2(g)$ is substantially smaller than the volume that is calculated using the ideal gas law. Assume all equipment is functioning properly. Explain why the measured volume of the $O_2(g)$ is smaller than the calculated volume. (The boiling point of $O_2(l)$ is $-183°C$.)

GO ON TO THE NEXT PAGE.

STOP

END OF EXAM

2. Answer the following questions relating to the chemistry of the halogens.

(a) The molecular formulas of diatomic bromine, chlorine, fluorine, and iodine are written below. Circle the formula of the molecule that has the longest bond length. Justify your choice in terms of atomic structure.

Br_2 Cl_2 F_2 I_2

A chemistry teacher wants to prepare Br_2. The teacher has access to the following three reagents: $NaBr(aq)$, $Cl_2(g)$, and $I_2(s)$.

Half-Reaction	$E°$ at 25°C (V)
$Br_2 + 2e^- \rightarrow 2Br^-$	1.07
$Cl_2 + 2e^- \rightarrow 2Cl^-$	1.36
$I_2 + 2e^- \rightarrow 2I^-$	0.53

(b) Using the data in the table above, write the balanced equation for the thermodynamically favorable reaction that will produce Br_2 when the teacher combines two of the reagents. Justify that the reaction is thermodynamically favorable by calculating the value of $E°$ for the reaction.

Br_2 and Cl_2 can react to form the compound $BrCl$.

(c) The boiling point of Br_2 is 332 K, whereas the boiling point of $BrCl$ is 278 K. Explain this difference in boiling point in terms of all the intermolecular forces present between molecules of <u>each</u> substance.

The compound $BrCl$ can decompose into Br_2 and Cl_2, as represented by the balanced chemical equation below.

$$2\,BrCl(g) \rightleftarrows Br_2(g) + Cl_2(g) \qquad \Delta H° = 1.6\ \text{kJ/mol}_{rxn}$$

A 0.100 mole sample of pure $BrCl(g)$ is placed in a previously evacuated, rigid 2.00 L container at 298 K. Eventually the system reaches equilibrium according to the equation above.

(d) Calculate the pressure in the container before equilibrium is established.

(e) Write the expression for the equilibrium constant, K_{eq}, for the decomposition of $BrCl$.

After the system has reached equilibrium, 42 percent of the original $BrCl$ sample has decomposed.

(f) Determine the value of K_{eq} for the decomposition reaction of $BrCl$ at 298 K.

(g) Calculate the bond energy of the Br-Cl bond, in kJ/mol, using $\Delta H°$ for the reaction (1.6 kJ/mol$_{rxn}$) and the information in the following table.

Bond	Bond Energy (kJ/mol)
Br – Br	193
Cl – Cl	243
Br – Cl	?

4. A student is doing experiments with $CO_2(g)$. Originally, a sample of the gas is in a rigid container at 299 K and 0.70 atm. The student increases the temperature of the $CO_2(g)$ in the container to 425 K.

   (a) Describe the effect of raising the temperature on the motion of the $CO_2(g)$ molecules.

   (b) Calculate the pressure of the $CO_2(g)$ in the container at 425 K.

   (c) In terms of kinetic molecular theory, briefly explain why the pressure of the $CO_2(g)$ in the container changes as it is heated to 425 K.

   (d) The student measures the actual pressure of the $CO_2(g)$ in the container at 425 K and observes that it is less than the pressure predicted by the ideal gas law. Explain this observation.

Sulfur atom =  Carbon atom =  Oxygen atom = 

Compound	Molecular Structure	Boiling Point at 1 atm (K)
CS_2		319
COS		223

4. The table above gives the molecular structures and boiling points for the compounds CS_2 and COS.

   (a) In terms of the types and relative strengths of all the intermolecular forces in each compound, explain why the boiling point of $CS_2(l)$ is higher than that of $COS(l)$.

   (b) A 10.0 g sample of $CS_2(l)$ is put in an evacuated 5.0 L rigid container. The container is sealed and heated to 325 K, at which temperature all of the $CS_2(l)$ has vaporized. What is the pressure in the container once all of the $CS_2(l)$ has vaporized?

CHEMISTRY

Section II

7 Questions

Time—1 hour and 45 minutes

YOU MAY USE YOUR CALCULATOR FOR THIS SECTION.

Directions: Questions 1–3 are long free-response questions that require about 23 minutes each to answer and are worth 10 points each. Questions 4–7 are short free-response questions that require about 9 minutes each to answer and are worth 4 points each.

Write your response in the space provided following each question. 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.

$$CS_2(g) + 3\ Cl_2(g) \rightarrow CCl_4(g) + S_2Cl_2(g)$$

1. Carbon tetrachloride, $CCl_4(g)$, can be synthesized according to the reaction represented above. A chemist runs the reaction at a constant temperature of 120°C in a rigid 25.0 L container.

(a) Chlorine gas, $Cl_2(g)$, is initially present in the container at a pressure of 0.40 atm.

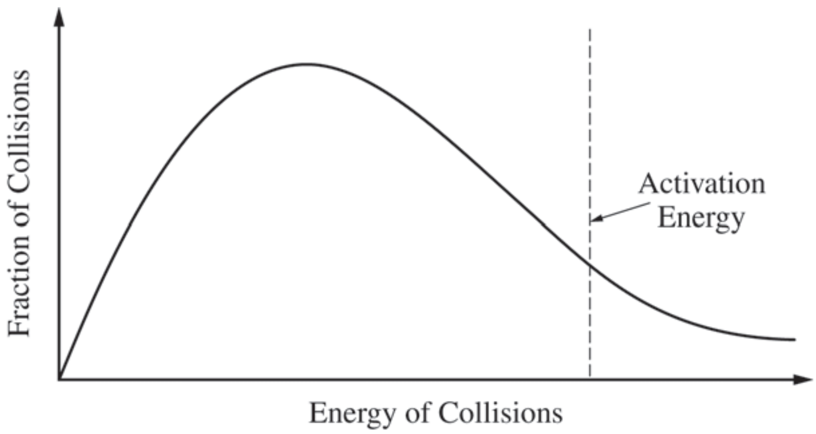
(i) How many moles of $Cl_2(g)$ are in the container?

(ii) How many grams of carbon disulfide, $CS_2(g)$, are needed to react completely with the $Cl_2(g)$?

(b) At 30°C the reaction is thermodynamically favorable, but no reaction is observed to occur. However, at 120°C, the reaction occurs at an observable rate.

(i) Explain how the higher temperature affects the collisions between the reactant molecules so that the reaction occurs at an observable rate at 120°C.

(ii) The graph below shows a distribution for the collision energies of reactant molecules at 120°C. Draw a second curve on the graph that shows the distribution for the collision energies of reactant molecules at 30°C.



(c) S_2Cl_2 is a product of the reaction.

(i) In the box below, complete the Lewis electron-dot diagram for the S_2Cl_2 molecule by drawing in all of the electron pairs.

Cl S S Cl

(ii) What is the approximate value of the Cl–S–S bond angle in the S_2Cl_2 molecule that you drew in part (c)(i) ? (If the two Cl–S–S bond angles are not equal, include both angles.)

(d) $CCl_4(g)$ can also be produced by reacting $CHCl_3(g)$ with $Cl_2(g)$ at 400°C, as represented by the equation below.

$$CHCl_3(g) + Cl_2(g) \rightarrow CCl_4(g) + HCl(g)$$

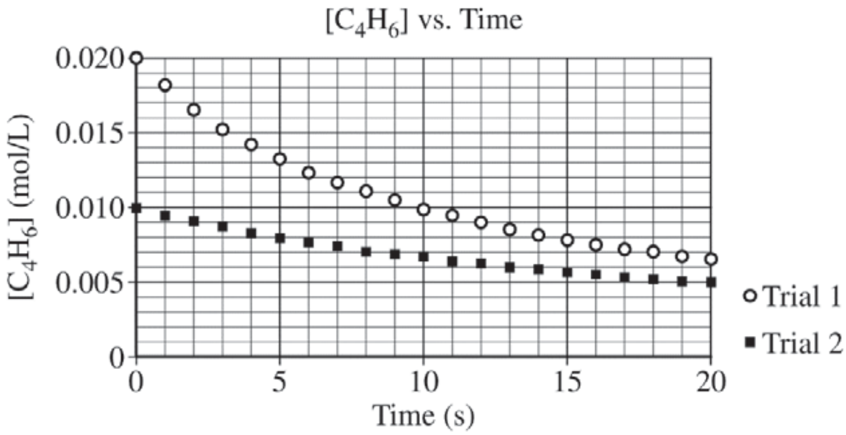
At the completion of the reaction a chemist successfully separates the $CCl_4(g)$ from the $HCl(g)$ by cooling the mixture to 70°C, at which temperature the $CCl_4(g)$ condenses while the $HCl(g)$ remains in the gaseous state.

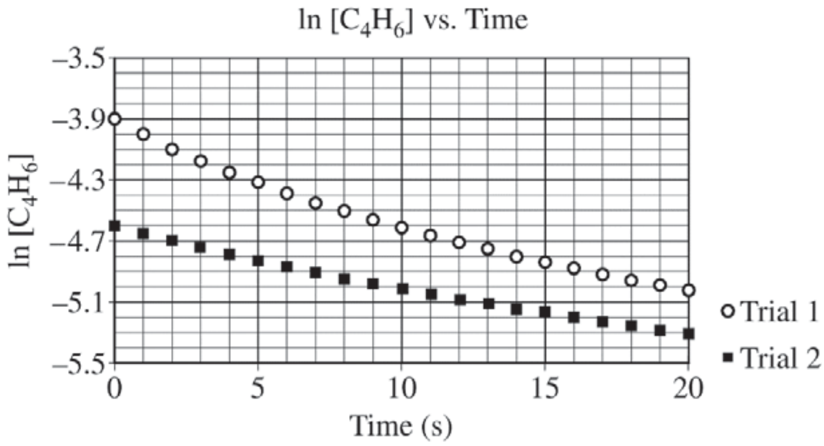
(i) Identify all types of intermolecular forces present in $HCl(l)$.

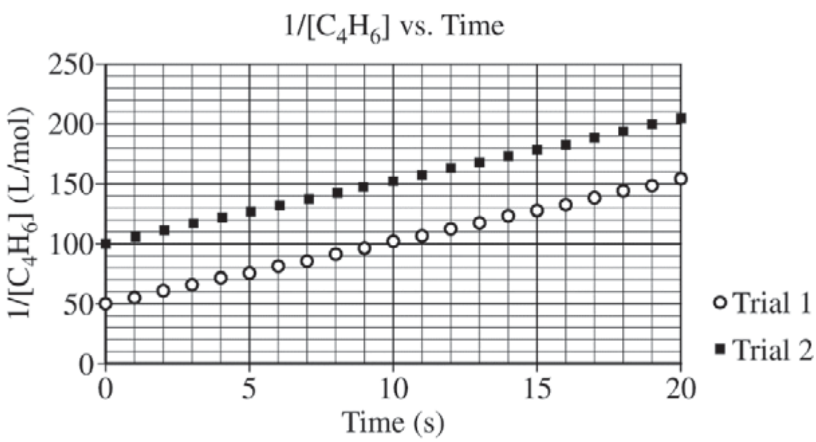
(ii) What can be inferred about the relative strengths of the intermolecular forces in $CCl_4(l)$ and $HCl(l)$? Justify your answer in terms of the information above.

$$2\ C_4H_6(g) \rightarrow C_8H_{12}(g)$$

5. At high temperatures the compound C_4H_6 (1,3-butadiene) reacts according to the equation above. The rate of the reaction was studied at 625 K in a rigid reaction vessel. Two different trials, each with a different starting concentration, were carried out. The data were plotted in three different ways, as shown below.







(a) For trial 1, calculate the initial pressure, in atm, in the vessel at 625 K. Assume that initially all the gas present in the vessel is C_4H_6.

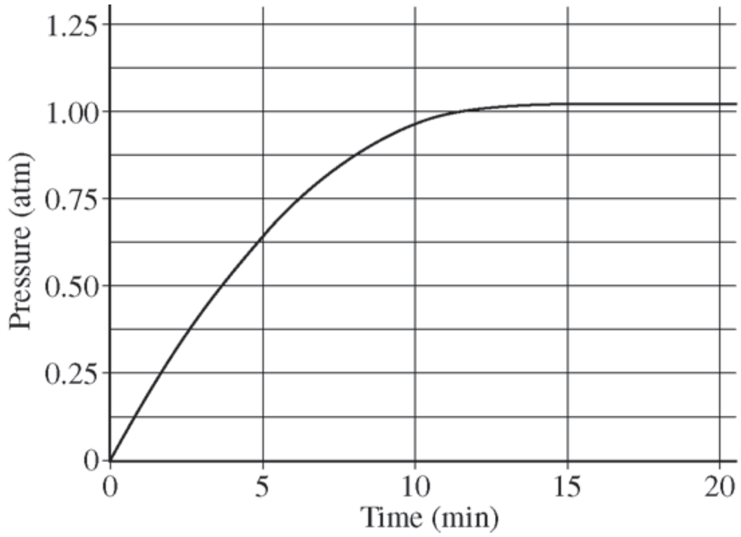
(b) Use the data plotted in the graphs to determine the order of the reaction with respect to C_4H_6.

(c) The initial rate of the reaction in trial 1 is 0.0010 mol/(L·s). Calculate the rate constant, k, for the reaction at 625 K.

AP Chemistry: **2014**

$$CaCO_3(s) \rightleftarrows CaO(s) + CO_2(g)$$

4. When heated, calcium carbonate decomposes according to the equation above. In a study of the decomposition of calcium carbonate, a student added a 50.0 g sample of powdered $CaCO_3(s)$ to a 1.00 L rigid container. The student sealed the container, pumped out all the gases, then heated the container in an oven at 1100 K. As the container was heated, the total pressure of the $CO_2(g)$ in the container was measured over time. The data are plotted in the graph below.



The student repeated the experiment, but this time the student used a 100.0 g sample of powdered $CaCO_3(s)$. In this experiment, the final pressure in the container was 1.04 atm, which was the same final pressure as in the first experiment.

(a) Calculate the number of moles of $CO_2(g)$ present in the container after 20 minutes of heating.

(b) The student claimed that the final pressure in the container in each experiment became constant because all of the $CaCO_3(s)$ had decomposed. Based on the data in the experiments, do you agree with this claim? Explain.

(c) After 20 minutes some $CO_2(g)$ was injected into the container, initially raising the pressure to 1.5 atm. Would the final pressure inside the container be less than, greater than, or equal to 1.04 atm? Explain your reasoning.

(d) Are there sufficient data obtained in the experiments to determine the value of the equilibrium constant, K_p, for the decomposition of $CaCO_3(s)$ at 1100 K? Justify your answer.

AP CHEMISTRY • EXERCISE SHEET

3.5 Kinetic Molecular Theory

Name: ____________ Class: ________ Date: __________ **Total: 11 marks**

KEY WORDS kinetic molecular theory 分子运动论 • maxwell-boltzmann 麦克斯韦 • solute 溶质 • solution 溶液

Objective

Build the skills to answer exam questions on the **kinetic molecular theory** of gases.

You must be able to:

- state the assumptions of the **kinetic molecular theory** 分子运动论
- link **temperature** to average kinetic energy
- read a **Maxwell-Boltzmann** 麦克斯韦-玻尔兹曼 speed distribution

1 Worked examples

Study these first. Each one shows the method for a question type used later — follow the steps and you can do the Practice and Exam-style questions yourself.

■ The assumptions

An ideal gas is modelled as: many tiny particles in constant random motion; negligible volume; no forces between them; and **elastic** collisions (no energy lost).

■ Temperature and kinetic energy

The **average kinetic energy** of the particles is proportional to the **absolute temperature**:

$$KE_{\text{avg}} = \tfrac{3}{2}k_B T.$$

Doubling T (in kelvin) doubles the average kinetic energy.

■ Speed and molar mass

At the same temperature, **lighter** molecules move **faster** (same KE means smaller mass $\Rightarrow$ larger speed). So H_2 moves faster than O_2 at the same T.

■ The Maxwell-Boltzmann distribution

The curve shows the spread of molecular speeds. Higher temperature shifts the peak **right** and **flattens** it (a wider spread, more fast molecules). The area under the curve is the total number of molecules.

2 Practice

Now apply the methods above.

