Week 1

AP Chemistry

Homework bundle for this week

本周作业合集

exercises.lol

Contents 目录

AP Chemistry Name: ________________ Score: ________

1. How many moles are in 44 g of CO_2 (molar mass 44 g/mol)?

   ________________ mol

2. An element is 60% of mass 10 and 40% of mass 11. Its average atomic mass (in u)?

   ________________ u

3. In water (H_2O, molar mass 18), what percent of the mass is oxygen (16)? (to nearest whole %)

   ________________ %

4. A 200 g solution is 15% sugar by mass. The mass of sugar (in g)?

   ________________ g

5. What is the electron configuration of oxygen (8 electrons)?

   ☐ $1s^2\ 2s^2\ 2p^4$

   ☐ $1s^2\ 2s^2\ 2p^6$

   ☐ $1s^2\ 2s^4\ 2p^2$

6. In a PES spectrum, the height of a peak is proportional to...

   ☐ the number of electrons in that subshell

   ☐ the mass of the atom

   ☐ the temperature

7. Across a period from left to right, the atomic radius...

   ☐ decreases

   ☐ increases

   ☐ stays the same

8. Valence electrons are the electrons in the...

   ☐ outermost shell

   ☐ innermost shell

   ☐ nucleus

9. One mole of any substance contains how many particles?

   ☐ 6.022×10^{23}

   ☐ 1000

☐ 6.022×10^{-23}

10. A mixture can have different proportions from one sample to another.

☐ True ☐ False

AP Chemistry

1. **1 mol**

   $n = m/M = 44/44 = 1$ mol.

2. **10.4 u**

   $0.60(10) + 0.40(11) = 6.0 + 4.4 = 10.4$ u.

3. **89 %**

   $16/18 \times 100 \approx 89\%$.

4. **30 g**

   $0.15 \times 200 = 30$ g.

5. $1s^2\ 2s^2\ 2p^4$

   $2 + 2 + 4 = 8$ electrons, filling 1s, 2s, then 2p.

6. **the number of electrons in that subshell**

   More electrons in a subshell means a taller peak.

7. **decreases**

   More protons pull the same shell in tighter, shrinking the atom.

8. **outermost shell**

   Valence electrons are the outermost ones and drive bonding.

9. 6.022×10^{23}

   A mole is Avogadro's number of particles, 6.022×10^{23}.

10. **True**

    Mixtures have variable composition, unlike pure compounds.

AP CHEMISTRY • EXERCISE SHEET

1.1 Moles and Molar Mass

Name: ____________ Class: ________ Date: __________ **Total: 16 marks**

KEY WORDS mole 摩尔 • molar mass 摩尔质量 • avogadro's number 阿伏伽德罗常数

Objective

Build the skills to answer exam questions on **moles and molar mass**.

You must be able to:

- use the **mole** 摩尔 as a fixed count, 6.022×10^{23} particles (**Avogadro's number** 阿伏伽德罗常数)
- use the **molar mass** 摩尔质量 (g/mol) to convert between grams and moles
- convert with $n = \frac{m}{M}$, and moles to particles by multiplying by Avogadro's number
- find the molar mass of a compound by adding atomic masses

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.

■ Moles from mass

$$n = \frac{m}{M}.$$

36 g of water ($M = 18$ g/mol) is $n = 36/18 = 2$ mol.

■ Molar mass of a compound

Add the atomic masses. For H_2O: $2(1) + 16 = 18$ g/mol. For CO_2: $12 + 2(16) = 44$ g/mol.

■ Moles to particles

Multiply by Avogadro's number: 2 mol is $2 \times 6.022 \times 10^{23} \approx 1.2 \times 10^{24}$ molecules.

2 Practice

Now apply the methods above.

2.1 How many moles are in 44 g of CO_2 ($M = 44$ g/mol)? [2]

2.2 Find the molar mass of water, H_2O (H = 1, O = 16). [2]

2.3 Find the mass of 3 mol of carbon atoms ($M = 12$ g/mol). [2]

2.4 State the number of particles in one mole. [1]

3 Exam-style questions

3.1 One mole of any substance contains [1]

- **A** 1000 particles
- **B** 6.022×10^{23} particles
- **C** 6.022×10^{-23} particles
- **D** 12 particles

3.2 The molar mass of CO_2 (C = 12, O = 16) is [1]

- **A** 28 g/mol
- **B** 44 g/mol
- **C** 12 g/mol
- **D** 60 g/mol

3.3 A sample contains 88 g of CO_2 ($M = 44$ g/mol).

(a) Find the number of moles. [2]

(b) Find the number of molecules (use 6.022×10^{23}). [2]

3.4 A student needs 0.5 mol of NaCl ($M = 58.5$ g/mol).

(a) Find the mass required. [2]

(b) State the units of molar mass. [1]

Solutions

2.1 $n = m/M = 44/44 = 1$ mol.

2.2 $2(1) + 16 = 18$ g/mol.

2.3 $m = nM = 3 \times 12 = 36$ g.

2.4 6.022×10^{23}.

3.1 B — a mole is Avogadro's number of particles.

3.2 B — $12 + 2(16) = 44$ g/mol.

3.3 (a) $n = 88/44 = 2$ mol. (b) $2 \times 6.022 \times 10^{23} = 1.2 \times 10^{24}$ molecules.

3.4 (a) $m = nM = 0.5 \times 58.5 = 29.25$ g. (b) g/mol (grams per mole).

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.

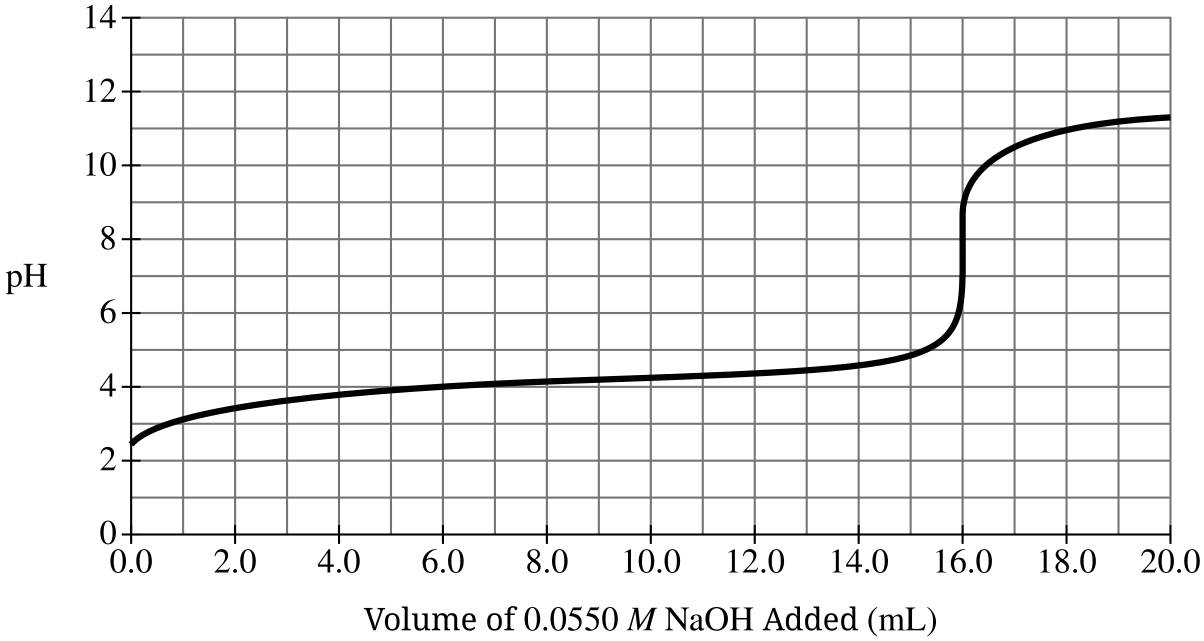
i. Calculate the number of moles of H_2O produced.

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.

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

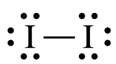
The student runs three trials of the reaction with different initial concentrations of HAsc and I_3^-, producing the following data.

Trial	[HAsc] (M)	$[\mathrm{I_3^-}]\,(M)$	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}

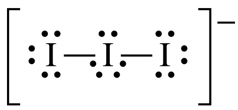
i. The rate law for the reaction is $rate = k[\mathrm{HAsc}][\mathrm{I_3^-}]$. Explain how the data in the table support the conclusion that the reaction is first order with respect to $[\mathrm{HAsc}]$.

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



I_3^-

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

CHEMISTRY

SECTION II

Time—1 hour and 45 minutes

7 Questions

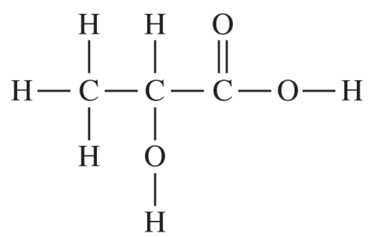
Directions: Questions 1–3 are long free-response questions that require about 23 minutes each to answer and are worth 10 points each. Questions 4–7 are short free-response questions that require about 9 minutes each to answer and are worth 4 points each.

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.

$$C_3H_6O_3(aq) + NaOH(aq) \rightarrow NaC_3H_5O_3(aq) + H_2O(l)$$

1. A student is studying the reaction between lactic acid, $C_3H_6O_3$, and sodium hydroxide, NaOH, as represented in the balanced equation above.

(a) The structural formula of lactic acid is shown in the following diagram. Circle the hydrogen atom that most readily participates in the chemical reaction with sodium hydroxide.



(b) The student begins the experiment by dissolving 10.22 g of sodium hydroxide (molar mass 40.00 g / mol) in enough water to produce 500. mL of solution. Calculate the molarity of the sodium hydroxide solution.