2.1 What is proportional to the absolute temperature of a gas? [1]

2.2 At the same temperature, which moves faster: He or Ar? Give a reason. [2]

2.3 What happens to the Maxwell-Boltzmann curve when temperature rises? [1]

3 Exam-style questions

3.1 According to kinetic molecular theory, collisions between ideal-gas particles are [1]

- **A** inelastic (energy lost)
- **B** elastic (no energy lost)
- **C** impossible
- **D** always head-on

3.2 Two gases, H_2 and O_2, are at the same temperature.

(a) Compare their average kinetic energies. [1]

(b) Compare their average speeds, with a reason. [2]

3.3 Describe how the Maxwell-Boltzmann speed distribution changes when a gas is heated, and what stays the same. [3]

Solutions

2.1 The average kinetic energy of the particles.

2.2 He — it has a smaller molar mass, so at equal kinetic energy it moves faster.

2.3 The peak shifts to higher speed and the curve flattens/broadens.

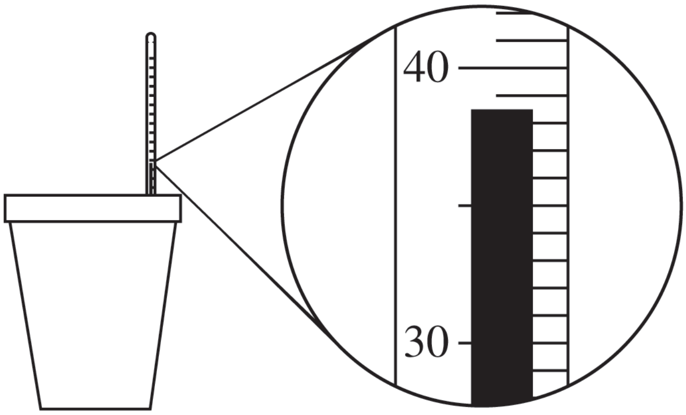
3.1 B — elastic collisions.

3.2 (a) Equal — average kinetic energy depends only on temperature. (b) H_2 is faster; it has a smaller mass, so for the same $KE = \frac{1}{2}mv^2$ it has a larger v.

3.3 Heating shifts the peak to a higher speed and lowers/broadens it (a wider spread with more fast molecules); the total area (number of molecules) stays the same.

4. A student performs an experiment to determine the specific heat capacity of a metal. The student places a cube of the metal in boiling water so its temperature will be 100.0°C. The student then places the metal cube into a calorimeter that contains water and records the highest temperature of the water. A data table and a diagram of the thermometer at the highest temperature are shown.

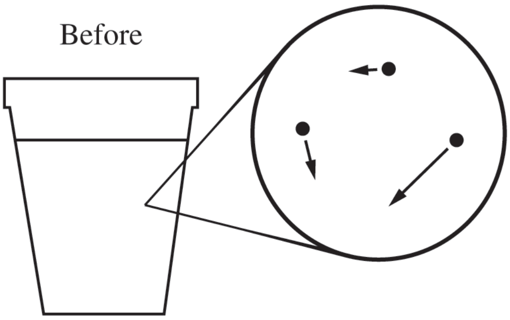
Mass of metal cube	98.1 g
Mass of water	52.0 g
Initial temperature of metal cube	100.0°C
Initial temperature of water	25.0°C
Highest temperature of water	?



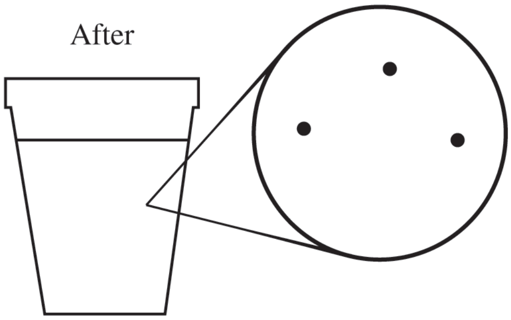
(a) What should the student report as the highest temperature of the water? ____________

(b) A particle-level representation of water molecules in the calorimeter before and after the metal cube was added is shown. The length of the arrows in the Before diagram represents the speed of the water molecules in the system. In the After diagram, draw an arrow for each molecule to indicate how the speed of each of the molecules changes after the metal cube is added.

Before



After



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Continue your response to **QUESTION 4** on this page.

(c) Assuming the metal transfers 2940 J of thermal energy to the water, calculate the specific heat of the metal in J/(g·°C).

(d) In a second experiment, 2940 J of thermal energy is transferred from 98.1 g of aluminum, which has a specific heat capacity of 0.897 J / (g·° C). Explain how the magnitude of the temperature change of the aluminum, ΔT_{Al}, compares with the magnitude of the temperature change of the metal in the original experiment.

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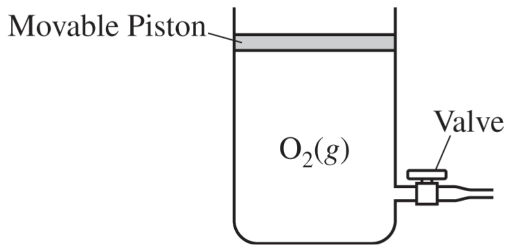
Begin your response to **QUESTION 7** on this page.



7. A student investigates gas behavior using a rigid cylinder with a movable piston of negligible mass, as shown in the diagram above. The cylinder contains 0.325 mol of $O_2(g)$.

(a) The cylinder has a volume of 7.95 L at 25°C and 1.00 atm. Calculate the density of the $O_2(g)$, in g/L, under these conditions.

(b) Attempting to change the density of the $O_2(g)$, the student opens the valve on the side of the cylinder, pushes down on the piston to release some of the gas, and closes the valve again. The temperature of the gas remains constant at 25°C. Will this action change the density of the gas remaining in the cylinder? Justify your answer.

GO ON TO THE NEXT PAGE.

(c) The student tries to change the density of the $O_2(g)$ by cooling the cylinder to $-55°C$, which causes the volume of the gas to decrease. Using principles of kinetic molecular theory, explain why the volume of the $O_2(g)$ decreases when the temperature decreases to $-55°C$.

(d) The student further cools the cylinder to $-180°C$ and observes that the measured volume of the $O_2(g)$ is substantially smaller than the volume that is calculated using the ideal gas law. Assume all equipment is functioning properly. Explain why the measured volume of the $O_2(g)$ is smaller than the calculated volume. (The boiling point of $O_2(l)$ is $-183°C$.)

GO ON TO THE NEXT PAGE.

STOP

END OF EXAM

4. A student is doing experiments with $CO_2(g)$. Originally, a sample of the gas is in a rigid container at 299 K and 0.70 atm. The student increases the temperature of the $CO_2(g)$ in the container to 425 K.

   (a) Describe the effect of raising the temperature on the motion of the $CO_2(g)$ molecules.

   (b) Calculate the pressure of the $CO_2(g)$ in the container at 425 K.

   (c) In terms of kinetic molecular theory, briefly explain why the pressure of the $CO_2(g)$ in the container changes as it is heated to 425 K.

   (d) The student measures the actual pressure of the $CO_2(g)$ in the container at 425 K and observes that it is less than the pressure predicted by the ideal gas law. Explain this observation.

3.6 Deviation from the Ideal Gas Law

Name: ____________ Class: ________ Date: __________ **Total: 11 marks**

KEY WORDS solution 溶液 • hydrogen bonding 氢键 • intermolecular forces 分子间作用力

Objective

Build the skills to answer exam questions on **deviations from the ideal gas law**.

You must be able to:

- state when real gases deviate (**high pressure, low temperature**)
- explain the two causes (particle **volume** and **attractions**)
- predict which gas is more ideal

1 Worked examples

Study these first. Each one shows the method for a question type used later — follow the steps and you can do the Practice and Exam-style questions yourself.

■ When deviations matter

Real gases behave most **ideally** at **high temperature** and **low pressure**. They deviate most at **low temperature** and **high pressure**, where the ideal assumptions break down.

■ The two causes

The ideal law assumes zero particle volume and no attractions. In reality:

- particles **do** take up volume — matters at high pressure (crowded);
- particles **do** attract — matters at low temperature (slow-moving, so attractions pull them together).

■ Effect on pressure

Attractions make real particles hit the walls a little **less** hard, so the real pressure is slightly **lower** than ideal. Particle volume makes the available space smaller, raising pressure at very high compression.

■ Which gas is more ideal

Small, nonpolar gases with weak IMFs (like He, H_2) behave most ideally. Large or polar gases (with strong attractions) deviate more.

2 Practice

Now apply the methods above.

2.1 Under what conditions do real gases behave most ideally? [1]

2.2 Name the two properties of real particles that the ideal law ignores. [2]

2.3 Which behaves more ideally: He or NH_3? Give a reason. [2]

3 Exam-style questions

3.1 Real gases deviate most from ideal behavior at [1]

- **A** high temperature and low pressure
- **B** low temperature and high pressure
- **C** standard conditions
- **D** any temperature

3.2 A gas is cooled to near its boiling point at high pressure.

(a) State whether it behaves more or less ideally. [1]

(b) Explain the role of intermolecular attractions at low temperature. [2]

3.3 Explain why He behaves more ideally than H_2O vapor, in terms of intermolecular forces. [2]

Solutions

2.1 High temperature and low pressure.

2.2 The volume of the particles; the attractions between particles.

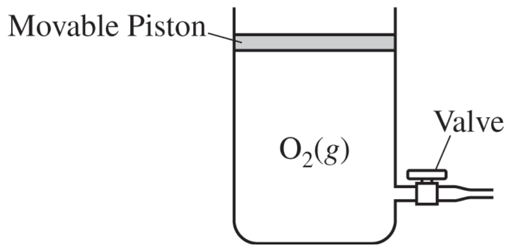
2.3 He — it is small and nonpolar with only weak dispersion forces, so it deviates less than the polar, hydrogen-bonding NH_3.

3.1 **B** — low temperature and high pressure.

3.2 (a) Less ideally. (b) At low temperature the particles move slowly, so intermolecular attractions pull them together, reducing the pressure below the ideal prediction.

3.3 He has only weak dispersion forces, while H_2O has strong hydrogen bonding; stronger attractions cause larger deviations, so He is more ideal.

Begin your response to **QUESTION 7** on this page.



7. A student investigates gas behavior using a rigid cylinder with a movable piston of negligible mass, as shown in the diagram above. The cylinder contains 0.325 mol of $O_2(g)$.

(a) The cylinder has a volume of 7.95 L at 25°C and 1.00 atm. Calculate the density of the $O_2(g)$, in g/L, under these conditions.

(b) Attempting to change the density of the $O_2(g)$, the student opens the valve on the side of the cylinder, pushes down on the piston to release some of the gas, and closes the valve again. The temperature of the gas remains constant at 25°C. Will this action change the density of the gas remaining in the cylinder? Justify your answer.

GO ON TO THE NEXT PAGE.

(c) The student tries to change the density of the $O_2(g)$ by cooling the cylinder to $-55°C$, which causes the volume of the gas to decrease. Using principles of kinetic molecular theory, explain why the volume of the $O_2(g)$ decreases when the temperature decreases to $-55°C$.

(d) The student further cools the cylinder to $-180°C$ and observes that the measured volume of the $O_2(g)$ is substantially smaller than the volume that is calculated using the ideal gas law. Assume all equipment is functioning properly. Explain why the measured volume of the $O_2(g)$ is smaller than the calculated volume. (The boiling point of $O_2(l)$ is $-183°C$.)

GO ON TO THE NEXT PAGE.

STOP

END OF EXAM

4. A student is doing experiments with $CO_2(g)$. Originally, a sample of the gas is in a rigid container at 299 K and 0.70 atm. The student increases the temperature of the $CO_2(g)$ in the container to 425 K.

   (a) Describe the effect of raising the temperature on the motion of the $CO_2(g)$ molecules.

   (b) Calculate the pressure of the $CO_2(g)$ in the container at 425 K.

   (c) In terms of kinetic molecular theory, briefly explain why the pressure of the $CO_2(g)$ in the container changes as it is heated to 425 K.

   (d) The student measures the actual pressure of the $CO_2(g)$ in the container at 425 K and observes that it is less than the pressure predicted by the ideal gas law. Explain this observation.

3.7 Solutions and Mixtures

Name: ______________ Class: _________ Date: ___________ **Total: 15 marks**

KEY WORDS solution 溶液 • molarity 摩尔浓度 • solute 溶质 • solvent 溶剂

Objective

Build the skills to answer exam questions on **solutions and mixtures** — concentration and molarity.

You must be able to:

- define **solute 溶质**, **solvent 溶剂**, and **solution 溶液**
- calculate **molarity 摩尔浓度** $M = \dfrac{\text{mol solute}}{\text{L solution}}$
- find moles or mass from a molarity

1 Worked examples

Study these first. Each one shows the method for a question type used later — follow the steps and you can do the Practice and Exam-style questions yourself.

■ Solute, solvent, solution

A **solute** dissolves in a **solvent** to make a **solution**. In salt water, salt is the solute and water the solvent.

■ Molarity

$$M = \frac{\text{moles of solute}}{\text{litres of solution}}.$$

Dissolving 0.5 mol in 2.0 L gives $\dfrac{0.5}{2.0} = 0.25$ M.

■ Finding moles from molarity

Rearrange: mol $= M \times V(\text{L})$. In 0.50 L of 2.0 M solution there are $2.0 \times 0.50 = 1.0$ mol.

■ From mass to molarity

Convert mass to moles first ($n = m/M_{\text{molar}}$), then divide by volume. 11.7 g of NaCl ($M_{\text{molar}} = 58.5$) is 0.20 mol; in 0.50 L that is 0.40 M.

2 Practice

Now apply the methods above.

2.1 Find the molarity of 0.40 mol dissolved in 2.0 L. [2]

2.2 How many moles are in 0.25 L of a 1.2 M solution? [2]

2.3 Identify the solute and solvent in a copper sulfate solution. [2]

3 Exam-style questions

3.1 Molarity is defined as [1]

- **A** mol solute per kg solvent
- **B** mol solute per L solution
- **C** g solute per L solution
- **D** L solution per mol solute

3.2 A solution is made by dissolving 0.50 mol of KCl in enough water to make 250 mL.

(a) Find the molarity. [3]

(b) How many moles are in 50 mL of this solution? [2]

3.3 What mass of NaOH ($M_{\text{molar}} = 40.0$ g/mol) is needed to make 500 mL of a 0.20 M solution? [3]

Solutions

2.1 $M = \dfrac{0.40}{2.0} = 0.20$ M.

2.2 mol $= 1.2 \times 0.25 = 0.30$ mol.

2.3 Solute: copper sulfate; solvent: water.

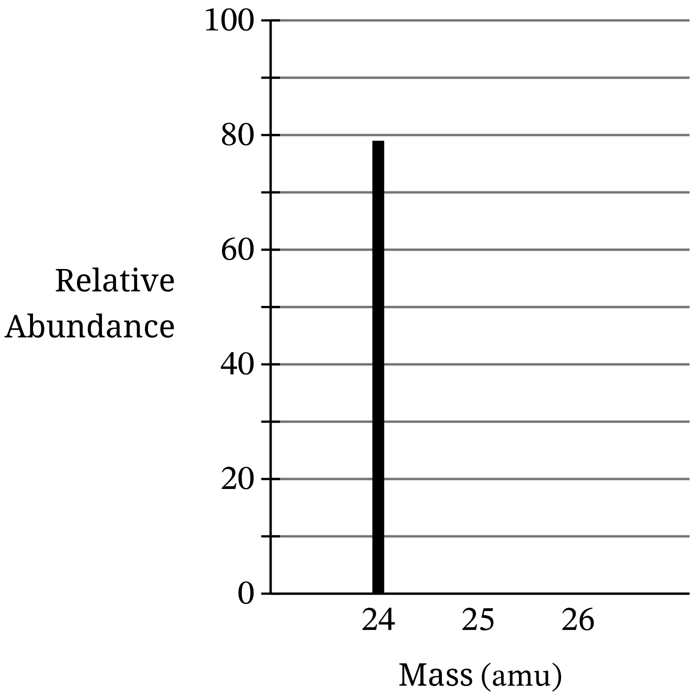
3.1 B — mol solute per litre of solution.

3.2 (a) 250 mL $= 0.250$ L; $M = \dfrac{0.50}{0.250} = 2.0$ M. (b) mol $= 2.0 \times 0.050 = 0.10$ mol.

3.3 mol $= 0.20 \times 0.500 = 0.10$ mol; mass $= 0.10 \times 40.0 = 4.0$ g.

1. Answer the following questions about magnesium.

A. An incomplete mass spectrum for magnesium is shown in the diagram.

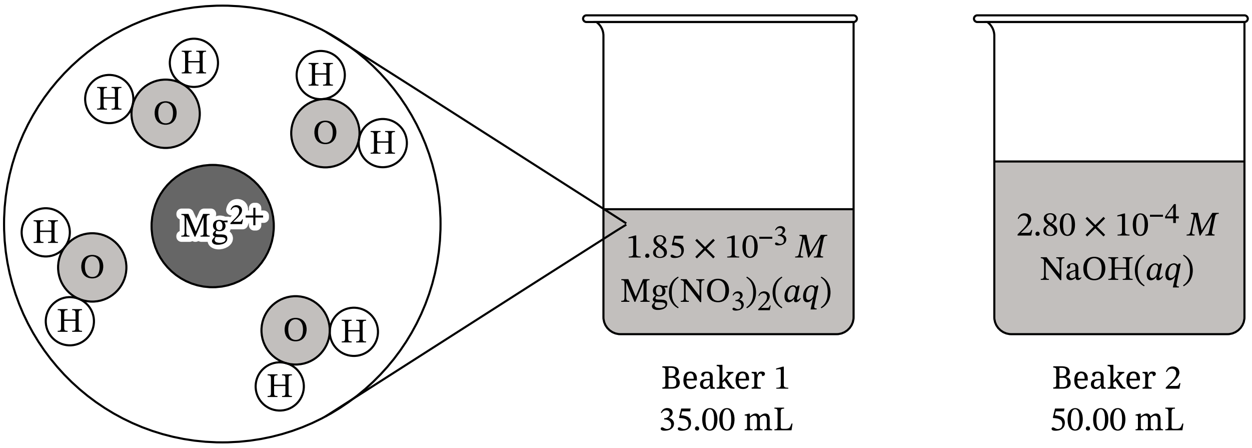


The percent abundance of magnesium-24 is 79%. The percent abundances of the other two natural isotopes of magnesium, magnesium-25 and magnesium-26, are approximately equal.

i. Complete the mass spectrum in part A by drawing thick lines in the appropriate locations to represent the percent abundance of magnesium-25 and magnesium-26.

ii. Describe the difference in atomic structure that accounts for the difference in mass between magnesium-25 and magnesium-26.

A student prepares a 1.85×10^{-3} M solution of $Mg(NO_3)_2(aq)$ in beaker 1 and a 2.80×10^{-4} M solution of $NaOH(aq)$ in beaker 2, as shown.



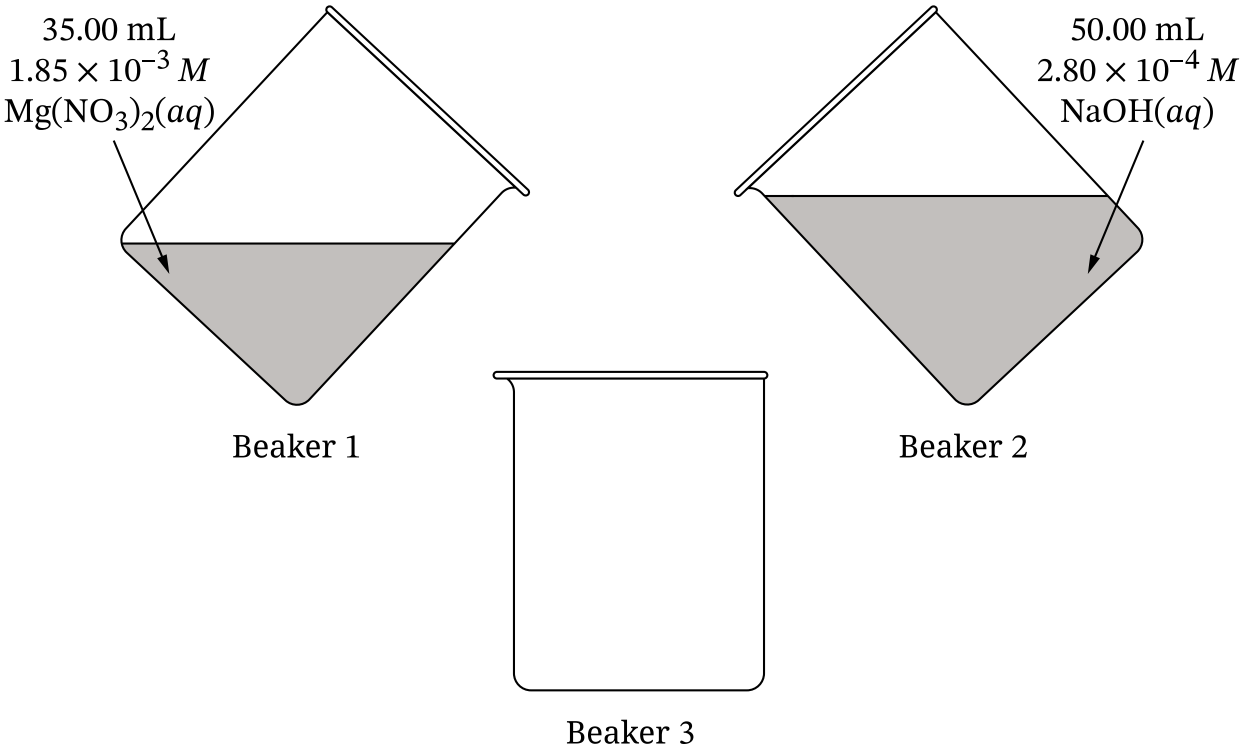
B. The particle diagram shown represents a magnesium ion, Mg^{2+}, in beaker 1. A sodium ion, Na^{+}, in beaker 2 has a weaker attraction to water than the Mg^{2+} does. Explain this phenomenon using Coulomb's law and each of the following.

i. The relative charge of the ions

ii. The relative radii of the ions

C. Calculate the pH of the solution in beaker 2.

D. A student combines 35.00 mL of 1.85×10^{-3} M $Mg(NO_3)_2(aq)$ with 50.00 mL of 2.80×10^{-4} M $NaOH(aq)$, as shown in the diagram. Calculate $[Mg^{2+}]$ after the two solutions are combined but before any reaction takes place. (Assume that volumes are additive.)



E. The dissolution of magnesium hydroxide is represented by the following equation.

$$Mg(OH)_2(s) \rightleftarrows Mg^{2+}(aq) + 2\ OH^-(aq) \qquad K_{sp} = 5.61\times10^{-12}$$

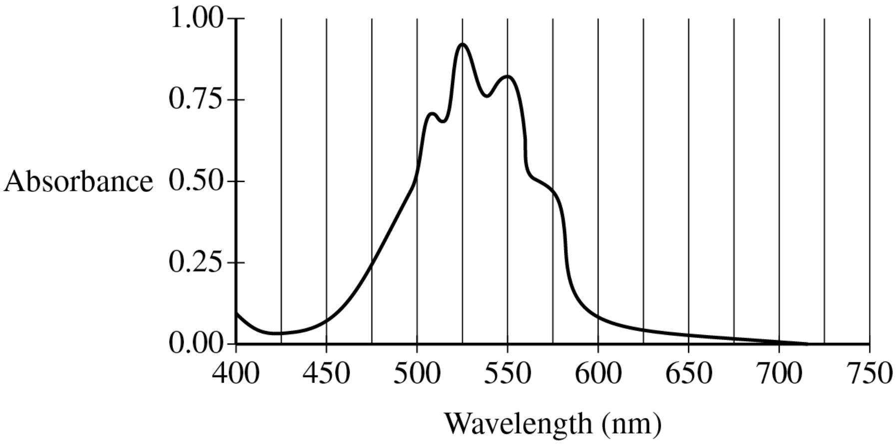
i. Write the expression for the solubility product constant, K_{sp}.

ii. After the two solutions are combined in beaker 3 as described in part D, but before any reaction takes place, $[OH^-] = 1.65\times10^{-4}$ M. Using your answer to part D, calculate the value of the reaction quotient, Q.

iii. Using the reaction quotient, Q, predict whether a precipitate should form as the mixture in beaker 3 approaches equilibrium. Justify your answer.

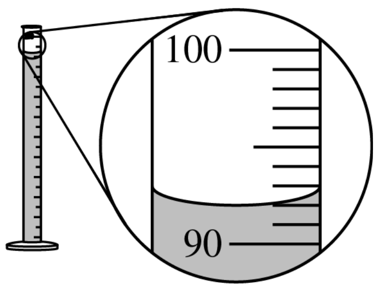
F. In a separate experiment, the student adds $HNO_3(aq)$ to decrease the pH of a saturated solution containing undissolved $Mg(OH)_2(s)$. Does the amount of undissolved $Mg(OH)_2(s)$ increase, decrease, or remain the same as the $HNO_3(aq)$ is added? Justify your answer.

. A student wants to determine the concentration of permanganate, $MnO_4^-(aq)$, in a solution. The student plans to use colorimetric analysis because solutions containing $MnO_4^-(aq)$ have a purple color.



(a) To determine the optimum wavelength for an experiment that measures the concentration of $MnO_4^-(aq)$, the student takes a sample of the solution and measures the amount of light absorbed by the sample over a range of wavelengths. The data are plotted in the graph shown. Identify the optimum wavelength that the student should use for the experimental procedure.

(b) The student uses a stock solution of 2.40×10^{-3} M $KMnO_4(aq)$ to prepare the standard solutions of $MnO_4^-(aq)$ that are needed to construct a calibration curve.



(i) The student uses a 100.0 mL graduated cylinder to measure a certain volume of $KMnO_4(aq)$ stock solution, as shown in the diagram given. What volume should the student record?

(ii) Calculate the volume, in mL, of 2.40×10^{-3} M $KMnO_4(aq)$ that is required to produce 100.0 mL of a standard 1.68×10^{-3} M $MnO_4^-(aq)$ solution.

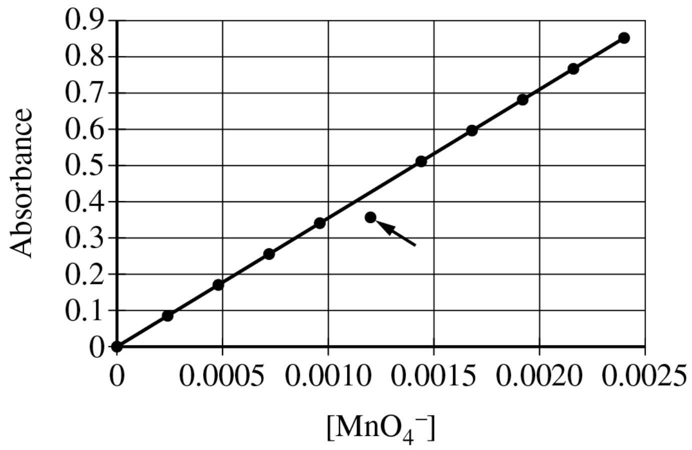
GO ON TO THE NEXT PAGE.

Continue your response to **QUESTION 6** on this page.

The student designs the following procedure to produce a calibration curve.

Step 1: Prepare several standard solutions that have known $MnO_4^-(aq)$ concentrations by dilution of the stock solution.
Step 2: Rinse the cuvette with distilled water.
Step 3: Rinse the cuvette with the standard solution and fill the cuvette with the standard solution.
Step 4: Measure the absorbance of the standard solution with the colorimeter.
Step 5: Repeat steps 2-4 for each of the standard solutions.

The data are plotted in the calibration curve shown. One of the data points (indicated with an arrow) on the calibration curve is below the line of best fit.



(c) Assuming that all lab equipment is functioning properly, identify which one of the procedural steps the student could have executed incorrectly that would explain why the marked data point is below the line of best fit. Justify your answer.

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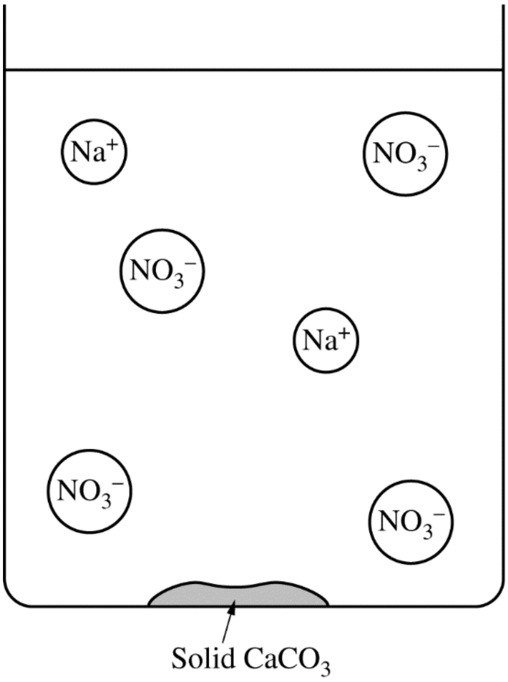
3. A student is given 50.0 mL of a solution of Na_2CO_3 of unknown concentration. To determine the concentration of the solution, the student mixes the solution with excess 1.0 *M* $Ca(NO_3)_2(aq)$, causing a precipitate to form. The balanced equation for the reaction is shown below.

$$Na_2CO_3(aq) + Ca(NO_3)_2(aq) \rightarrow 2\ NaNO_3(aq) + CaCO_3(s)$$

(a) Write the net ionic equation for the reaction that occurs when the solutions of Na_2CO_3 and $Ca(NO_3)_2$ are mixed.

(b) The diagram below is incomplete. Draw in the species needed to accurately represent the major ionic species remaining in the solution after the reaction has been completed.



The student filters and dries the precipitate of $CaCO_3$ (molar mass 100.1 g/mol) and records the data in the table below.

Volume of Na_2CO_3 solution	50.0 mL
Volume of 1.0 *M* $Ca(NO_3)_2$ added	100.0 mL
Mass of $CaCO_3$ precipitate collected	0.93 g

(c) Determine the number of moles of Na_2CO_3 in the original 50.0 mL of solution.

(d) The student realizes that the precipitate was not completely dried and claims that as a result, the calculated Na_2CO_3 molarity is too low. Do you agree with the student's claim? Justify your answer.

(e) After the precipitate forms and is filtered, the liquid that passed through the filter is tested to see if it can conduct electricity. What would be observed? Justify your answer.

The student decides to determine the molarity of the same Na_2CO_3 solution using a second method. When Na_2CO_3 is dissolved in water, $CO_3^{2-}(aq)$ hydrolyzes to form $HCO_3^-(aq)$, as shown by the following equation.

$$CO_3^{2-}(aq) + H_2O(l) \rightleftarrows HCO_3^-(aq) + OH^-(aq) \qquad K_b = \frac{[HCO_3^-][OH^-]}{[CO_3^{2-}]} = 2.1 \times 10^{-4}$$

(f) The student decides to first determine $[OH^-]$ in the solution, then use that result to calculate the initial concentration of $CO_3^{2-}(aq)$.

(i) Identify a laboratory method (not titration) that the student could use to collect data to determine $[OH^-]$ in the solution.

(ii) Explain how the student could use the measured value in part (f)(i) to calculate the initial concentration of $CO_3^{2-}(aq)$. (Do not do any numerical calculations.)

(g) In the original Na_2CO_3 solution at equilibrium, is the concentration of $HCO_3^-(aq)$ greater than, less than, or equal to the concentration of $CO_3^{2-}(aq)$? Justify your answer.

(h) The student needs to make a CO_3^{2-}/HCO_3^- buffer. Is the Na_2CO_3 solution suitable for making a buffer with a pH of 6? Explain why or why not.

3.8 Representations of Solutions

Name: ______________ Class: __________ Date: ____________ **Total: 10 marks**

KEY WORDS particle diagram 微粒图 • strong electrolyte 强电解质 • solution 溶液 • solute 溶质

Objective

Build the skills to answer exam questions on **representations of solutions** — the particle-level picture.

You must be able to:

- draw/interpret a **particle diagram** 微粒图 of a dissolved ionic compound
- show that a **strong electrolyte** 强电解质 dissolves into separate ions
- distinguish a solution of ions from a solution of molecules

1 Worked examples

Study these first. Each one shows the method for a question type used later — follow the steps and you can do the Practice and Exam-style questions yourself.

■ Ionic compounds dissolve into ions

When NaCl dissolves, it separates into Na^+ and Cl^- ions, each surrounded by water molecules (**hydrated**). A correct particle diagram shows **separate** + and − ions, not NaCl units.

■ Counting ions

One formula unit of $CaCl_2$ gives **three** ions in solution: one Ca^{2+} and two Cl^-. So 0.1 mol $CaCl_2$ releases 0.1 mol Ca^{2+} and 0.2 mol Cl^-.