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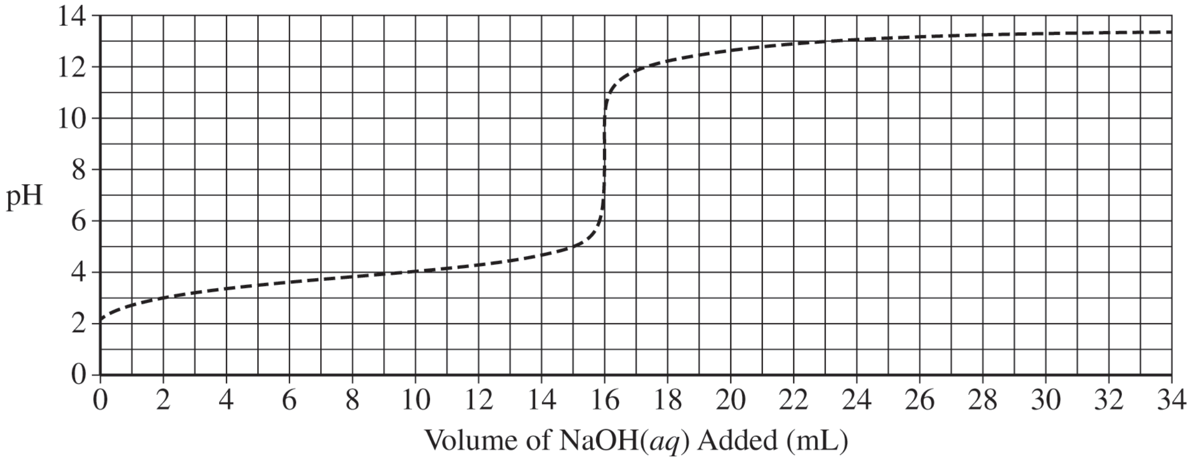
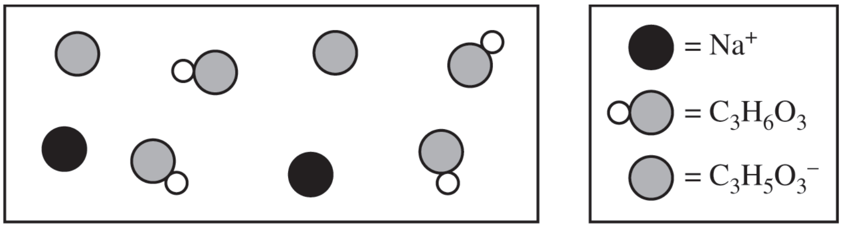
Continue your response to **QUESTION 1** on this page.

The student uses the sodium hydroxide solution from part (b), a buret, a pH meter, and a 100 mL Erlenmeyer flask to titrate a 25.0 mL sample of lactic acid solution. The student's data are shown in the following graph.



(c) Use the information in the graph to determine the approximate pK_a of lactic acid. ____________



(d) The preceding diagram represents the relative amounts of major species in a sample of the solution in the flask at one point during the titration. (Note that water molecules are omitted.)

(i) Draw an X on the preceding titration curve at a point in the titration where the reaction mixture would be represented by this diagram.

(ii) Justify your answer.

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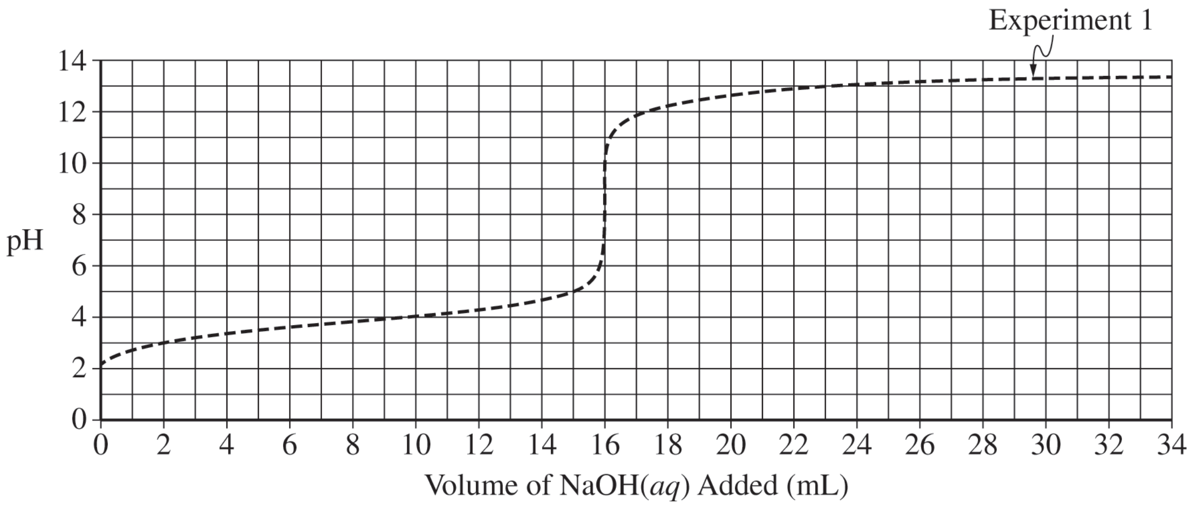
Continue your response to **QUESTION 1** on this page.

Experiment	Mass of $NaOH(s)$ (grams)	Volume of Solution (mL)	Titration Curve
1	10.22	500.	Already shown on graph
2	20.44	500.	?

(iii) The student repeats the experiment but uses a solution of $NaOH(aq)$ with twice the concentration, as shown in the preceding table. On the following graph, draw the titration curve that would be expected for experiment 2.



(e) In a third experiment, the student investigates the enthalpy of the reaction between lactic acid and sodium hydroxide. The student combines 100.0 mL of a 0.500 M lactic acid solution at 20.0°C with 100.0 mL of a 0.500 M NaOH solution at 20.0°C in a calorimeter. The final temperature of the resulting combined solution is 23.2°C. Assume that the density of each solution before combining is 1.00 g / mL and that the specific heat capacity of the combined solution is 4.2 J / (g · °C).

(i) Calculate the quantity of heat produced in the reaction, in J.

GO ON TO THE NEXT PAGE.

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

(ii) Calculate the molar enthalpy of reaction, in kJ / mol_{rxn}. Include the sign in your answer.

(iii) The student claims that if heat is lost from the calorimeter to the surrounding air during the reaction, then the experimental value of the molar enthalpy of reaction will be smaller in magnitude than the actual value. Do you agree or disagree with the student's claim? Justify your answer.

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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.

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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.

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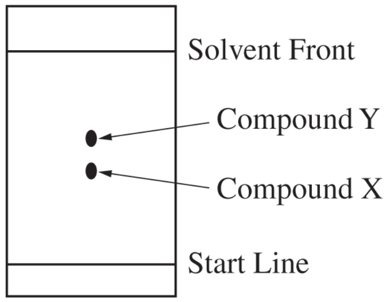
Continue your response to **QUESTION 7** on this page.

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

CHEMISTRY

SECTION II

Time—1 hour and 45 minutes

7 Questions

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'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.

. Answer the following questions related to manganese compounds.

(a) Manganese has several common oxidation states.

(i) Write the complete electron configuration for an Mn atom in the ground state.

(ii) When manganese forms cations, electrons are lost from which subshell first? Identify both the number and letter associated with the subshell.

A student performs an experiment to produce a manganese salt of unknown composition, $Mn_xCl_y(aq)$, and determine its empirical formula. The student places a sample of $Mn(s)$ in a beaker containing excess $HCl(aq)$, as represented by the following equation.

$$x\ Mn(s) + y\ HCl(aq) \rightarrow Mn_xCl_y(aq) + \frac{y}{2} H_2(g)$$

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

The student heats the resulting mixture until only $Mn_xCl_y(s)$ remains in the beaker. The data are given in the following table.

Mass of empty beaker	60.169 g
Mass of beaker and $Mn(s)$	61.262 g
Mass of beaker and Mn_xCl_y after heating to constant mass	62.673 g

(b) Calculate the mass of Cl in the sample of $Mn_xCl_y(s)$ remaining in the beaker.

(c) Calculate the number of moles of Cl in the sample of $Mn_xCl_y(s)$ remaining in the beaker.

(d) The student determines that 0.0199 mol of Mn was used in the experiment. Use the data to determine the empirical formula of the $Mn_xCl_y(s)$.

(e) The student repeats the experiment using the same amounts of Mn and HCl and notices that some of the Mn_xCl_y splatters out of the beaker as it is heated to dryness. Will the number of moles of Cl calculated for this trial be greater than, less than, or equal to the number calculated in part (c) ? Justify your answer.

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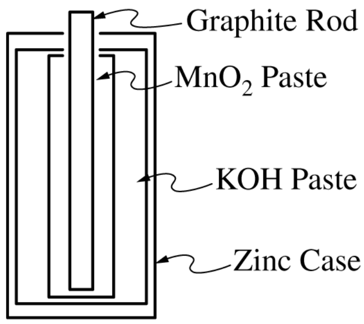
Continue your response to **QUESTION 1** on this page.

(f) Another compound of manganese, MnO_2, is used in alkaline batteries, represented by the following diagram. Some half-reactions are given in the table.



Reduction Half-Reaction	$E°$ (V)
$Zn^{2+}(aq) + 2\,e^- \rightarrow Zn(s)$	−0.76
$ZnO(s) + H_2O(l) + 2\,e^- \rightarrow Zn(s) + 2\,OH^-(aq)$	−1.28
$2\,MnO_2(s) + H_2O(l) + 2\,e^- \rightarrow Mn_2O_3(s) + 2\,OH^-(aq)$	0.15

(i) Based on the half-reactions given in the table, write the balanced net ionic equation for the reaction that has the greatest thermodynamic favorability.

(ii) Calculate the value of E°_{cell} for the overall reaction.

(iii) Calculate the value of $\Delta G°$ in kJ/mol_{rxn}.

(iv) A student claims that the total mass of an alkaline battery decreases as the battery operates because the anode loses mass. Do you agree with the student's claim? Justify your answer.

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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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CHEMISTRY

Section II

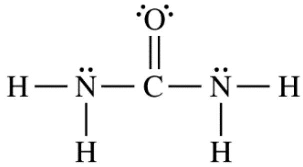
Time—1 hour and 45 minutes

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.