■ Molecular solutes stay whole

A molecular solute like sugar or ethanol dissolves as **whole molecules** — no ions form, so the solution does **not** conduct electricity.

■ Electrolytes vs non-electrolytes

A **strong electrolyte** (soluble ionic compound, strong acid) fully separates into ions and conducts; a **non-electrolyte** (sugar) stays molecular and does not conduct.

2 Practice

Now apply the methods above.

2.1 What ions form when KBr dissolves? [1]

2.2 How many ions are released per formula unit of Na_2SO_4? [1]

2.3 Does a sugar solution conduct electricity? Give a reason. [2]

3 Exam-style questions

3.1 A particle diagram of dissolved NaCl should show [1]

- **A** NaCl units floating together
- **B** separate Na^+ and Cl^- ions
- **C** Na and Cl atoms
- **D** Cl_2 molecules

3.2 0.20 mol of $CaCl_2$ is dissolved in water.

(a) Write the dissociation and the moles of each ion. [2]

(b) Find the total moles of ions in solution. [1]

3.3 Explain why a solution of NaCl conducts electricity but a solution of glucose does not. [2]

Solutions

2.1 K^+ and Br^-.

2.2 Three (two Na^+ and one SO_4^{2-}).

2.3 No — sugar dissolves as neutral molecules, so there are no free ions to carry charge.

3.1 B — separate hydrated Na^+ and Cl^- ions.

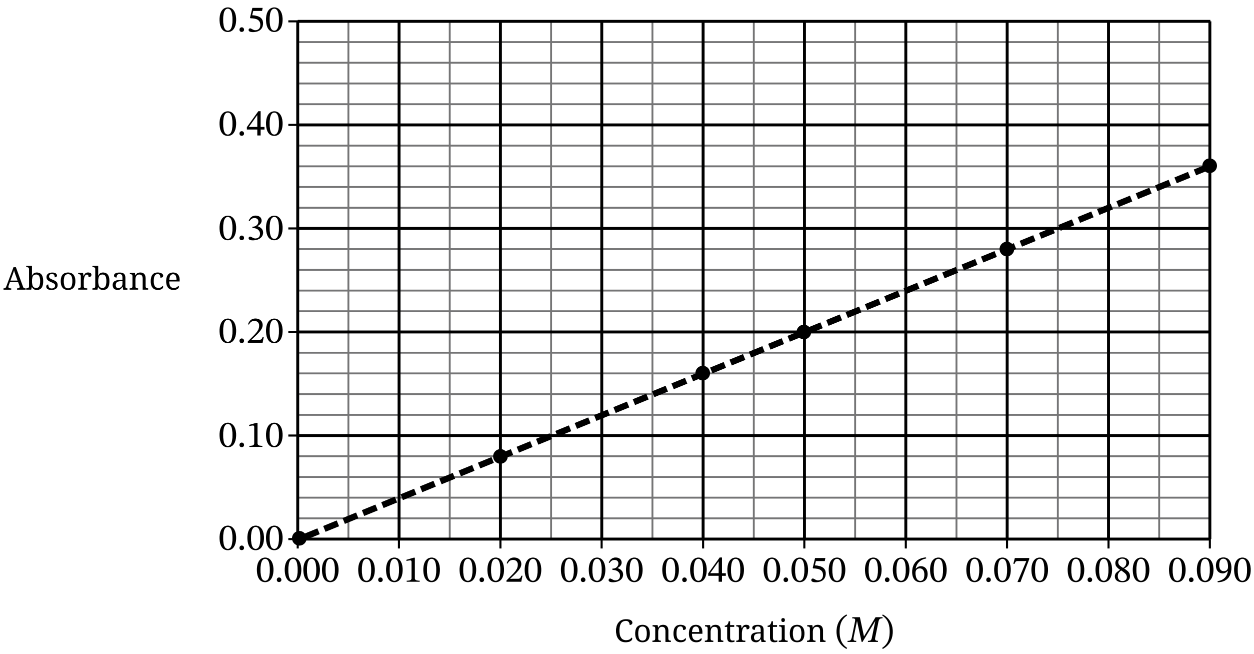
3.2 (a) $CaCl_2 \rightarrow Ca^{2+} + 2\,Cl^-$; 0.20 mol Ca^{2+} and 0.40 mol Cl^-. (b) $0.20 + 0.40 = 0.60$ mol ions.

3.3 NaCl separates into mobile ions that carry charge; glucose stays as neutral molecules with no ions, so it cannot conduct.

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.

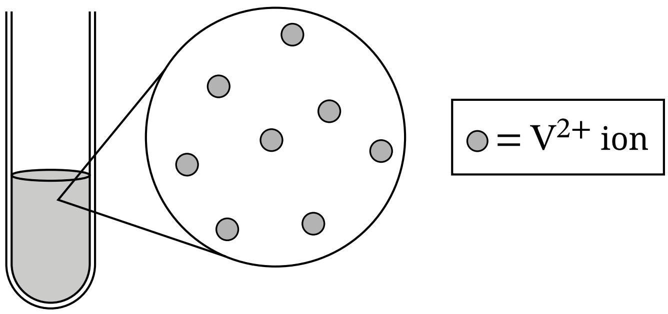
Figure 1



Part A

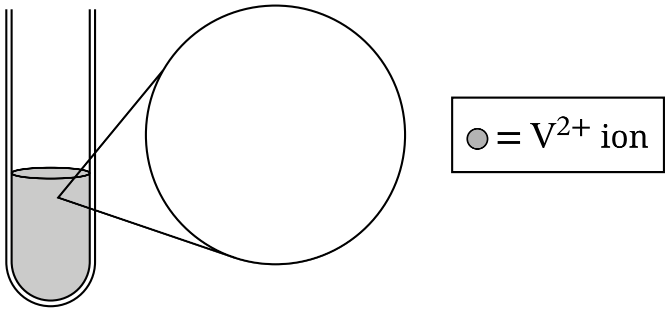
The student measures an absorbance of 0.32 for a $V^{2+}(aq)$ solution. The concentration of V^{2+} ions in the solution is represented by the particle diagram in the circle in Figure 2. In the circle in Figure 3, **draw** the correct number of V^{2+} ions to represent the concentration of a solution 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.

7. A student conducts a chromatography experiment and needs to prepare 100.0 mL of 0.340 M $NaCl(aq)$ to use as the solvent.

(a) Calculate the mass of solid NaCl (molar mass 58.44 g/mol) needed to prepare the 100.0 mL of 0.340 M $NaCl(aq)$.

(b) In the following table, briefly list the additional steps necessary to prepare the 100.0 mL of 0.340 M $NaCl(aq)$ solution using only materials selected from the choices given. Assume that all appropriate safety measures are already in place. Not all materials in the list may be needed.

- Solid NaCl
- Distilled water
- Weighing paper and scoop
- Balance
- 100.0 mL volumetric flask
- 50.0 mL graduated cylinder
- Pipet
- 150 mL beakers
- Chromatography paper

Step	Step Description and Materials Used
1.	Use the weighing paper and scoop to measure the correct mass of solid NaCl on the balance.
2.	
3.	Swirl the mixture to dissolve the solid NaCl.
4.	
5.	Stopper and invert the mixture several times to ensure that the mixture is homogeneous.

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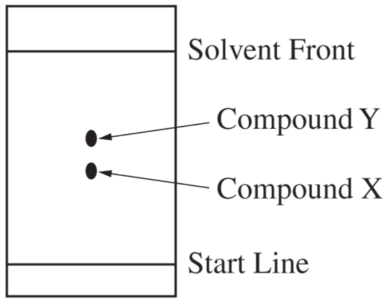
Continue your response to **QUESTION 7** on this page.

The student uses the NaCl(aq) solvent to separate a mixture of compounds X and Y in a chromatography experiment. After 30 minutes, the student removes the chromatography paper from the chamber. The results of the experiment are shown.



(c) A second student conducts the same chromatography experiment but removes the chromatography paper from the chamber after 15 minutes instead of 30 minutes. Predict the effect, if any, this would have on the separation distance between compounds X and Y in the new experiment. Explain your reasoning.

STOP

END OF EXAM

3. Answer the following questions relating to the element aluminum, Al.

(a) Write the complete ground-state electron configuration of an Al atom.

(b) Based on principles of atomic structure, explain why the radius of the Al atom is larger than the radius of the Al^{3+} ion.

A student plans to combine solid aluminum with an aqueous solution of silver ions. The student determines the mass of solid $AgNO_3$ needed to prepare the solution with a specific concentration.

(c) In the following table, briefly list the steps necessary to prepare 200.0 mL of an aqueous solution of $AgNO_3$ using only equipment selected from the choices given. Assume that all appropriate safety measures are already in place. Not all equipment or lines in the table may be needed.

- Solid $AgNO_3$
- Distilled water
- Balance
- Weighing paper and scoop
- 200.00 mL volumetric flask
- 50.0 mL graduated cylinder
- 250 mL beakers
- Pipet

Step	Step Description
1.	Use weighing paper to measure the determined mass of solid $AgNO_3$ on a balance.
2.	

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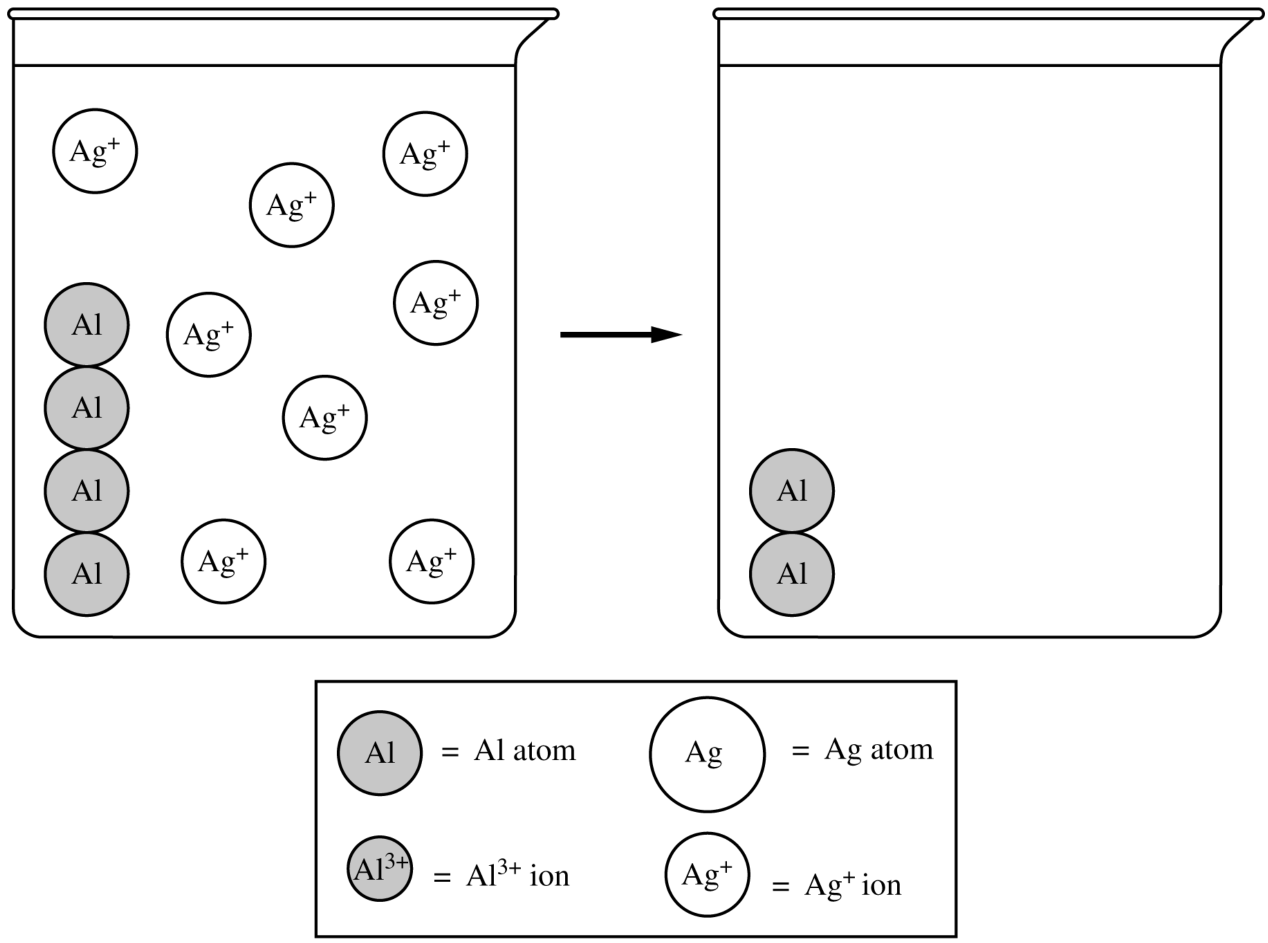
Continue your response to **QUESTION 6** on this page.

After preparing the solution, the student places some of the solution into a beaker and adds a sample of aluminum. The reaction represented by the following equation occurs.

$$Al(s) + 3\ Ag^{+}(aq) \rightarrow Al^{3+}(aq) + 3\ Ag(s)$$

(d) The following diagram gives an incomplete particulate representation of the reaction. The beaker on the left represents the system before the mixture reacts. Complete the drawing on the right to represent the system after the reaction has occurred. Be sure to include 1) the correct type and number of particles based on the number shown on the left and 2) the relative spacing to depict the appropriate phases.



The student finds the standard reduction potentials given in the table, which are related to the reaction that occurs.

Half-Reaction	$E°$
$Ag^{+}(aq) + e^{-} \rightarrow Ag(s)$	0.80 V
$Al^{3+}(aq) + 3\ e^{-} \rightarrow Al(s)$	−1.66 V

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Continue your response to **QUESTION 3** on this page.

(e) Using the standard reduction potentials, calculate the value of $E°$ for the reaction.

(f) Based on the value of $E°$, would the standard free energy change of the reaction under standard conditions, $\Delta G°$, be positive, negative, or zero? Justify your answer.

(g) Once the reaction appears to stop progressing, would the change in free energy, ΔG, be positive, negative, or zero? Justify your answer.

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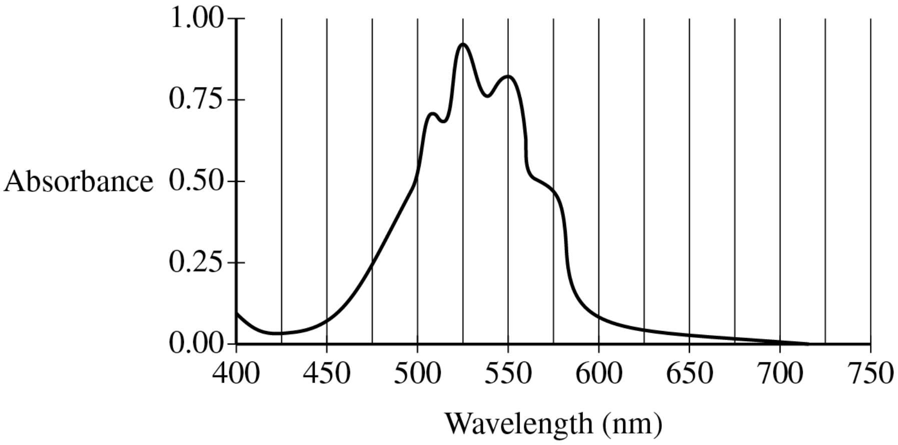
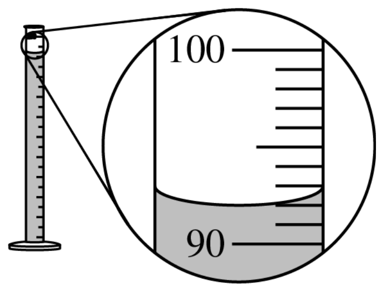
. A student wants to determine the concentration of permanganate, $MnO_4^-(aq)$, in a solution. The student plans to use colorimetric analysis because solutions containing $MnO_4^-(aq)$ have a purple color.



(a) To determine the optimum wavelength for an experiment that measures the concentration of $MnO_4^-(aq)$, the student takes a sample of the solution and measures the amount of light absorbed by the sample over a range of wavelengths. The data are plotted in the graph shown. Identify the optimum wavelength that the student should use for the experimental procedure.

(b) The student uses a stock solution of 2.40×10^{-3} M $KMnO_4(aq)$ to prepare the standard solutions of $MnO_4^-(aq)$ that are needed to construct a calibration curve.



(i) The student uses a 100.0 mL graduated cylinder to measure a certain volume of $KMnO_4(aq)$ stock solution, as shown in the diagram given. What volume should the student record?

(ii) Calculate the volume, in mL, of 2.40×10^{-3} M $KMnO_4(aq)$ that is required to produce 100.0 mL of a standard 1.68×10^{-3} M $MnO_4^-(aq)$ solution.

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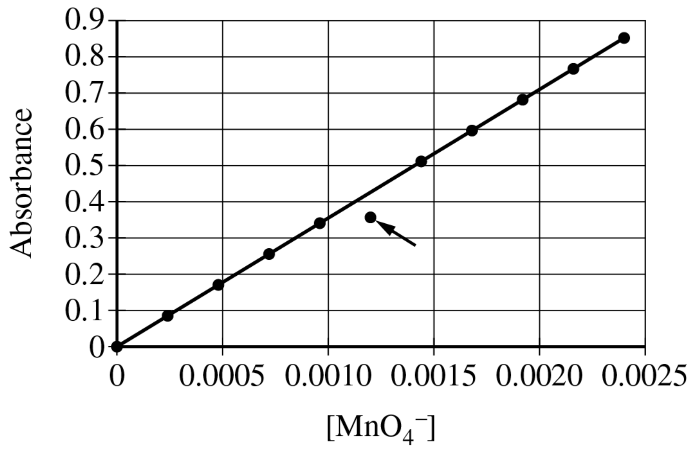
The student designs the following procedure to produce a calibration curve.

Step 1: Prepare several standard solutions that have known $MnO_4^-(aq)$ concentrations by dilution of the stock solution.
Step 2: Rinse the cuvette with distilled water.
Step 3: Rinse the cuvette with the standard solution and fill the cuvette with the standard solution.
Step 4: Measure the absorbance of the standard solution with the colorimeter.
Step 5: Repeat steps 2-4 for each of the standard solutions.

The data are plotted in the calibration curve shown. One of the data points (indicated with an arrow) on the calibration curve is below the line of best fit.



(c) Assuming that all lab equipment is functioning properly, identify which one of the procedural steps the student could have executed incorrectly that would explain why the marked data point is below the line of best fit. Justify your answer.

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3. A student is given the task of determining the molar concentration of a $CuSO_4$ solution using two different procedures, precipitation and spectrophotometry.

For the precipitation experiment, the student adds 20.0 mL of 0.200 M $Ba(NO_3)_2$ to 50.0 mL of the $CuSO_4(aq)$. The reaction goes to completion, and a white precipitate forms. The student filters the precipitate and dries it overnight. The data are given in the following table.

Mass of dry filter paper	0.764 g
Volume of $CuSO_4(aq)$	50.0 mL
Volume of 0.200 M $Ba(NO_3)_2$	20.0 mL
Mass of filter paper and dried precipitate	1.136 g

(a) Write a balanced net ionic equation for the precipitation reaction.

(b) Calculate the number of moles of precipitate formed.

(c) Calculate the molarity of the original $CuSO_4$ solution.

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For the spectrophotometry experiment, the student first makes a standard curve. The student uses a 0.1000 M solution of $CuSO_4(aq)$ to make three more solutions of known concentration (0.0500 M, 0.0300 M, and 0.0100 M) in 50.00 mL volumetric flasks.

(d) Calculate the volume of 0.1000 M $CuSO_4(aq)$ needed to make 50.00 mL of 0.0500 M $CuSO_4(aq)$.

(e) Briefly describe the procedure the student should follow to make 50.00 mL of 0.0500 M $CuSO_4(aq)$ using 0.1000 M $CuSO_4(aq)$, a 50.00 mL volumetric flask, and other standard laboratory equipment. Assume that all appropriate safety precautions will be taken.

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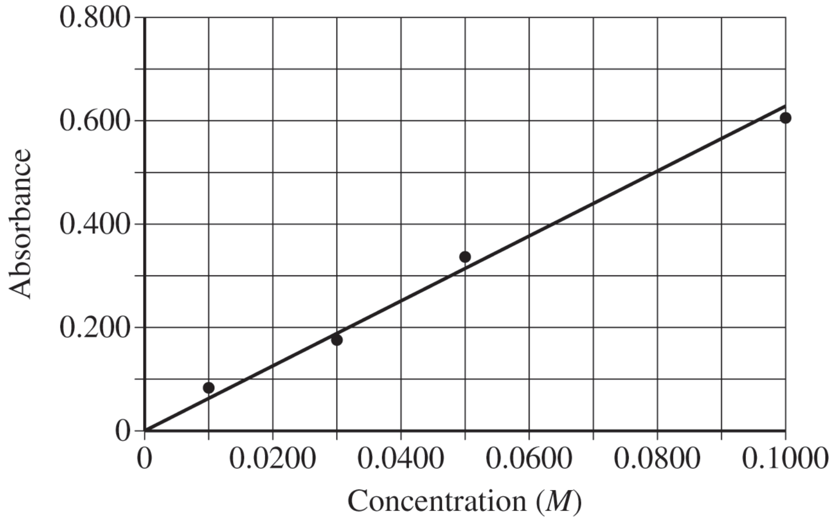
The standard curve is given below.



(f) The absorbance of the $CuSO_4$ solution of unknown concentration is 0.219. Determine the molarity of the solution.

(g) A second student performs the same experiment. There are a few drops of water in the cuvette before the second student adds the $CuSO_4(aq)$ solution of unknown concentration. Will this result in a $CuSO_4(aq)$ concentration for the unknown that is greater than, less than, or equal to the concentration determined in part (f) ? Justify your answer.

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6. A student is studying the properties of $CaSO_4$ and $PbSO_4$. The student has samples of both compounds, which are white powders.

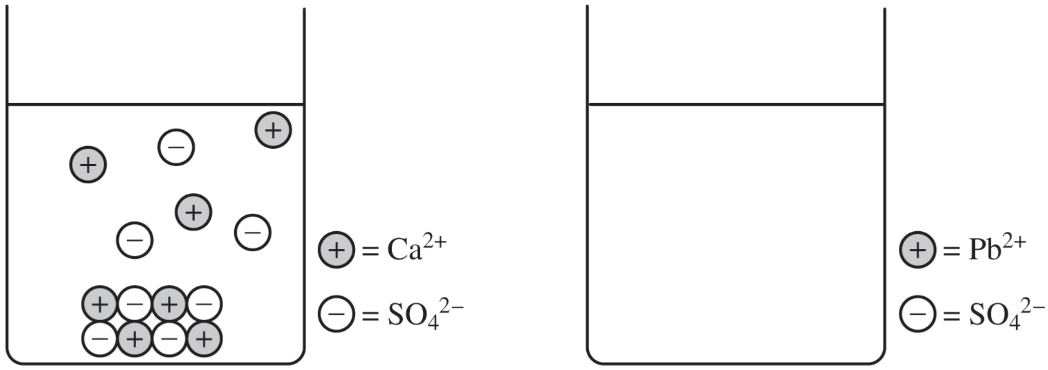
(a) The student tests the electrical conductivity of each solid and observes that neither solid conducts electricity. Describe the structures of the solids that account for their inability to conduct electricity.

The student places excess $CaSO_4(s)$ in a beaker containing $100\,\text{mL}$ of water and places excess $PbSO_4(s)$ in another beaker containing $100\,\text{mL}$ of water. The student stirs the contents of the beakers and then measures the electrical conductivity of the solution in each beaker. The student observes that the conductivity of the solution in the beaker containing the $CaSO_4(s)$ is higher than the conductivity of the solution in the beaker containing the $PbSO_4(s)$.

(b) Which compound is more soluble in water, $CaSO_4(s)$ or $PbSO_4(s)$? Justify your answer based on the results of the conductivity test.

GO ON TO THE NEXT PAGE.

The left side of the diagram below shows a particulate representation of the contents of the beaker containing the $CaSO_4(s)$ from the solution conductivity experiment.



Higher Conductivity Solution

Lower Conductivity Solution

(c) Draw a particulate representation of $PbSO_4(s)$ and the ions dissolved in the solution in the beaker on the right in the diagram. Draw the particles to look like those shown to the right of the beaker. Draw an appropriate number of dissolved ions relative to the number of dissolved ions in the beaker on the left.

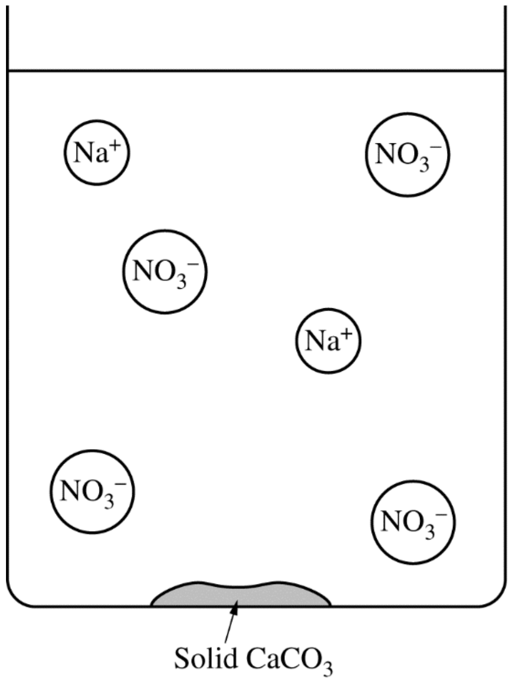
(d) The student attempts to increase the solubility of $CaSO_4(s)$ by adding 10.0 mL of 2 M $H_2SO_4(aq)$ to the beaker, and observes that additional precipitate forms in the beaker. Explain this observation.

3. A student is given 50.0 mL of a solution of Na_2CO_3 of unknown concentration. To determine the concentration of the solution, the student mixes the solution with excess 1.0 *M* $Ca(NO_3)_2(aq)$, causing a precipitate to form. The balanced equation for the reaction is shown below.

$$Na_2CO_3(aq) + Ca(NO_3)_2(aq) \rightarrow 2\ NaNO_3(aq) + CaCO_3(s)$$

(a) Write the net ionic equation for the reaction that occurs when the solutions of Na_2CO_3 and $Ca(NO_3)_2$ are mixed.

(b) The diagram below is incomplete. Draw in the species needed to accurately represent the major ionic species remaining in the solution after the reaction has been completed.



The student filters and dries the precipitate of $CaCO_3$ (molar mass 100.1 g/mol) and records the data in the table below.

Volume of Na_2CO_3 solution	50.0 mL
Volume of 1.0 *M* $Ca(NO_3)_2$ added	100.0 mL
Mass of $CaCO_3$ precipitate collected	0.93 g

(c) Determine the number of moles of Na_2CO_3 in the original 50.0 mL of solution.

(d) The student realizes that the precipitate was not completely dried and claims that as a result, the calculated Na_2CO_3 molarity is too low. Do you agree with the student's claim? Justify your answer.

(e) After the precipitate forms and is filtered, the liquid that passed through the filter is tested to see if it can conduct electricity. What would be observed? Justify your answer.

The student decides to determine the molarity of the same Na_2CO_3 solution using a second method. When Na_2CO_3 is dissolved in water, $CO_3^{2-}(aq)$ hydrolyzes to form $HCO_3^-(aq)$, as shown by the following equation.

$$CO_3^{2-}(aq) + H_2O(l) \rightleftarrows HCO_3^-(aq) + OH^-(aq) \qquad K_b = \frac{[HCO_3^-][OH^-]}{[CO_3^{2-}]} = 2.1 \times 10^{-4}$$

(f) The student decides to first determine $[OH^-]$ in the solution, then use that result to calculate the initial concentration of $CO_3^{2-}(aq)$.

(i) Identify a laboratory method (not titration) that the student could use to collect data to determine $[OH^-]$ in the solution.

(ii) Explain how the student could use the measured value in part (f)(i) to calculate the <u>initial</u> concentration of $CO_3^{2-}(aq)$. (Do not do any numerical calculations.)

(g) In the original Na_2CO_3 solution at equilibrium, is the concentration of $HCO_3^-(aq)$ greater than, less than, or equal to the concentration of $CO_3^{2-}(aq)$? Justify your answer.

(h) The student needs to make a CO_3^{2-}/HCO_3^- buffer. Is the Na_2CO_3 solution suitable for making a buffer with a pH of 6? Explain why or why not.

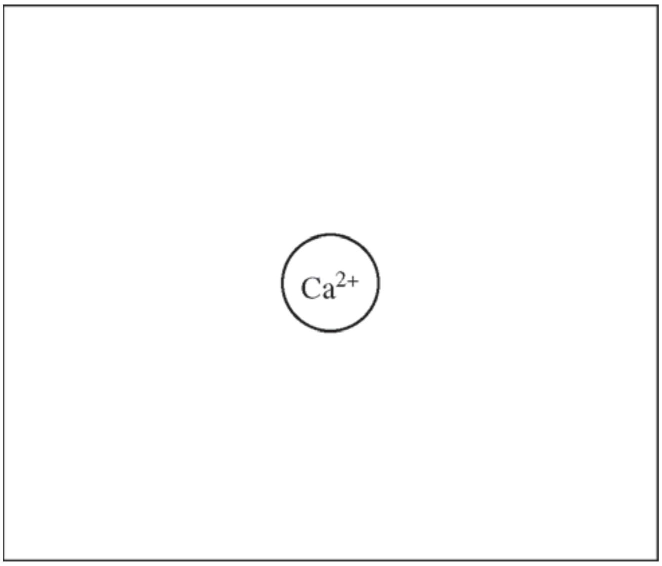
4. Answer the following questions about the solubility of $Ca(OH)_2$ ($K_{sp} = 1.3 \times 10^{-6}$).

   (a) Write a balanced chemical equation for the dissolution of $Ca(OH)_2(s)$ in pure water.

   (b) Calculate the molar solubility of $Ca(OH)_2$ in 0.10 M $Ca(NO_3)_2$.

   (c) In the box below, complete a particle representation diagram that includes <u>four</u> water molecules with proper orientation around the Ca^{2+} ion.

   Represent water molecules as .



3.9 Separation of Solutions and Mixtures

Name: ______________ Class: __________ Date: ____________ **Total: 9 marks**

KEY WORDS chromatography 色谱 • distillation 蒸馏 • filtration 过滤 • solvent 溶剂 • solution 溶液

Objective

Build the skills to answer exam questions on the **separation of solutions and mixtures**.

You must be able to:

- match a separation method to a mixture (**filtration** 过滤, **distillation** 蒸馏, **chromatography** 色谱)
- explain the property each method exploits
- describe **chromatography** separating by attraction

1 Worked examples

Study these first. Each one shows the method for a question type used later — follow the steps and you can do the Practice and Exam-style questions yourself.

■ Filtration

Filtration separates an **insoluble solid** from a liquid: the solid stays on the filter paper (residue), the liquid passes through (filtrate). Use it for sand in water.

■ Distillation

Distillation separates a dissolved solute from its solvent, or two liquids with different **boiling points**. The lower-boiling component evaporates first, then condenses and is collected.

■ Chromatography

Chromatography separates dissolved substances by how strongly they are **attracted** to a stationary phase vs a moving solvent. Components that stick less travel **further**. Used to separate dyes or pigments.

■ Choosing a method

Match the method to the difference you can exploit: solubility (filtration), boiling point (distillation), or relative attraction/solubility (chromatography).

2 Practice

Now apply the methods above.

2.1 Which method separates sand from water? [1]

2.2 Which method would you use to get pure water from salt water? [1]

2.3 What property does distillation exploit? [1]

3 Exam-style questions

3.1 Chromatography separates substances based on differences in [1]

- **A** boiling point
- **B** particle size
- **C** attraction to the stationary phase
- **D** density

3.2 A student has a mixture of salt, sand, and water.

(a) State how to remove the sand. [1]

(b) State how to then recover the salt from the salt water. [2]

3.3 In a chromatography experiment, dye X travels further up the paper than dye Y. Explain what this tells you about the two dyes. [2]

Solutions

2.1 Filtration.

2.2 Distillation.

2.3 Difference in boiling points.

3.1 **C** — attraction to the stationary phase (vs the moving solvent).

3.2 (a) Filter the mixture — sand stays as the residue. (b) Evaporate or distil the salt water to leave/collect the salt.

3.3 Dye X is less strongly attracted to the paper (or more soluble in the solvent), so it travels further; dye Y is held back more strongly.

7. A student conducts a chromatography experiment and needs to prepare 100.0 mL of 0.340 *M* $NaCl(aq)$ to use as the solvent.

(a) Calculate the mass of solid NaCl (molar mass 58.44 g/mol) needed to prepare the 100.0 mL of 0.340 *M* $NaCl(aq)$.