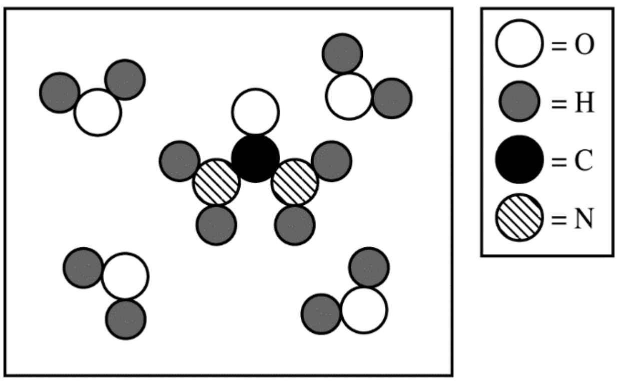
Write your response in the space provided following each question. Examples and equations may be included in your responses where appropriate. For calculations, clearly show the method used and the steps involved in arriving at your answers. You must show your work to receive credit for your answer.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

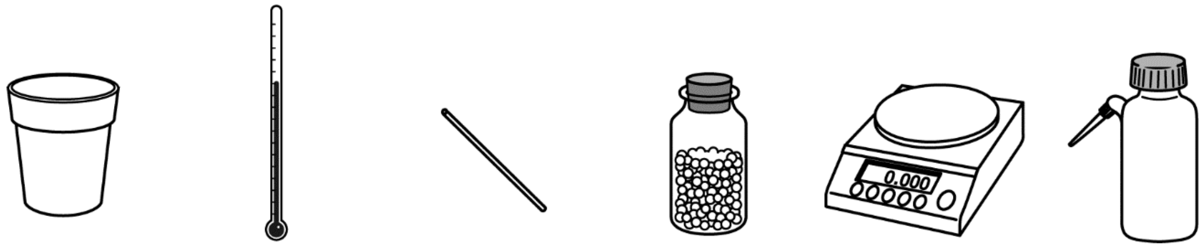


$$H_2NCONH_2(s) \rightleftarrows H_2NCONH_2(aq)$$

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.

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.

$$Na_2S_2O_3(aq) + 4\ NaOCl(aq) + 2\ NaOH(aq) \rightarrow 2\ Na_2SO_4(aq) + 4\ NaCl(aq) + H_2O(l)$$

1. A student performs an experiment to determine the value of the enthalpy change, ΔH°_{rxn}, for the oxidation-reduction reaction represented by the balanced equation above.

   (a) Determine the oxidation number of Cl in NaOCl.

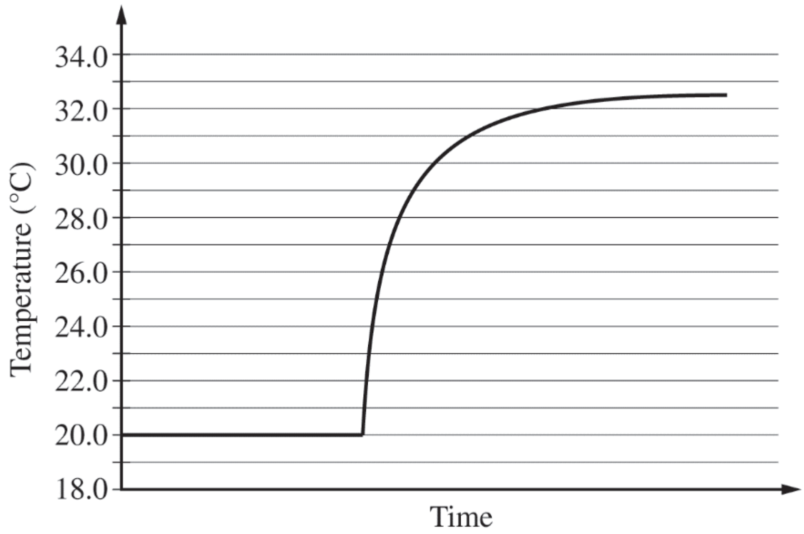
   (b) Calculate the number of grams of $Na_2S_2O_3$ needed to prepare 100.00 mL of 0.500 *M* $Na_2S_2O_3(aq)$.

   In the experiment, the student uses the solutions shown in the table below.

Solution	Concentration (*M*)	Volume (mL)
$Na_2S_2O_3(aq)$	0.500	5.00
$NaOCl(aq)$	0.500	5.00
$NaOH(aq)$	0.500	5.00

   (c) Using the balanced equation for the oxidation-reduction reaction and the information in the table above, determine which reactant is the limiting reactant. Justify your answer.

The solutions, all originally at 20.0°C, are combined in an insulated calorimeter. The temperature of the reaction mixture is monitored, as shown in the graph below.



(d) According to the graph, what is the temperature change of the reaction mixture?

(e) The mass of the reaction mixture inside the calorimeter is 15.21 g.

(i) Calculate the magnitude of the heat energy, in joules, that is released during the reaction. Assume that the specific heat of the reaction mixture is 3.94 J/(g·°C) and that the heat absorbed by the calorimeter is negligible.

(ii) Using the balanced equation for the oxidation-reduction reaction and your answer to part (c), calculate the value of the enthalpy change of the reaction, ΔH°_{rxn}, in kJ/mol$_{rxn}$. Include the appropriate algebraic sign with your answer.

The student repeats the experiment, but this time doubling the volume of each of the reactants, as shown in the table below.

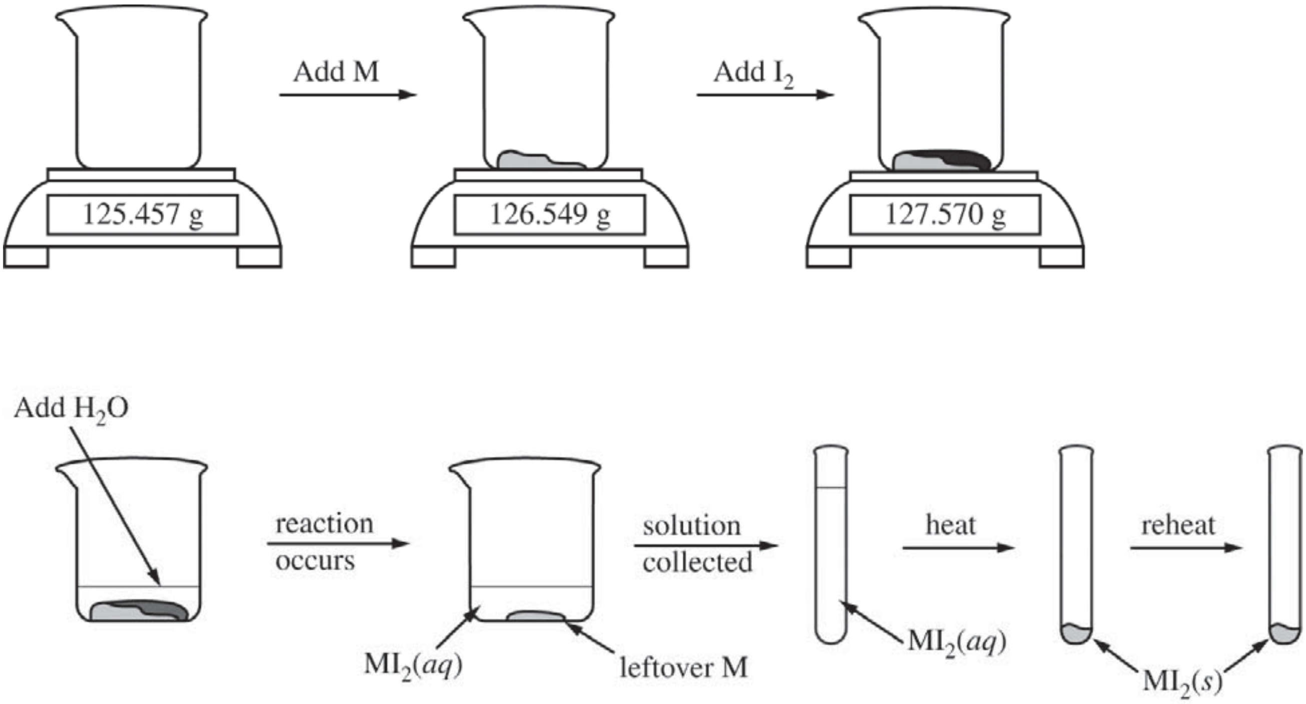
Solution	Concentration (M)	Volume (mL)
$Na_2S_2O_3(aq)$	0.500	10.0
$NaOCl(aq)$	0.500	10.0
$NaOH(aq)$	0.500	10.0

(f) The magnitude of the enthalpy change, ΔH°_{rxn}, in kJ/mol$_{rxn}$, calculated from the results of the second experiment is the same as the result calculated in part (e)(ii). Explain this result.

(g) Write the balanced net ionic equation for the given reaction.

$$M + I_2 \rightarrow MI_2$$

3. To determine the molar mass of an unknown metal, M, a student reacts iodine with an excess of the metal to form the water-soluble compound MI_2, as represented by the equation above. The reaction proceeds until all of the I_2 is consumed. The $MI_2(aq)$ solution is quantitatively collected and heated to remove the water, and the product is dried and weighed to constant mass. The experimental steps are represented below, followed by a data table.



Data for Unknown Metal Lab	
Mass of beaker	125.457 g
Mass of beaker + metal M	126.549 g
Mass of beaker + metal M + I_2	127.570 g
Mass of MI_2, first weighing	1.284 g
Mass of MI_2, second weighing	1.284 g

(a) Given that the metal M is in excess, calculate the number of moles of I_2 that reacted.

(b) Calculate the molar mass of the unknown metal M.

The student hypothesizes that the compound formed in the synthesis reaction is ionic.

(c) Propose an experimental test the student could perform that could be used to support the hypothesis. Explain how the results of the test would support the hypothesis if the substance was ionic.

The student hypothesizes that Br_2 will react with metal M more vigorously than I_2 did because Br_2 is a liquid at room temperature.

(d) Explain why I_2 is a solid at room temperature whereas Br_2 is a liquid. Your explanation should clearly reference the types and relative strengths of the intermolecular forces present in each substance.

While cleaning up after the experiment, the student wishes to dispose of the unused solid I_2 in a responsible manner. The student decides to convert the solid I_2 to $I^-(aq)$ anion. The student has access to three solutions, $H_2O_2(aq)$, $Na_2S_2O_3(aq)$, and $Na_2S_4O_6(aq)$, and the standard reduction table shown below.

Half reaction	$E°$ (V)
$S_4O_6^{2-}(aq) + 2\,e^- \rightarrow 2\,S_2O_3^{2-}(aq)$	0.08
$I_2(s) + 2\,e^- \rightarrow 2\,I^-(aq)$	0.54
$O_2(g) + 2\,H^+(aq) + 2\,e^- \rightarrow H_2O_2(aq)$	0.68

(e) Which solution should the student add to $I_2(s)$ to reduce it to $I^-(aq)$? Circle your answer below. Justify your answer, including a calculation of $E°$ for the overall reaction.

$H_2O_2(aq)$ $\qquad$ $Na_2S_2O_3(aq)$ $\qquad$ $Na_2S_4O_6(aq)$

(f) Write the balanced net-ionic equation for the reaction between I_2 and the solution you selected in part (e).

1.2 Mass Spectra of Elements

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

KEY WORDS mass spectrum 质谱图 • isotope 同位素 • relative abundance 相对丰度 • average atomic mass 平均原

Objective

Build the skills to answer exam questions on **mass spectra of elements**.