(b) In the following table, briefly list the additional steps necessary to prepare the 100.0 mL of 0.340 *M* $NaCl(aq)$ solution using only materials selected from the choices given. Assume that all appropriate safety measures are already in place. Not all materials in the list may be needed.

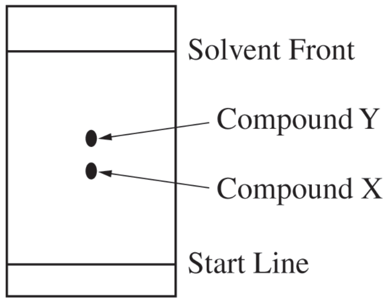
- Solid NaCl
- Distilled water
- Weighing paper and scoop
- Balance
- 100.0 mL volumetric flask
- 50.0 mL graduated cylinder
- Pipet
- 150 mL beakers
- Chromatography paper

Step	Step Description and Materials Used
1.	Use the weighing paper and scoop to measure the correct mass of solid NaCl on the balance.
2.	
3.	Swirl the mixture to dissolve the solid NaCl.
4.	
5.	Stopper and invert the mixture several times to ensure that the mixture is homogeneous.

GO ON TO THE NEXT PAGE.

Continue your response to **QUESTION 7** on this page.

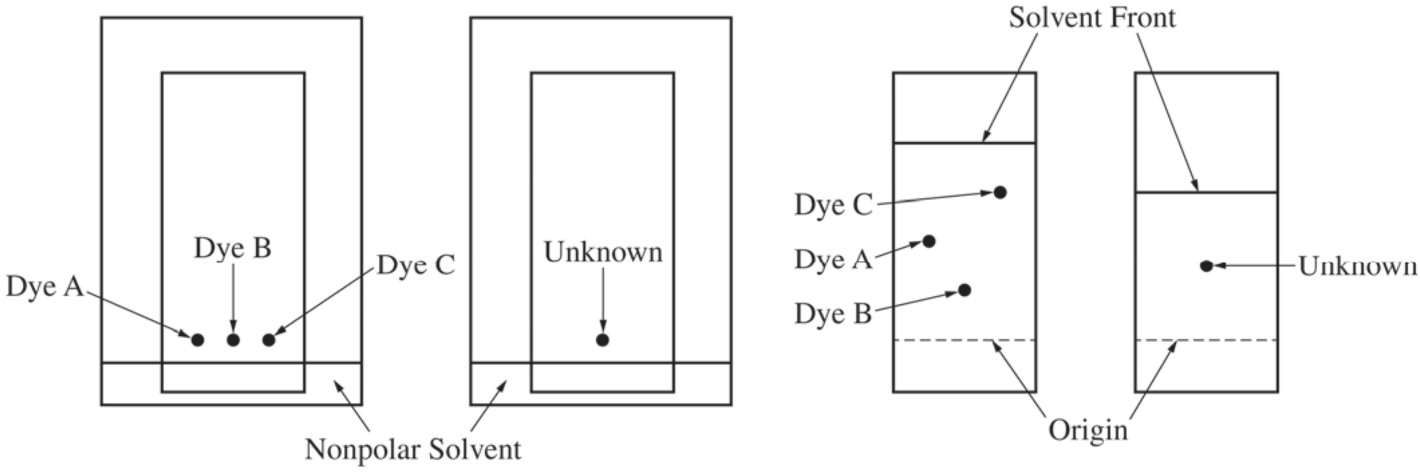
The student uses the $NaCl(aq)$ solvent to separate a mixture of compounds X and Y in a chromatography experiment. After 30 minutes, the student removes the chromatography paper from the chamber. The results of the experiment are shown.



(c) A second student conducts the same chromatography experiment but removes the chromatography paper from the chamber after 15 minutes instead of 30 minutes. Predict the effect, if any, this would have on the separation distance between compounds X and Y in the new experiment. Explain your reasoning.

STOP

END OF EXAM



Chromatography Chambers

Developed Chromatograms

4. A student investigates various dyes using paper chromatography. The student has samples of three pure dyes, labeled A, B, and C, and an unknown sample that contains one of the three dyes. The student prepares the chromatography chambers shown above on the left by putting a drop of each dye at the indicated position on the chromatography paper (a polar material) and standing the paper in a nonpolar solvent. The developed chromatograms are shown above on the right.

(a) Which dye (A, B, or C) is the least polar? Justify your answer in terms of the interactions between the dyes and the solvent or between the dyes and the paper.

(b) Which dye is present in the unknown sample? Justify your answer.

AP CHEMISTRY • EXERCISE SHEET

3.10 Solubility

Name: ______________ Class: __________ Date: ____________ **Total: 10 marks**

KEY WORDS solubility 溶解度 • solution 溶液 • solvent 溶剂 • solute 溶质 • intermolecular forces 分子间作用力

Objective

Build the skills to answer exam questions on **solubility** — "like dissolves like".

You must be able to:

- apply the rule **like dissolves like** (polar dissolves polar, nonpolar dissolves nonpolar)
- predict whether a solute dissolves in a given solvent
- explain solubility with intermolecular forces

1 Worked examples

Study these first. Each one shows the method for a question type used later — follow the steps and you can do the Practice and Exam-style questions yourself.

■ Like dissolves like

A solute dissolves best in a solvent with **similar** intermolecular forces:

- **polar/ionic** solutes dissolve in **polar** solvents (water);
- **nonpolar** solutes dissolve in **nonpolar** solvents (oil, hexane).

■ Why it works

Dissolving requires the solute-solvent attractions to be comparable to the attractions being broken. Water can hydrate ions and hydrogen-bond to polar molecules, but has nothing to offer a nonpolar molecule.

■ A worked prediction

Will NaCl dissolve in water? Yes — ionic solute, polar solvent, water surrounds the ions. Will oil dissolve in water? No — nonpolar solute, polar solvent (they separate).

■ Molecules with both parts

A molecule with a polar and a nonpolar end (like soap) can bridge the two, which is why soap cleans grease.

2 Practice

Now apply the methods above.

2.1 State the "like dissolves like" rule. [1]

2.2 Will a nonpolar substance dissolve in water? Give a reason. [2]

2.3 Name a good solvent for an ionic compound. [1]

3 Exam-style questions

3.1 A polar solute is most soluble in [1]

- **A** a nonpolar solvent
- **B** a polar solvent
- **C** any solvent equally
- **D** no solvent

3.2 Iodine (I_2, nonpolar) is shaken with water and with hexane (nonpolar).

(a) In which solvent does it dissolve better? [1]

(b) Explain using intermolecular forces. [2]

3.3 Explain why ethanol (CH_3CH_2OH) is soluble in water but hexane is not. [2]

Solutions

2.1 A solute dissolves in a solvent with similar intermolecular forces (polar dissolves polar, nonpolar dissolves nonpolar).

2.2 No — water is polar; it cannot form favorable attractions with a nonpolar solute, so they stay separate.

2.3 Water (a polar solvent).

3.1 **B** — a polar solvent.

3.2 (a) Hexane. (b) I_2 is nonpolar, so it mixes with the nonpolar hexane (similar dispersion forces) but not with polar, hydrogen-bonded water.

3.3 Ethanol has an $-OH$ group that hydrogen-bonds with water, so it dissolves; hexane is entirely nonpolar and cannot form such attractions with water.

CHEMISTRY

SECTION II

Time—1 hour and 45 minutes

7 Questions

YOU MAY USE YOUR CALCULATOR FOR THIS SECTION.

Directions: Questions 1–3 are long free-response questions that require about 23 minutes each to answer and are worth 10 points each. Questions 4–7 are short free-response questions that require about 9 minutes each to answer and are worth 4 points each.

For each question, show your work for each part in the space provided after that part. 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.

1. A student reacts 0.300 g of methyl salicylate ($C_8H_8O_3$) with a stoichiometric amount of a strong base. This product is then acidified to produce salicylic acid crystals ($HC_7H_5O_3$).

(a) For every 1 mole of $C_8H_8O_3$ (molar mass 152.15 g/mol) reactant used, 1 mole of salicylic acid crystals ($HC_7H_5O_3$, molar mass 138.12 g/mol) is produced. Calculate the maximum mass, in grams, of $HC_7H_5O_3$ that could be produced in this reaction.

GO ON TO THE NEXT PAGE.

Continue your response to **QUESTION 1** on this page.

As part of the experimental procedure to purify the $HC_7H_5O_3$ crystals after the reaction is complete, the crystals are filtered from the reaction mixture, rinsed with distilled water, and dried. Some physical properties of $HC_7H_5O_3$ are given in the following table.

Properties of Salicylic Acid ($HC_7H_5O_3$)	
Melting point	159°C
Solubility in H_2O at 25°C	2.2 g/L
Specific heat capacity	1.17 J/(g·°C)
Heat of fusion	27.1 kJ/mol

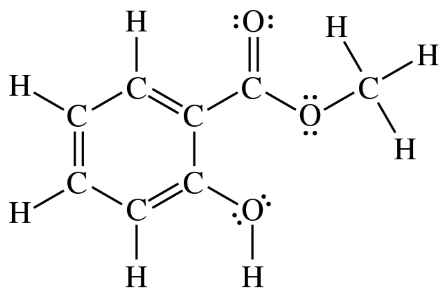
(b) The student's experiment results in an 87% yield of dry $HC_7H_5O_3$. The student suggests that some of the $HC_7H_5O_3$ crystals dissolved in the distilled water during the rinsing step. Is the student's claim consistent with the calculated percent yield value? Justify your answer.

(c) Given the physical properties in the table, calculate the quantity of heat that must be absorbed to increase the temperature of a 0.105 g sample of dry $HC_7H_5O_3$ (molar mass 138.12 g / mol) crystals from 25°C to the melting point of 159°C and melt the crystals completely.

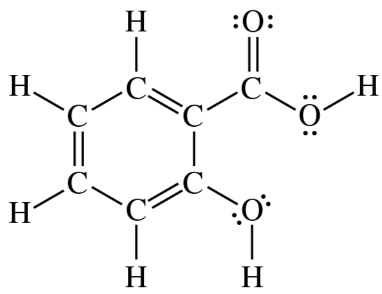
GO ON TO THE NEXT PAGE.

Continue your response to **QUESTION 1** on this page.

The structures and melting points for methyl salicylate and salicylic acid are shown.



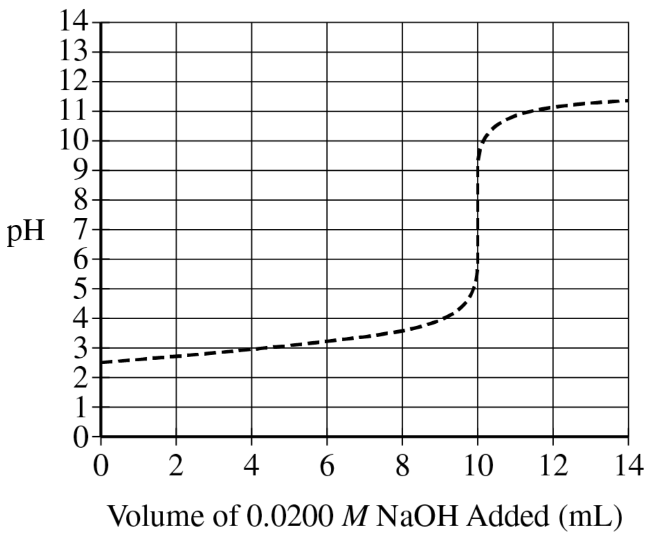
Methyl Salicylate
Melting Point: –9°C



Salicylic Acid
Melting Point: 159°C

(d) The same three types of intermolecular forces (London dispersion forces, dipole-dipole interactions, and hydrogen bonding) exist among molecules of each substance. Explain why the melting point of salicylic acid is higher than that of methyl salicylate.

The student titrates 20.0 mL of 0.0100 M $HC_7H_5O_3(aq)$ with 0.0200 M NaOH, using a probe to monitor the pH of the solution. The data are plotted producing the following titration curve.



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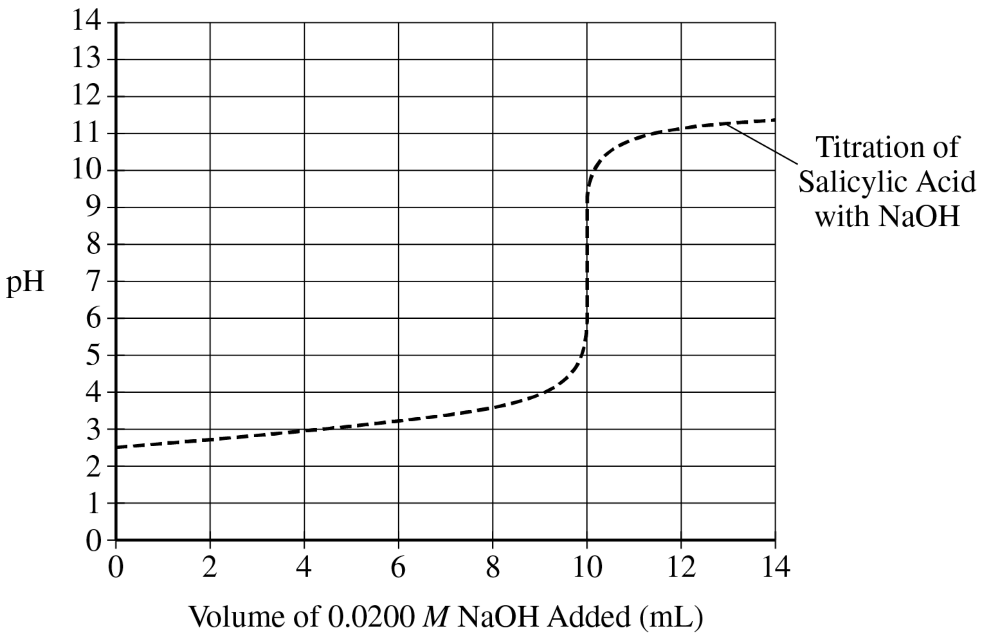
(e) Using the information in the graph, estimate the pK_a of $HC_7H_5O_3$. _______________

(f) When the pH of the titration mixture is 4.00, is there a higher concentration of the weak acid, $HC_7H_5O_3$, or its conjugate base, $C_7H_5O_3^-$, in the flask? Justify your answer.

(g) The student researches benzoic acid ($HC_7H_5O_2$) and finds that it has similar properties to salicylic acid ($HC_7H_5O_3$). The K_a for benzoic acid is 6.3×10^{-5}. Calculate the value of pK_a for benzoic acid.

(h) The student performs a second titration, this time titrating 20.0 mL of a 0.0100 M benzoic acid solution with 0.0200 M NaOH. Sketch the curve that would result from this titration of benzoic acid on the following graph, which already shows the original curve from the titration of 20.0 mL of 0.0100 M salicylic acid. The initial pH of the benzoic acid solution is 3.11.



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6. A student is studying the properties of $CaSO_4$ and $PbSO_4$. The student has samples of both compounds, which are white powders.

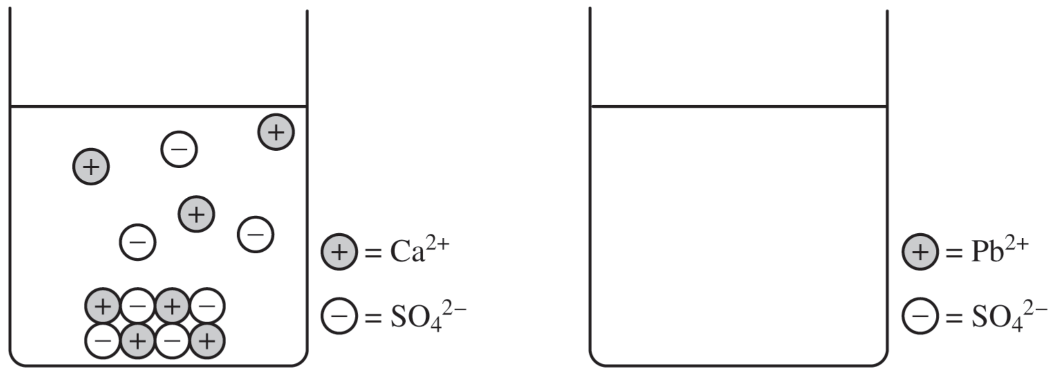
(a) The student tests the electrical conductivity of each solid and observes that neither solid conducts electricity. Describe the structures of the solids that account for their inability to conduct electricity.

The student places excess $CaSO_4(s)$ in a beaker containing 100 mL of water and places excess $PbSO_4(s)$ in another beaker containing 100 mL of water. The student stirs the contents of the beakers and then measures the electrical conductivity of the solution in each beaker. The student observes that the conductivity of the solution in the beaker containing the $CaSO_4(s)$ is higher than the conductivity of the solution in the beaker containing the $PbSO_4(s)$.

(b) Which compound is more soluble in water, $CaSO_4(s)$ or $PbSO_4(s)$? Justify your answer based on the results of the conductivity test.

GO ON TO THE NEXT PAGE.

The left side of the diagram below shows a particulate representation of the contents of the beaker containing the $CaSO_4(s)$ from the solution conductivity experiment.



Higher Conductivity Solution

Lower Conductivity Solution

(c) Draw a particulate representation of $PbSO_4(s)$ and the ions dissolved in the solution in the beaker on the right in the diagram. Draw the particles to look like those shown to the right of the beaker. Draw an appropriate number of dissolved ions relative to the number of dissolved ions in the beaker on the left.

(d) The student attempts to increase the solubility of $CaSO_4(s)$ by adding 10.0 mL of 2 M $H_2SO_4(aq)$ to the beaker, and observes that additional precipitate forms in the beaker. Explain this observation.

GO ON TO THE NEXT PAGE.

CHEMISTRY

Section II

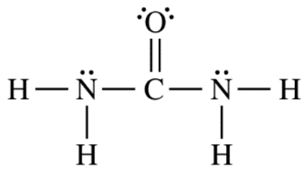
Time—1 hour and 45 minutes

7 Questions

YOU MAY USE YOUR CALCULATOR FOR THIS SECTION.

Directions: Questions 1–3 are long free-response questions that require about 23 minutes each to answer and are worth 10 points each. Questions 4–7 are short free-response questions that require about 9 minutes each to answer and are worth 4 points each.

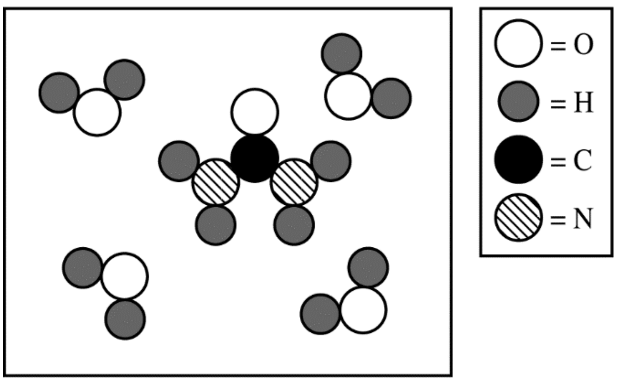
Write your response in the space provided following each question. Examples and equations may be included in your responses where appropriate. For calculations, clearly show the method used and the steps involved in arriving at your answers. You must show your work to receive credit for your answer.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



1. The compound urea, H_2NCONH_2, is widely used in chemical fertilizers. The complete Lewis electron-dot diagram for the urea molecule is shown above.

   (a) Identify the hybridization of the valence orbitals of the carbon atom in the urea molecule.

   (b) Urea has a high solubility in water, due in part to its ability to form hydrogen bonds. A urea molecule and four water molecules are represented in the box below. Draw ONE dashed line (----) to indicate a possible location of a hydrogen bond between a water molecule and the urea molecule.

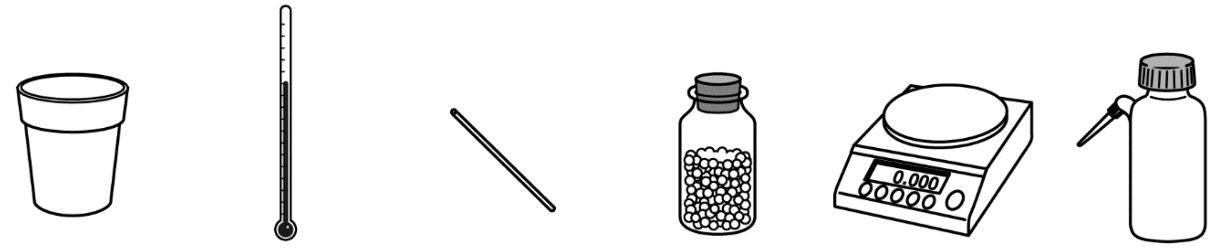


$$H_2NCONH_2(s) \rightleftarrows H_2NCONH_2(aq)$$

The dissolution of urea is represented by the equation above. A student determines that 5.39 grams of H_2NCONH_2 (molar mass 60.06 g/mol) can dissolve in water to make 5.00 mL of a saturated solution at 20.°C.

(c) Calculate the concentration of urea, in mol/L, in the saturated solution at 20.°C.

(d) The student also determines that the concentration of urea in a saturated solution at 25°C is 19.8 *M*. Based on this information, is the dissolution of urea endothermic or exothermic? Justify your answer in terms of Le Chatelier's principle.



Polystyrene Cup — Thermometer — Stirring Rod — Bottle of Urea — Balance — Distilled Water

(e) The equipment shown above is provided so that the student can determine the value of the molar heat of solution for urea. Knowing that the specific heat of the solution is 4.18 J/(g·°C), list the specific measurements that are required to be made during the experiment.

	$S°$ (J/(mol·K))
$H_2NCONH_2(s)$	104.6
$H_2NCONH_2(aq)$	?

(f) The entropy change for the dissolution of urea, ΔS°_{soln} , is 70.1 J/(mol·K) at 25°C. Using the information in the table above, calculate the absolute molar entropy, $S°$, of aqueous urea.

(g) Using particle-level reasoning, explain why ΔS°_{soln} is positive for the dissolution of urea in water.

(h) The student claims that $\Delta S°$ for the process contributes to the thermodynamic favorability of the dissolution of urea at 25°C. Use the thermodynamic information above to support the student's claim.

AP CHEMISTRY • EXERCISE SHEET

3.11 Spectroscopy and the Electromagnetic Spectrum

Name: ______________ Class: __________ Date: ____________ **Total: 9 marks**

KEY WORDS electromagnetic spectrum 电磁波谱 • spectroscopy 光谱学 • solution 溶液

Objective

Build the skills to answer exam questions on **spectroscopy and the electromagnetic spectrum**.

You must be able to:

- order the **electromagnetic spectrum 电磁波谱** by energy/wavelength
- link the type of transition to the region (microwave, IR, UV-Vis)
- explain how absorption reveals structure

1 Worked examples

Study these first. Each one shows the method for a question type used later — follow the steps and you can do the Practice and Exam-style questions yourself.

The spectrum by energy

From low to high energy (long to short wavelength): radio < microwave < **infrared (IR)** < visible < **ultraviolet (UV)** < X-ray. Higher energy means shorter wavelength and higher frequency.

Matching region to transition

Each region excites a different kind of change:

- **Microwave** — molecular rotation;
- **Infrared** — bond vibration;
- **UV-Visible** — electron transitions between energy levels.

Absorption reveals structure

A molecule **absorbs** the wavelengths whose energy matches one of its transitions. The pattern of absorptions is a fingerprint of the bonds and electrons present.

■ **Energy-wavelength relationship**

Energy and wavelength are **inversely** related: $E = \dfrac{hc}{\lambda}$. Shorter wavelength $\Rightarrow$ more energetic photon.

2 Practice

Now apply the methods above.

2.1 Which has more energy: UV or infrared radiation? [1]

2.2 Which region of the spectrum causes bond **vibration**? [1]

2.3 As wavelength decreases, what happens to photon energy? [1]

3 Exam-style questions

3.1 Electron transitions between energy levels are typically caused by [1]

- **A** microwaves
- **B** infrared
- **C** UV-visible light
- **D** radio waves

3.2 A molecule absorbs strongly in the infrared region.

(a) What kind of molecular motion is being excited? [1]

(b) Explain what "absorption" means at the particle level. [2]

3.3 Arrange these in order of increasing energy: infrared, X-ray, visible, microwave. [2]

Solutions

2.1 UV.

2.2 Infrared.

2.3 It increases.

3.1 C — UV-visible light drives electron transitions.

3.2 (a) Bond vibration. (b) The molecule takes in a photon whose energy exactly matches an allowed transition, raising it to a higher-energy state.

3.3 microwave $<$ infrared $<$ visible $<$ X-ray.

3.12 Properties of Photons

Name: ______________ Class: _________ Date: ___________ **Total: 13 marks**

KEY WORDS photons 光子 • solution 溶液

Objective

Build the skills to answer exam questions on the **properties of photons** — energy, frequency, and wavelength.

You must be able to:

- use $E = h\nu$ and $c = \lambda\nu$
- convert between energy, frequency, and wavelength
- find the energy of a photon or a mole of photons

1 Worked examples

Study these first. Each one shows the method for a question type used later — follow the steps and you can do the Practice and Exam-style questions yourself.

The photon equations

$$E = h\nu, \qquad c = \lambda\nu, \qquad E = \frac{hc}{\lambda},$$

with $h = 6.63 \times 10^{-34}$ J s and $c = 3.00 \times 10^{8}$ m s^{-1}.

Frequency from wavelength

For $\lambda = 500$ nm $= 5.00 \times 10^{-7}$ m:

$$\nu = \frac{c}{\lambda} = \frac{3.00 \times 10^{8}}{5.00 \times 10^{-7}} = 6.00 \times 10^{14} \text{ Hz}.$$

Energy of one photon

$$E = h\nu = (6.63 \times 10^{-34})(6.00 \times 10^{14}) = 3.98 \times 10^{-19} \text{ J}.$$

Energy per mole

Multiply by Avogadro's number: $E_{\text{mol}} = E \times 6.022 \times 10^{23}$. Here $\approx 2.4 \times 10^{5}$ J/mol $=$ 240 kJ/mol.

2 Practice

Now apply the methods above.

2.1 Write the equation linking a photon's energy and frequency. [1]

2.2 Find the frequency of light with $\lambda = 6.00 \times 10^{-7}$ m. [2]

2.3 Find the energy of a photon of frequency 5.0×10^{14} Hz. [2]

3 Exam-style questions

3.1 The energy of a photon is [1]

- **A** inversely proportional to frequency
- **B** proportional to frequency
- **C** independent of frequency
- **D** proportional to wavelength

3.2 A laser emits light of wavelength 650 nm.

(a) Convert to metres and find the frequency. [3]

(b) Find the energy of one photon. [2]

3.3 Explain why UV photons are more damaging to skin than visible photons, in terms of photon energy. [2]

Solutions

2.1 $E = h\nu$.

2.2 $\nu = \dfrac{3.00 \times 10^8}{6.00 \times 10^{-7}} = 5.00 \times 10^{14}$ Hz.

2.3 $E = (6.63 \times 10^{-34})(5.0 \times 10^{14}) = 3.3 \times 10^{-19}$ J.

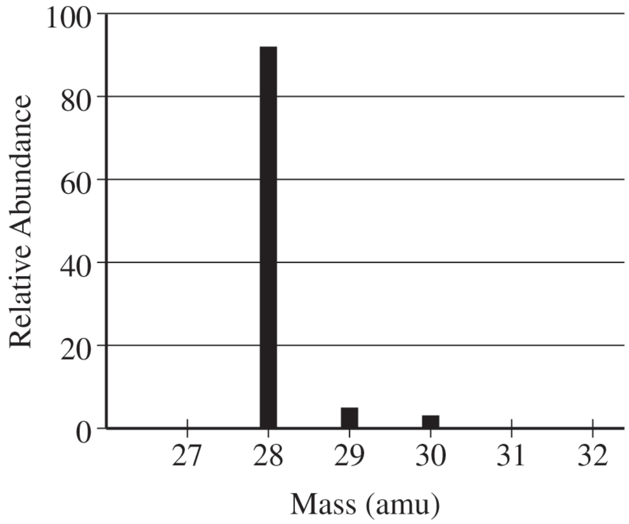
3.1 **B** — $E = h\nu$, proportional to frequency.

3.2 (a) 650 nm $= 6.50 \times 10^{-7}$ m; $\nu = \dfrac{3.00 \times 10^8}{6.50 \times 10^{-7}} = 4.62 \times 10^{14}$ Hz. (b) $E = h\nu = (6.63 \times 10^{-34})(4.62 \times 10^{14}) = 3.06 \times 10^{-19}$ J.

3.3 UV light has a shorter wavelength and higher frequency, so by $E = h\nu$ each UV photon carries more energy — enough to break bonds/damage molecules that visible photons cannot.

2. Answer the following questions about the element Si and some of its compounds.

(a) The mass spectrum of a pure sample of Si is shown below.



(i) How many protons and how many neutrons are in the nucleus of an atom of the most abundant isotope of Si ?

(ii) Write the ground-state electron configuration of Si.

Two compounds that contain Si are SiO_2 and SiH_4.

(b) At 161 K, SiH_4 boils but SiO_2 remains as a solid. Using principles of interparticle forces, explain the difference in boiling points.

At high temperatures, SiH_4 decomposes to form solid silicon and hydrogen gas.

(c) Write a balanced equation for the reaction.

A table of absolute entropies of some substances is given below.

Substance	$S°$ (J/(mol · K))
$H_2(g)$	131
$Si(s)$	18
$SiH_4(g)$	205

(d) Explain why the absolute molar entropy of $Si(s)$ is less than that of $H_2(g)$.

(e) Calculate the value, in J/(mol· K), of $\Delta S°$ for the reaction.

(f) The reaction is thermodynamically favorable at all temperatures. Explain why the reaction occurs only at high temperatures.

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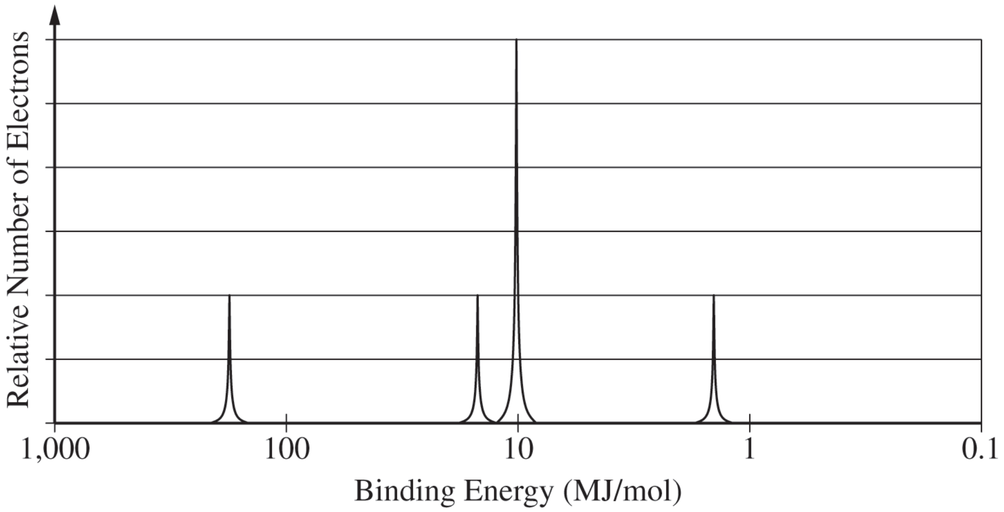
(g) A partial photoelectron spectrum of pure Si is shown below. On the spectrum, draw the missing peak that corresponds to the electrons in the $3p$ sublevel.



(h) Using principles of atomic structure, explain why the first ionization energy of Ge is lower than that of Si.

(i) A single photon with a wavelength of 4.00×10^{-7} m is absorbed by the Si sample. Calculate the energy of the photon in joules.

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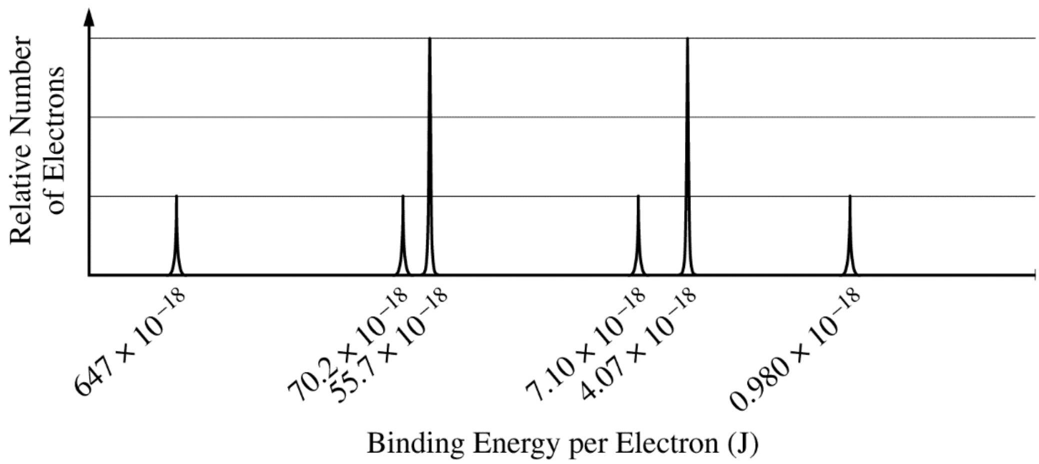
5. The complete photoelectron spectrum of an element in its ground state is represented below.