You must be able to:

- describe **isotopes** 同位素 as atoms of one element with different numbers of neutrons
- read a **mass spectrum** 质谱图 (peak position = mass, peak height = relative abundance)
- calculate the **average atomic mass** 平均原子质量 as an abundance-weighted average
- convert percentage abundances to fractions before averaging

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.

■ Isotopes

Isotopes share protons but differ in neutrons, so they differ in mass. Chlorine occurs as chlorine-35 and chlorine-37.

■ Weighted average

Multiply each isotope mass by its fractional abundance and add:

$$\bar{m} = \sum(\text{fraction}) \times (\text{isotope mass}).$$

Chlorine (75% mass 35, 25% mass 37):

$$\bar{m} = 0.75(35) + 0.25(37) = 35.5 \text{ u}.$$

■ The average is pulled toward the common isotope

The more abundant isotope pulls the average toward its own mass.

2 Practice

Now apply the methods above.

2.1 State how two isotopes of the same element differ. [1]

2.2 An element is 60% mass 10 and 40% mass 11. Find its average atomic mass. [2]

2.3 On a mass spectrum, what does the height of a peak show? [1]

2.4 Two isotopes of mass 20 and 22 are each 50% abundant. Find the average mass. [2]

3 Exam-style questions

3.1 Isotopes of an element have the same number of [1]

- **A** neutrons
- **B** protons
- **C** total particles
- **D** nothing

3.2 An element is 90% mass 20 and 10% mass 22. Its average atomic mass is closest to [1]

- **A** 20.0
- **B** 20.2
- **C** 21.0
- **D** 22.0

3.3 Boron has two isotopes: boron-10 (20%) and boron-11 (80%).

(a) Find the average atomic mass. [2]

(b) State which isotope the average lies closer to, and why. [1]

3.4 A mass spectrum of an element shows two peaks: mass 63 (69%) and mass 65 (31%).

(a) Find the average atomic mass. [2]

(b) Identify the element (hint: this is its relative atomic mass). [1]

Solutions

2.1 In the number of neutrons (same protons, different mass).

2.2 $0.60(10) + 0.40(11) = 10.4$ u.

2.3 Its relative abundance.

2.4 $0.5(20) + 0.5(22) = 21$ u.

3.1 **B** — the same number of protons.

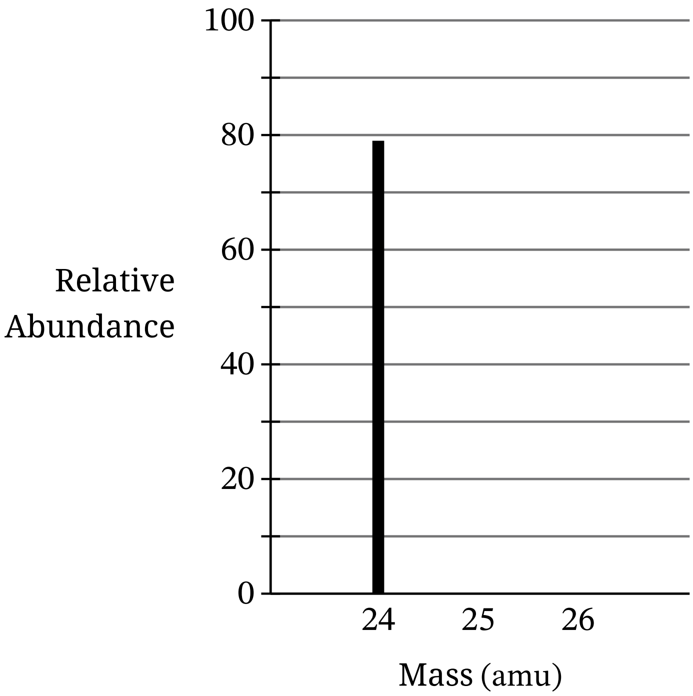
3.2 **B** — $0.90(20) + 0.10(22) = 20.2$.

3.3 (a) $0.20(10) + 0.80(11) = 10.8$ u. (b) Closer to boron-11, since it is more abundant.

3.4 (a) $0.69(63) + 0.31(65) = 63.6$ u. (b) Copper (Cu).

1. Answer the following questions about magnesium.

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

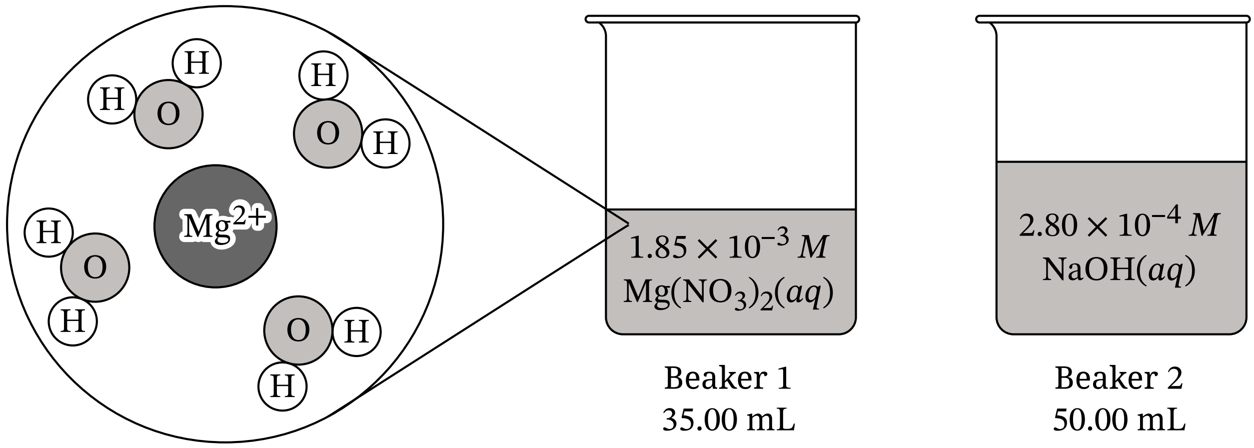


The percent abundance of magnesium-24 is 79%. The percent abundances of the other two natural isotopes of magnesium, magnesium-25 and magnesium-26, are approximately equal.

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.



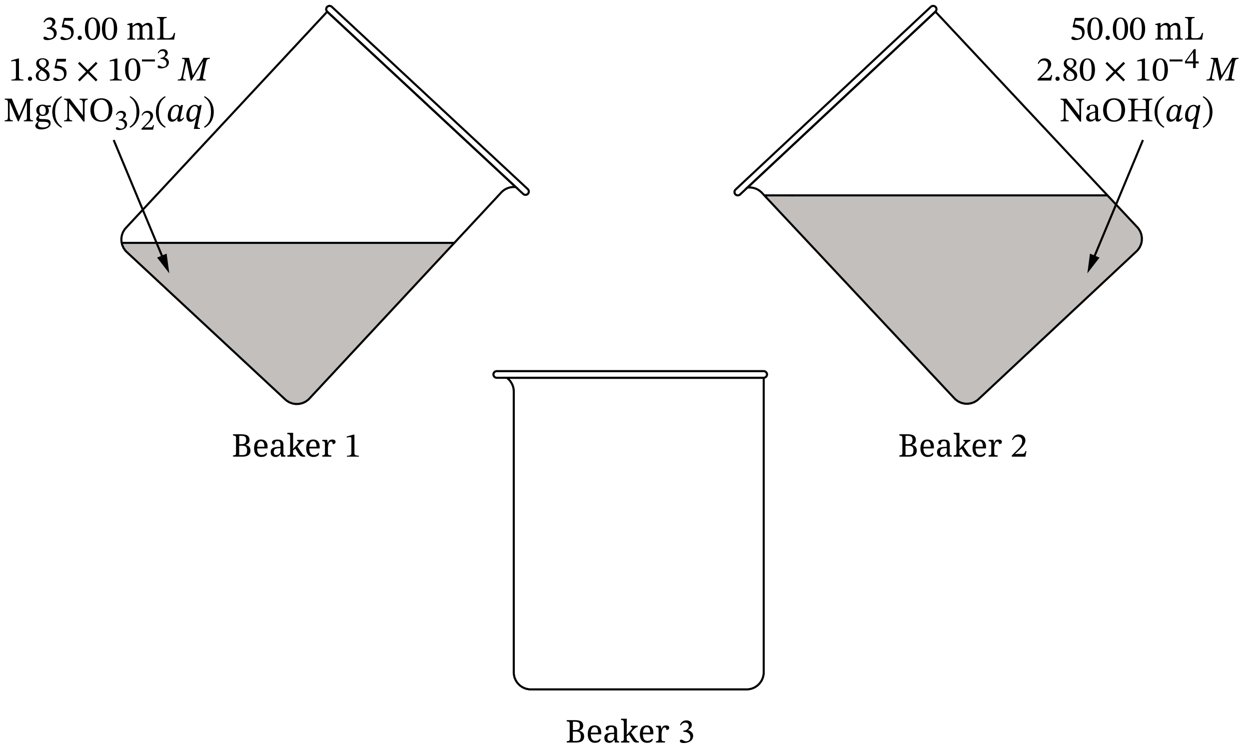
B. The particle diagram shown represents a magnesium ion, Mg^{2+}, in beaker 1. A sodium ion, Na^{+}, in beaker 2 has a weaker attraction to water than the Mg^{2+} does. Explain this phenomenon using Coulomb's law and each of the following.

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.

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

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

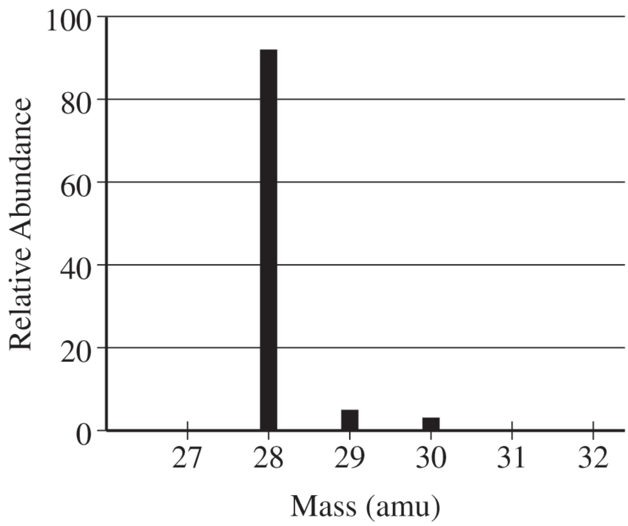
ii. After the two solutions are combined in beaker 3 as described in part D, but before any reaction takes place, $[OH^-] = 1.65\times10^{-4}$ M. Using your answer to part D, calculate the value of the reaction quotient, Q.

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.

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.

GO ON TO THE NEXT PAGE.

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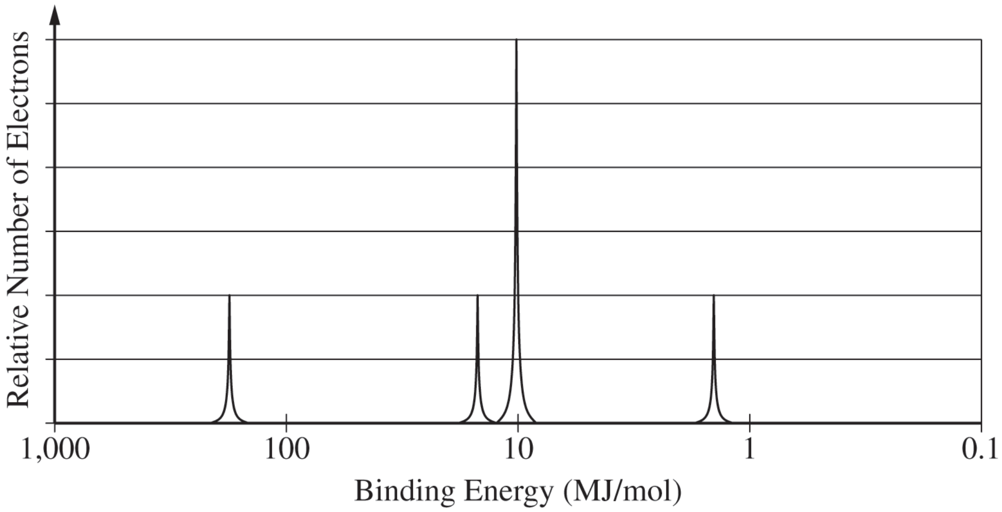
(g) A partial photoelectron spectrum of pure Si is shown below. On the spectrum, draw the missing peak that corresponds to the electrons in the $3p$ sublevel.



(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.

GO ON TO THE NEXT PAGE.

1.3 Elemental Composition of Pure Substances

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

KEY WORDS empirical formula 实验式 • molecular formula 分子式 • percent composition 百分组成 • molar mass 摩尔质量 • moles 摩尔

Objective

Build the skills to answer exam questions on **the elemental composition of pure substances**.

You must be able to:

- calculate the **percent composition 百分组成** by mass of each element
- find an **empirical formula 实验式** from mass percentages
- find a **molecular formula 分子式** from the empirical formula and molar mass
- convert masses to moles and divide by the smallest

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.

■ Percent composition

$$\%\ \text{element} = \frac{\text{mass of that element}}{\text{total mass}} \times 100\%.$$

In water ($M = 18$), oxygen is $16/18 \times 100 \approx 89\%$.

■ Empirical formula

Convert each element's mass to moles, then divide by the smallest. For 40% C, 6.7% H, 53.3% O (per 100 g): C = 3.33, H = 6.7, O = 3.33 mol; dividing by 3.33 gives CH_2O.

■ Molecular formula

Divide the true molar mass by the empirical mass for the multiple n. Glucose: empirical CH_2O (30), molar mass 180, so $n = 6$, giving $C_6H_{12}O_6$.

2 Practice

Now apply the methods above.

2.1 In water (H_2O, $M = 18$), what percent of the mass is oxygen (16)? [2]

2.2 State what an empirical formula gives. [1]

2.3 A compound has empirical mass 30 and molar mass 90. Find the multiple n. [2]

2.4 After dividing by the smallest you get a ratio $1 : 1.5$. State the whole-number ratio. [1]

3 Exam-style questions

3.1 The empirical formula of a compound gives [1]

- **A** the exact number of atoms in a molecule
- **B** the simplest whole-number ratio of atoms
- **C** the molar mass
- **D** the percent composition

3.2 A compound is 75% carbon and 25% hydrogen by mass (C = 12, H = 1). Its empirical formula is [1]

- **A** CH
- **B** CH_2
- **C** CH_4
- **D** C_2H

3.3 A compound is 40% sulfur and 60% oxygen by mass (S = 32, O = 16).

(a) Find the empirical formula. [3]

(b) State the method you used. [1]

3.4 A compound has empirical formula CH_2 (empirical mass 14) and a molar mass of 56 g/mol.

(a) Find the multiple n. [1]

(b) Write the molecular formula. [1]

Solutions

2.1 $16/18 \times 100 \approx 89\%$.

2.2 The simplest whole-number ratio of atoms.

2.3 $n = 90/30 = 3$.

2.4 2 : 3 (multiply both by 2).

3.1 **B** — the simplest whole-number ratio of atoms.

3.2 **C** — C: $75/12 = 6.25$, H: $25/1 = 25$; ratio 1 : 4, so CH_4.

3.3 (a) Per 100 g: $S = 40/32 = 1.25$, $O = 60/16 = 3.75$ mol; divide by 1.25: S 1, O 3; empirical formula SO_3. (b) Convert mass percents to moles and divide by the smallest.

3.4 (a) $n = 56/14 = 4$. (b) C_4H_8.

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.

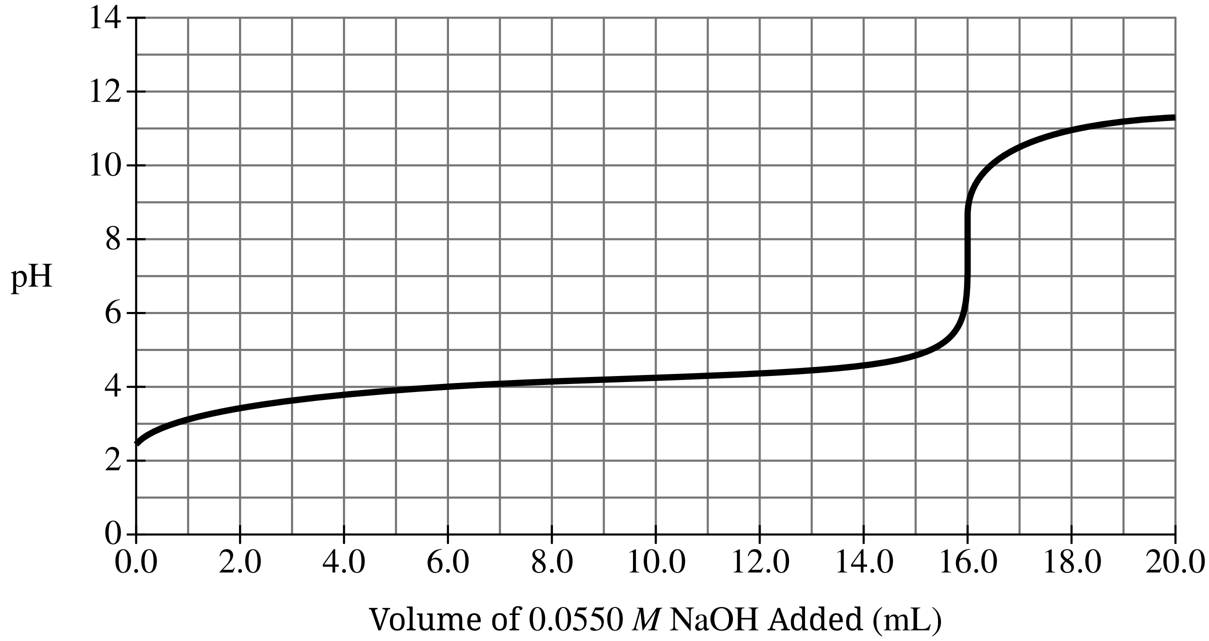
i. Calculate the number of moles of H_2O produced.

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.

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

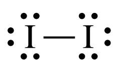
The student runs three trials of the reaction with different initial concentrations of HAsc and I_3^-, producing the following data.

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}

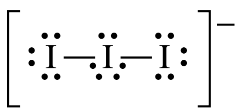
i. The rate law for the reaction is $rate = k[\text{HAsc}][I_3^-]$. Explain how the data in the table support the conclusion that the reaction is first order with respect to $[\text{HAsc}]$.

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



I_3^-

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.

1.4 Composition of Mixtures

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

KEY WORDS mixture 混合物 • mass percent 质量分数 • moles 摩尔 • molar mass 摩尔质量

Objective

Build the skills to answer exam questions on **the composition of mixtures**.

You must be able to:

- distinguish a **mixture 混合物** (variable composition) from a pure compound
- calculate the **mass percent 质量分数** of a component
- use the fact that all components' mass percents add to 100%
- convert a component mass to moles with its molar mass

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.

■ Mixtures vary

A mixture has no fixed formula: salt water can be weak or strong. Its components keep their identity and can be separated physically.

■ Mass percent

$$\% \text{ component} = \frac{\text{mass of component}}{\text{mass of mixture}} \times 100\%.$$

A 50 g alloy that is 30% copper contains $0.30 \times 50 = 15$ g of copper.

■ Percents sum to 100

If an alloy is 60% iron, the rest (40%) is the other metal.

2 Practice

Now apply the methods above.

2.1 A 200 g solution is 15% sugar by mass. Find the mass of sugar. [2]

2.2 State one way a mixture differs from a pure compound. [1]

2.3 An alloy is 60% iron; the rest is carbon. Find the mass percent of carbon. [1]

2.4 A sample contains 24 g of carbon ($M = 12$). Find the moles of carbon. [2]

3 Exam-style questions

3.1 Which statement about a mixture is true? [1]

- **A** it has a fixed formula
- **B** its composition can vary
- **C** it cannot be separated
- **D** it is always a solid

3.2 A 40 g mixture contains 10 g of salt. The mass percent of salt is [1]

- **A** 10%
- **B** 25%
- **C** 40%
- **D** 4%

3.3 A 250 g brass sample is 65% copper and 35% zinc by mass.

(a) Find the mass of copper. [2]

(b) Find the mass of zinc. [1]

3.4 A mixture contains 18 g of water ($M = 18$) and 46 g of ethanol ($M = 46$).

(a) Find the moles of each. [2]

(b) State whether the composition of a mixture is fixed. [1]

Solutions

2.1 $0.15 \times 200 = 30$ g.

2.2 A mixture has variable composition (or can be separated physically).

2.3 $100 - 60 = 40\%$.

2.4 $n = m/M = 24/12 = 2$ mol.

3.1 **B** — its composition can vary.

3.2 **B** — $10/40 \times 100 = 25\%$.