(a) Based on the spectrum,

(i) write the ground-state electron configuration of the element, and

(ii) identify the element.

(b) Calculate the wavelength, in meters, of electromagnetic radiation needed to remove an electron from the valence shell of an atom of the element.

AP CHEMISTRY • EXERCISE SHEET

3.13 The Beer-Lambert Law

Name: ______________ Class: __________ Date: ____________ **Total: 13 marks**

KEY WORDS absorbance 吸光度 • solution 溶液

Objective

Build the skills to answer exam questions on the **Beer-Lambert law** — linking absorbance to concentration.

You must be able to:

- use $A = \varepsilon bc$ (**absorbance 吸光度**)
- interpret a calibration plot of A vs concentration
- find an unknown concentration from absorbance

1 Worked examples

Study these first. Each one shows the method for a question type used later — follow the steps and you can do the Practice and Exam-style questions yourself.

■ The Beer-Lambert law

$$A = \varepsilon bc,$$

where A is absorbance, ε the molar absorptivity, b the path length, and c the concentration. Absorbance is **proportional to concentration** (fixed ε and b).

■ A worked value

If $\varepsilon = 200$ L mol^{-1}cm^{-1}, $b = 1.0$ cm, $c = 0.0020$ M:

$$A = (200)(1.0)(0.0020) = 0.40.$$

■ The calibration line

Plot A (y) against concentration (x): a straight line through the origin with slope εb. Read an unknown concentration by finding its absorbance on the line.

■ Finding an unknown

If a sample has $A = 0.30$ and the calibration line is $A = 150\,c$, then $c = \dfrac{0.30}{150} = 0.0020$ M.

2 Practice

Now apply the methods above.

2.1 Write the Beer-Lambert law and name each symbol. [2]

2.2 Find A for $\varepsilon = 500$, $b = 1.0$ cm, $c = 0.0010$ M. [2]

2.3 Absorbance is proportional to which quantity? [1]

3 Exam-style questions

3.1 In $A = \varepsilon bc$, doubling the concentration c (with ε, b fixed) [1]

- **A** halves A
- **B** doubles A
- **C** leaves A unchanged
- **D** squares A

3.2 A calibration line for a dye is $A = 250\,c$ (with c in mol/L).

(a) Find the absorbance of a 0.0016 M solution. [2]

(b) A sample gives $A = 0.50$. Find its concentration. [2]

3.3 A solution's absorbance is measured as 0.80 with $\varepsilon = 400$ L mol^{-1}cm^{-1} and $b =$

1.0 cm. Find the concentration. [3]

Solutions

2.1 $A = \varepsilon bc$: A absorbance, ε molar absorptivity, b path length, c concentration.

2.2 $A = (500)(1.0)(0.0010) = 0.50$.

2.3 Concentration.

3.1 **B** — A is proportional to c, so doubling c doubles A.

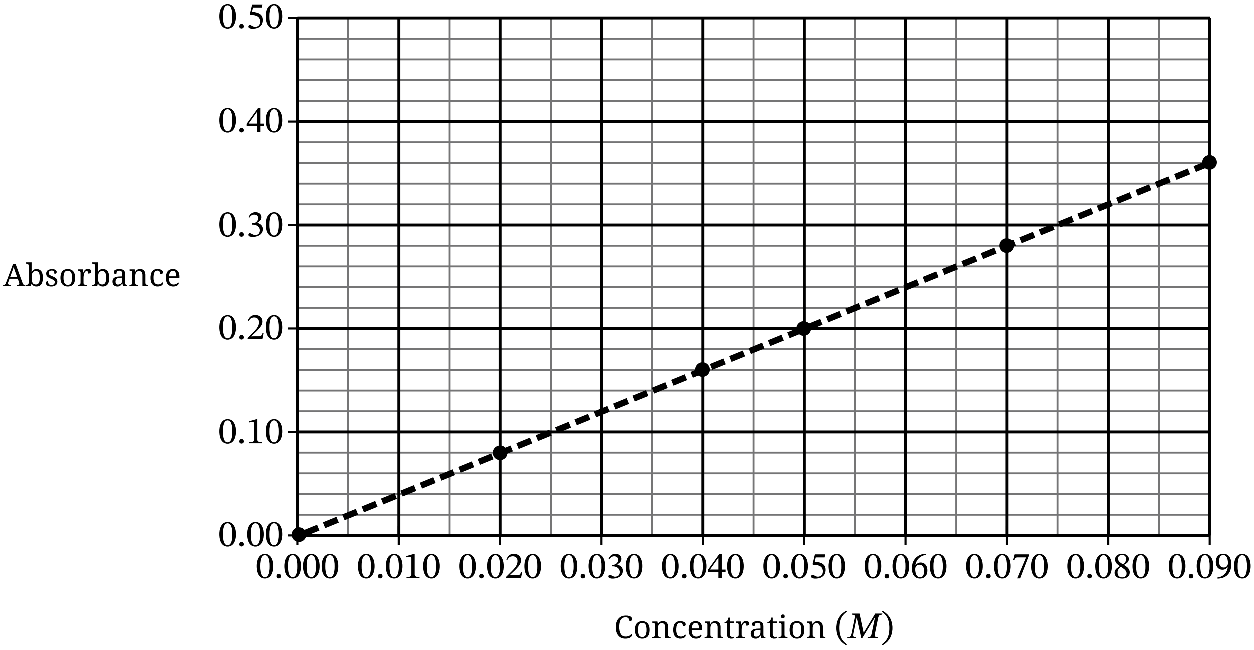
3.2 (a) $A = 250(0.0016) = 0.40$. (b) $c = \dfrac{0.50}{250} = 0.0020$ M.

3.3 $c = \dfrac{A}{\varepsilon b} = \dfrac{0.80}{(400)(1.0)} = 0.0020$ M.

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.

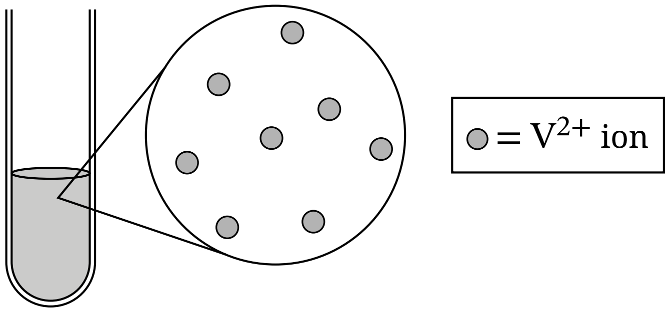
Figure 1



Part A

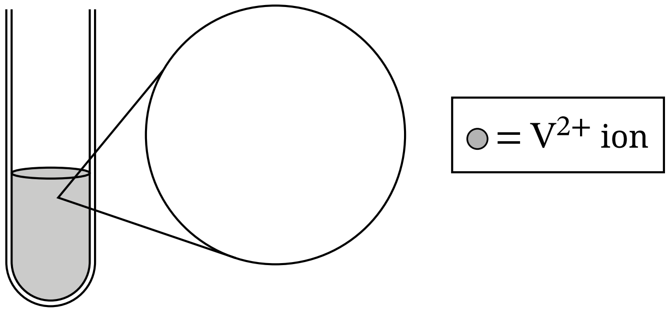
The student measures an absorbance of 0.32 for a $V^{2+}(aq)$ solution. The concentration of V^{2+} ions in the solution is represented by the particle diagram in the circle in Figure 2. In the circle in Figure 3, **draw** the correct number of V^{2+} ions to represent the concentration of a solution 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 $3.00\ \text{mL}$ of this $V^{2+}(aq)$ solution to a $25.0\ \text{mL}$ volumetric flask, dilutes to the mark on the flask with distilled water, and measures the absorbance of the diluted solution.

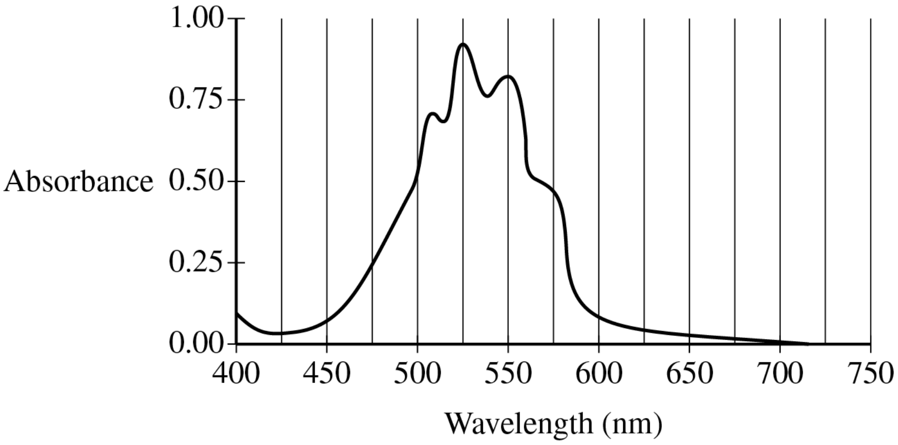
i. The absorbance of the diluted solution is 0.22. **Determine** the molarity of $V^{2+}(aq)$ in the diluted solution.

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

Part C

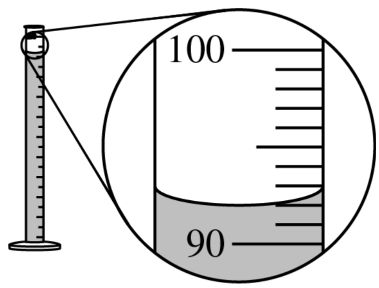
The concentration of $V^{2+}(aq)$ calculated in part B (ii) is lower than the actual concentration of the undiluted solution. The student claims that the calculated concentration is too low because during the dilution step, the final level of the solution was higher than the mark on the volumetric flask.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

. A student wants to determine the concentration of permanganate, $MnO_4^-(aq)$, in a solution. The student plans to use colorimetric analysis because solutions containing $MnO_4^-(aq)$ have a purple color.



(a) To determine the optimum wavelength for an experiment that measures the concentration of $MnO_4^-(aq)$, the student takes a sample of the solution and measures the amount of light absorbed by the sample over a range of wavelengths. The data are plotted in the graph shown. Identify the optimum wavelength that the student should use for the experimental procedure.

(b) The student uses a stock solution of 2.40×10^{-3} M $KMnO_4(aq)$ to prepare the standard solutions of $MnO_4^-(aq)$ that are needed to construct a calibration curve.



(i) The student uses a 100.0 mL graduated cylinder to measure a certain volume of $KMnO_4(aq)$ stock solution, as shown in the diagram given. What volume should the student record?

(ii) Calculate the volume, in mL, of 2.40×10^{-3} M $KMnO_4(aq)$ that is required to produce 100.0 mL of a standard 1.68×10^{-3} M $MnO_4^-(aq)$ solution.

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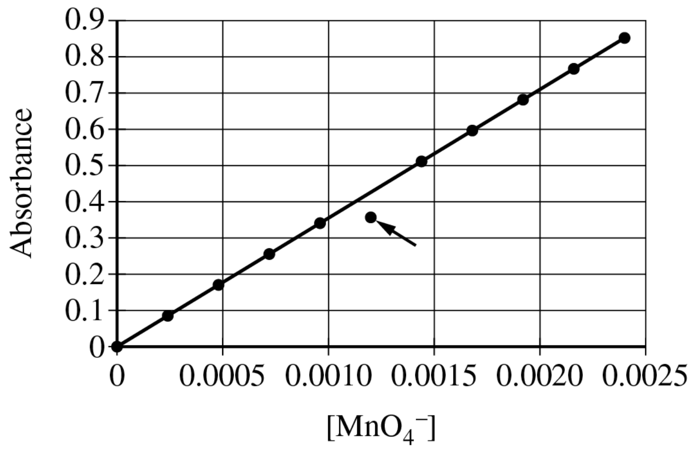
Continue your response to **QUESTION 6** on this page.

The student designs the following procedure to produce a calibration curve.

Step 1: Prepare several standard solutions that have known $MnO_4^-(aq)$ concentrations by dilution of the stock solution.
Step 2: Rinse the cuvette with distilled water.
Step 3: Rinse the cuvette with the standard solution and fill the cuvette with the standard solution.
Step 4: Measure the absorbance of the standard solution with the colorimeter.
Step 5: Repeat steps 2-4 for each of the standard solutions.

The data are plotted in the calibration curve shown. One of the data points (indicated with an arrow) on the calibration curve is below the line of best fit.



(c) Assuming that all lab equipment is functioning properly, identify which one of the procedural steps the student could have executed incorrectly that would explain why the marked data point is below the line of best fit. Justify your answer.

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3. A student is given the task of determining the molar concentration of a $CuSO_4$ solution using two different procedures, precipitation and spectrophotometry.

For the precipitation experiment, the student adds 20.0 mL of 0.200 M $Ba(NO_3)_2$ to 50.0 mL of the $CuSO_4(aq)$. The reaction goes to completion, and a white precipitate forms. The student filters the precipitate and dries it overnight. The data are given in the following table.

Mass of dry filter paper	0.764 g
Volume of $CuSO_4(aq)$	50.0 mL
Volume of 0.200 M $Ba(NO_3)_2$	20.0 mL
Mass of filter paper and dried precipitate	1.136 g

(a) Write a balanced net ionic equation for the precipitation reaction.

(b) Calculate the number of moles of precipitate formed.

(c) Calculate the molarity of the original $CuSO_4$ solution.

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For the spectrophotometry experiment, the student first makes a standard curve. The student uses a 0.1000 M solution of $CuSO_4(aq)$ to make three more solutions of known concentration (0.0500 M, 0.0300 M, and 0.0100 M) in 50.00 mL volumetric flasks.

(d) Calculate the volume of 0.1000 M $CuSO_4(aq)$ needed to make 50.00 mL of 0.0500 M $CuSO_4(aq)$.

(e) Briefly describe the procedure the student should follow to make 50.00 mL of 0.0500 M $CuSO_4(aq)$ using 0.1000 M $CuSO_4(aq)$, a 50.00 mL volumetric flask, and other standard laboratory equipment. Assume that all appropriate safety precautions will be taken.

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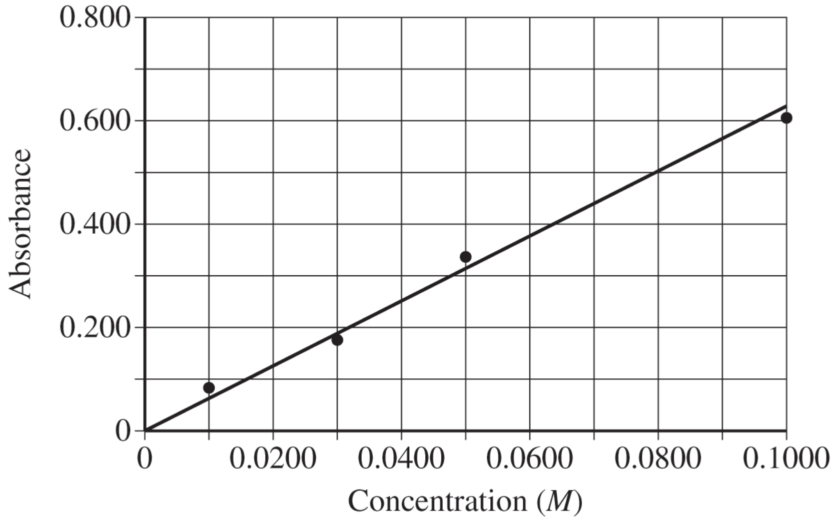
The standard curve is given below.



(f) The absorbance of the $CuSO_4$ solution of unknown concentration is 0.219. Determine the molarity of the solution.

(g) A second student performs the same experiment. There are a few drops of water in the cuvette before the second student adds the $CuSO_4(aq)$ solution of unknown concentration. Will this result in a $CuSO_4(aq)$ concentration for the unknown that is greater than, less than, or equal to the concentration determined in part (f) ? Justify your answer.

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