3.3 (a) $0.65 \times 250 = 162.5$ g. (b) $0.35 \times 250 = 87.5$ g.

3.4 (a) water $= 18/18 = 1$ mol; ethanol $= 46/46 = 1$ mol. (b) No — it is variable.

AP CHEMISTRY • EXERCISE SHEET

1.5 Atomic Structure and Electron Configuration

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

KEY WORDS electron configuration 电子排布 • electrons 电子 • nucleus 原子核

Objective

Build the skills to answer exam questions on **atomic structure and electron configuration**.

You must be able to:

- describe an atom as a nucleus of protons and neutrons with **electrons 电子** in shells
- write an **electron configuration 电子排布** by filling lowest-energy subshells first
- recall the filling order (including $4s$ before $3d$)
- check that the superscripts sum to the electron count

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.

■ Filling order

Electrons fill from lowest energy up: $1s$ $2s$ $2p$ $3s$ $3p$ $4s$ $3d\ldots$ Each s holds 2, each p holds 6, each d holds 10.

■ Writing a configuration

Oxygen (8 electrons): $1s^2\ 2s^2\ 2p^4$. Sodium (11): $1s^2\ 2s^2\ 2p^6\ 3s^1$.

■ Check the sum

The superscripts must add to the total electron count. For sodium, $2+2+6+1 = 11$.

2 Practice

Now apply the methods above.

2.1 Write the electron configuration of oxygen (8 electrons). [2]

2.2 Which subshell fills first, $4s$ or $3d$? [1]

2.3 The configuration $1s^2\ 2s^2\ 2p^6\ 3s^1$ has how many electrons? [1]

2.4 What holds the electrons to the nucleus? [1]

3 Exam-style questions

3.1 In an atom, the electrons are held to the nucleus by [1]

- **A** gravity
- **B** Coulombic (electrostatic) attraction
- **C** magnetism
- **D** friction

3.2 The electron configuration of neon (10 electrons) is [1]

- **A** $1s^2\ 2s^2\ 2p^6$
- **B** $1s^2\ 2s^2\ 2p^4$
- **C** $1s^2\ 2s^4\ 2p^4$
- **D** $1s^2\ 2s^2\ 2p^8$

3.3 Consider the element magnesium (12 electrons).

(a) Write its electron configuration. [2]

(b) State how many electrons are in its outer ($3s$) shell. [1]

3.4 An atom has the configuration $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^4$.

(a) Find the total number of electrons. [2]

(b) State whether inner-shell or outer-shell electrons are harder to remove. [1]

Solutions

2.1 $1s^2\ 2s^2\ 2p^4$.

2.2 $4s$.

2.3 11.

2.4 Coulombic (electrostatic) attraction.

3.1 **B** — Coulombic attraction.

3.2 **A** — $1s^2\ 2s^2\ 2p^6$ $(2+2+6=10)$.

3.3 (a) $1s^2\ 2s^2\ 2p^6\ 3s^2$. (b) 2.

3.4 (a) $2+2+6+2+4=16$. (b) Inner-shell electrons.

Question 1

1. A student performs a calorimetry experiment with KCl.

Part A

Consider the K^+ ion in KCl.

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

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

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

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

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

Part B

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

Part C

Use the data in the table to do the following.

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

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

Part D

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

Part E

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

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

Part F

RbCl has a K_{sp} of 57 at 20°C.

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

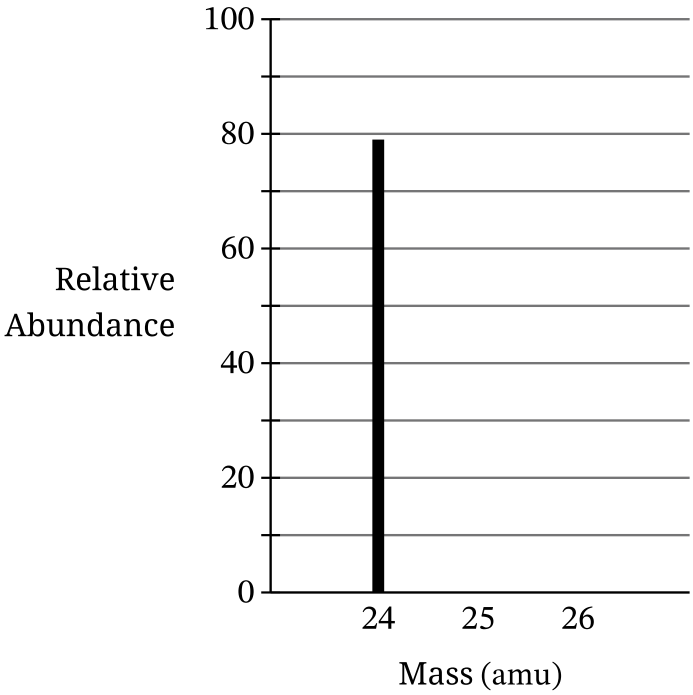
ii. **Calculate** the molar solubility of RbCl in a saturated solution at 20°C. Show the work that leads to your answer.

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

AP Chemistry: **2025**

1. Answer the following questions about magnesium.

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

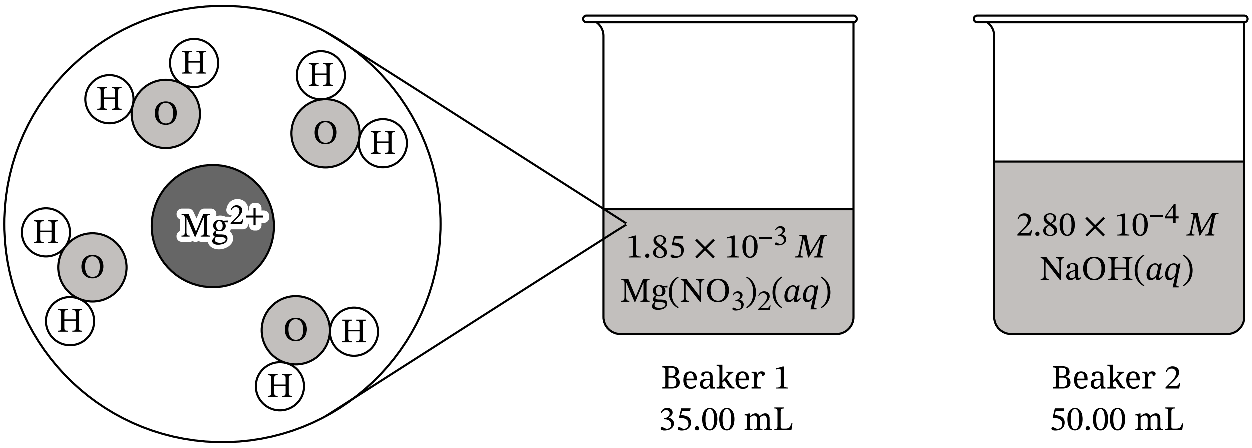


The percent abundance of magnesium-24 is 79%. The percent abundances of the other two natural isotopes of magnesium, magnesium-25 and magnesium-26, are approximately equal.

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 magnesiu--- --.

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.



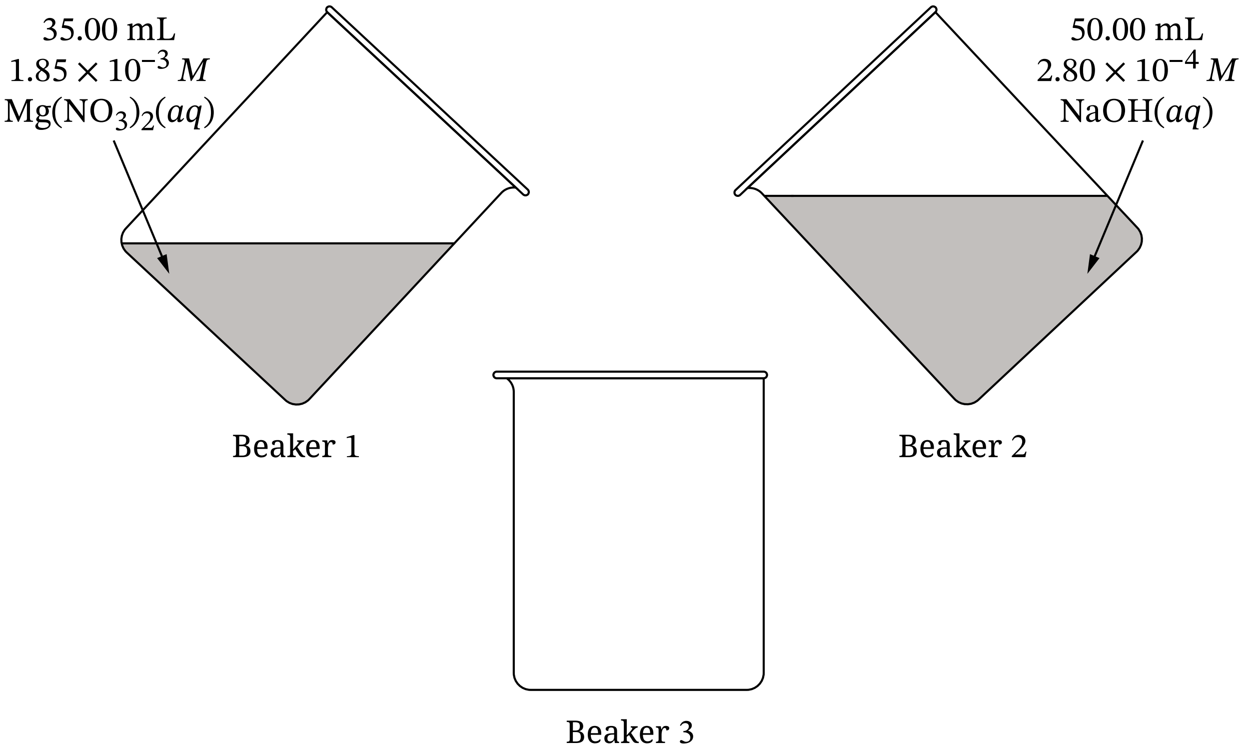
B. The particle diagram shown represents a magnesium ion, Mg^{2+}, in beaker 1. A sodium ion, Na^{+}, in beaker 2 has a weaker attraction to water than the Mg^{2+} does. Explain this phenomenon using Coulomb's law and each of the following.

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} $M\,\mathrm{Mg(NO_3)_2}(aq)$ with 50.00 mL of 2.80×10^{-4} $M\,\mathrm{NaOH}(aq)$, as shown in the diagram. Calculate $[\mathrm{Mg^{2+}}]$ 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.

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

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, $[\mathrm{OH^-}] = 1.65\times10^{-4}$ 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 $\mathrm{HNO_3}(aq)$ to decrease the pH of a saturated solution containing undissolved $\mathrm{Mg(OH)_2}(s)$. Does the amount of undissolved $\mathrm{Mg(OH)_2}(s)$ increase, decrease, or remain the same as the $\mathrm{HNO_3}(aq)$ is added? Justify your answer.

CHEMISTRY

SECTION II

Time—1 hour and 45 minutes

7 Questions

irections: Questions 1–3 are long free-response questions that require about 23 minutes each to answer and are orth 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 nvolved in arriving at your answers. You must show your work to receive credit for your answer. Pay attention to ignificant figures.

. Answer the following questions related to manganese compounds.

(a) Manganese has several common oxidation states.

(i) Write the complete electron configuration for an Mn atom in the ground state.

(ii) When manganese forms cations, electrons are lost from which subshell first? Identify both the number and letter associated with the subshell.

A student performs an experiment to produce a manganese salt of unknown composition, $Mn_xCl_y(aq)$, and determine its empirical formula. The student places a sample of $Mn(s)$ in a beaker containing excess $HCl(aq)$, as represented by the following equation.

$$x\ Mn(s) + y\ HCl(aq) \rightarrow Mn_xCl_y(aq) + \frac{y}{2} H_2(g)$$

GO ON TO THE NEXT PAGE.

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

The student heats the resulting mixture until only $Mn_xCl_y(s)$ remains in the beaker. The data are given in the following table.

Mass of empty beaker	60.169 g
Mass of beaker and $Mn(s)$	61.262 g
Mass of beaker and Mn_xCl_y after heating to constant mass	62.673 g

(b) Calculate the mass of Cl in the sample of $Mn_xCl_y(s)$ remaining in the beaker.

(c) Calculate the number of moles of Cl in the sample of $Mn_xCl_y(s)$ remaining in the beaker.

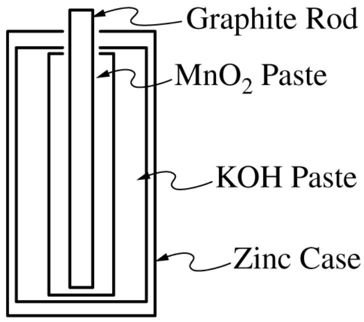
(d) The student determines that 0.0199 mol of Mn was used in the experiment. Use the data to determine the empirical formula of the $Mn_xCl_y(s)$.

(e) The student repeats the experiment using the same amounts of Mn and HCl and notices that some of the Mn_xCl_y splatters out of the beaker as it is heated to dryness. Will the number of moles of Cl calculated for this trial be greater than, less than, or equal to the number calculated in part (c) ? Justify your answer.

GO ON TO THE NEXT PAGE.

Continue your response to QUESTION 1 on this page.

(f) Another compound of manganese, MnO_2, is used in alkaline batteries, represented by the following diagram. Some half-reactions are given in the table.



Reduction Half-Reaction	$E°$ (V)
$Zn^{2+}(aq) + 2\,e^- \rightarrow Zn(s)$	−0.76
$ZnO(s) + H_2O(l) + 2\,e^- \rightarrow Zn(s) + 2\,OH^-(aq)$	−1.28
$2\,MnO_2(s) + H_2O(l) + 2\,e^- \rightarrow Mn_2O_3(s) + 2\,OH^-(aq)$	0.15

(i) Based on the half-reactions given in the table, write the balanced net ionic equation for the reaction that has the greatest thermodynamic favorability.

(ii) Calculate the value of E°_{cell} for the overall reaction.

(iii) Calculate the value of $\Delta G°$ in kJ/mol_{rxn}.

(iv) A student claims that the total mass of an alkaline battery decreases as the battery operates because the anode loses mass. Do you agree with the student's claim? Justify your answer.

GO ON TO THE NEXT PAGE.

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

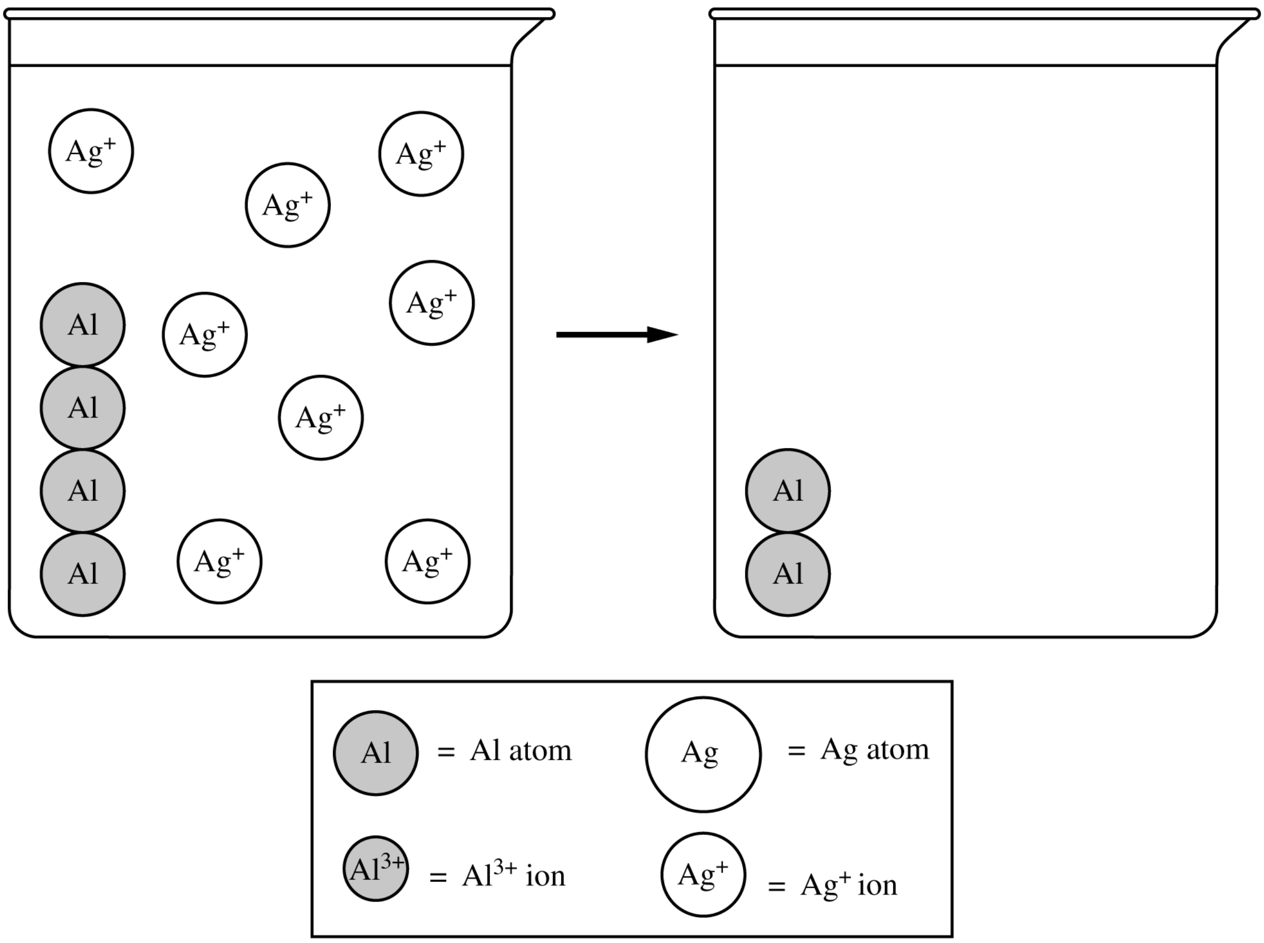
Step	Step Description
1.	Use weighing paper to measure the determined mass of solid $AgNO_3$ on a balance.
2.	

GO ON TO THE NEXT 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

GO ON TO THE NEXT PAGE.

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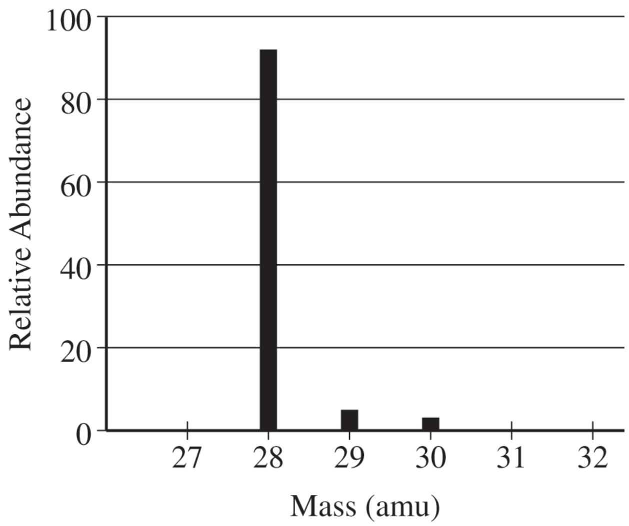
2. Answer the following questions about the element Si and some of its compounds.

(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.

GO ON TO THE NEXT PAGE.

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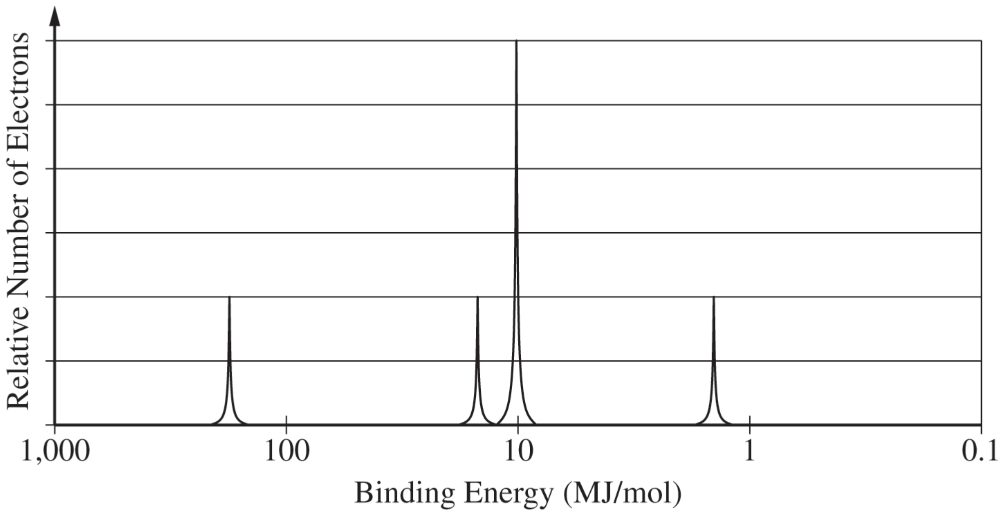
(g) A partial photoelectron spectrum of pure Si is shown below. On the spectrum, draw the missing peak that corresponds to the electrons in the $3p$ sublevel.

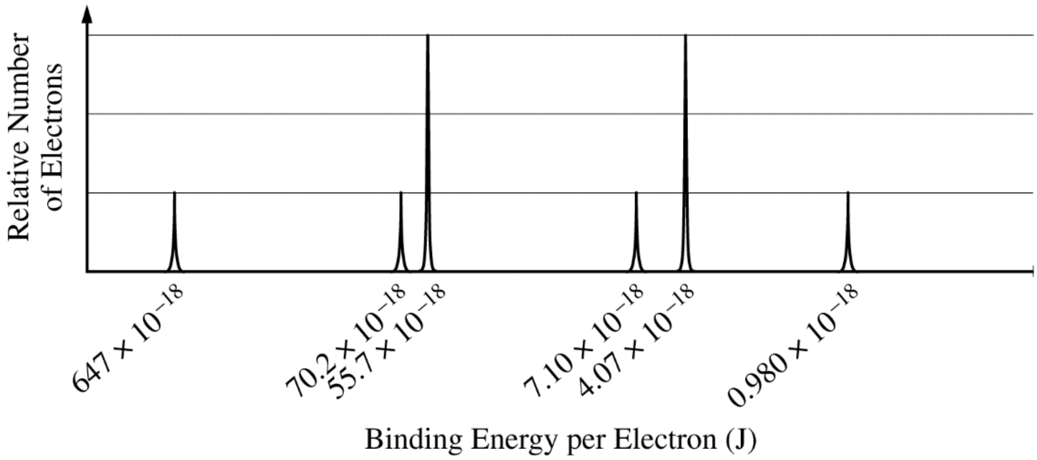


(h) Using principles of atomic structure, explain why the first ionization energy of Ge is lower than that of Si.

(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.

GO ON TO THE NEXT PAGE.

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.

3. Answer the following questions relating to Fe and its ions, Fe^{2+} and Fe^{3+}.

(a) Write the ground-state electron configuration of the Fe^{2+} ion.

Ion	Ionic Radius (pm)
Fe^{2+}	92
Fe^{3+}	79

(b) The radii of the ions are given in the table above. Using principles of atomic structure, explain why the radius of the Fe^{2+} ion is larger than the radius of the Fe^{3+} ion.

(c) Fe^{3+} ions interact more strongly with water molecules in aqueous solution than Fe^{2+} ions do. Give one reason for this stronger interaction, and justify your answer using Coulomb's law.

A student obtains a solution that contains an unknown concentration of $Fe^{2+}(aq)$. To determine the concentration of $Fe^{2+}(aq)$ in the solution, the student titrates a sample of the solution with $MnO_4^-(aq)$, which converts $Fe^{2+}(aq)$ to $Fe^{3+}(aq)$, as represented by the following equation.

$$5\,Fe^{2+}(aq) + MnO_4^-(aq) + 8\,H^+(aq) \rightarrow 5\,Fe^{3+}(aq) + Mn^{2+}(aq) + 4\,H_2O(l)$$

(d) Write the balanced equation for the half-reaction for the oxidation of $Fe^{2+}(aq)$ to $Fe^{3+}(aq)$.

(e) The student titrates a 10.0 mL sample of the $Fe^{2+}(aq)$ solution. Calculate the value of $[Fe^{2+}]$ in the solution if it takes 17.48 mL of added 0.0350 M $KMnO_4(aq)$ to reach the equivalence point of the titration.

To deliver the 10.0 mL sample of the $Fe^{2+}(aq)$ solution in part (e), the student has the choice of using one of the pieces of glassware listed below.

- 25 mL buret
- 25 mL graduated cylinder
- 25 mL beaker
- 25 mL volumetric flask

(f) Explain why the 25 mL volumetric flask would be a poor choice to use for delivering the required volume of the $Fe^{2+}(aq)$ solution.

In a separate experiment, the student is given a sample of powdered $Fe(s)$ that contains an inert impurity. The student uses a procedure to oxidize the $Fe(s)$ in the sample to $Fe_2O_3(s)$. The student collects the following data during the experiment.

Mass of $Fe(s)$ with inert impurity	6.724 g
Mass of $Fe_2O_3(s)$ produced	7.531 g

(g) Calculate the number of moles of Fe in the $Fe_2O_3(s)$ produced.

(h) Calculate the percent by mass of Fe in the original sample of powdered $Fe(s)$ with the inert impurity.

(i) If the oxidation of the $Fe(s)$ in the original sample was incomplete so that some of the 7.531 g of product was $FeO(s)$ instead of $Fe_2O_3(s)$, would the calculated mass percent of $Fe(s)$ in the original sample be higher, lower, or the same as the actual mass percent of $Fe(s)$? Justify your answer.

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.

1. A student investigates the enthalpy of solution, ΔH_{soln}, for two alkali metal halides, $LiCl$ and $NaCl$. In addition to the salts, the student has access to a calorimeter, a balance with a precision of ±0.1 g, and a thermometer with a precision of ±0.1°C.

(a) To measure ΔH_{soln} for $LiCl$, the student adds 100.0 g of water initially at 15.0°C to a calorimeter and adds 10.0 g of $LiCl(s)$, stirring to dissolve. After the $LiCl$ dissolves completely, the maximum temperature reached by the solution is 35.6°C.

(i) Calculate the magnitude of the heat absorbed by the solution during the dissolution process, assuming that the specific heat capacity of the solution is 4.18 J/(g·°C). Include units with your answer.

(ii) Determine the value of ΔH_{soln} for $LiCl$ in kJ/mol_{rxn}.

To explain why ΔH_{soln} for $NaCl$ is different than that for $LiCl$, the student investigates factors that affect ΔH_{soln} and finds that ionic radius and lattice enthalpy (which can be defined as the ΔH associated with the separation of a solid crystal into gaseous ions) contribute to the process. The student consults references and collects the data shown in the table below.

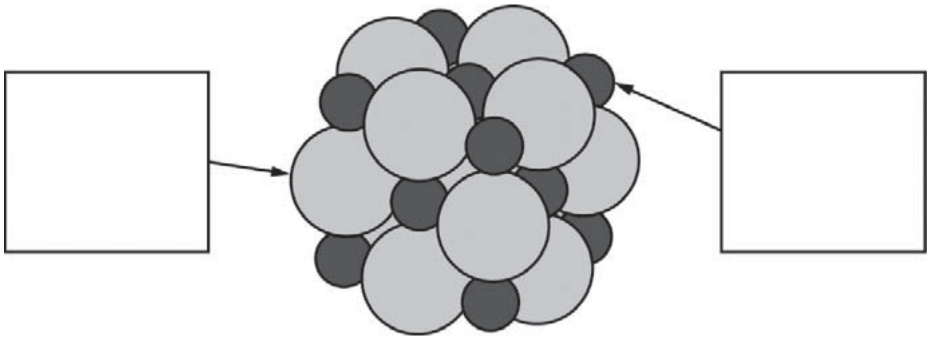
Ion	Ionic Radius (pm)
Li^+	76
Na^+	102

(b) Write the complete electron configuration for the Na^+ ion in the ground state.

(c) Using principles of atomic structure, explain why the Na^+ ion is larger than the Li^+ ion.

(d) Which salt, $LiCl$ or $NaCl$, has the greater lattice enthalpy? Justify your answer.

(e) Below is a representation of a portion of a crystal of $LiCl$. Identify the ions in the representation by writing the appropriate formulas (Li^+ or Cl^-) in the boxes below.



(f) The lattice enthalpy of $LiCl$ is positive, indicating that it takes energy to break the ions apart in $LiCl$. However, the dissolution of $LiCl$ in water is an exothermic process. Identify all particle-particle interactions that contribute significantly to the dissolution process being exothermic. For each interaction, include the particles that interact and the specific type of intermolecular force between those particles.

CHEMISTRY

Section II

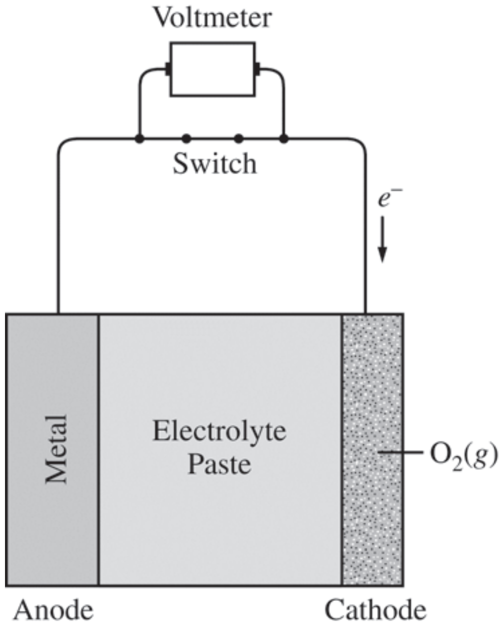
7 Questions

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.



1. Metal-air cells are a relatively new type of portable energy source consisting of a metal anode, an alkaline electrolyte paste that contains water, and a porous cathode membrane that lets in oxygen from the air. A schematic of the cell is shown above. Reduction potentials for the cathode and three possible metal anodes are given in the table below.

Half Reaction	E at pH 11 and 298 K (V)
$O_2(g) + 2\,H_2O(l) + 4\,e^- \rightarrow 4\,OH^-(aq)$	+0.34
$ZnO(s) + H_2O(l) + 2\,e^- \rightarrow Zn(s) + 2\,OH^-(aq)$	−1.31
$Na_2O(s) + H_2O(l) + 2\,e^- \rightarrow 2\,Na(s) + 2\,OH^-(aq)$	−1.60
$CaO(s) + H_2O(l) + 2\,e^- \rightarrow Ca(s) + 2\,OH^-(aq)$	−2.78

(a) Early forms of metal-air cells used zinc as the anode. Zinc oxide is produced as the cell operates according to the overall equation below.

$$2\ Zn(s) + O_2(g) \rightarrow 2\ ZnO(s)$$

(i) Using the data in the table above, calculate the cell potential for the zinc-air cell.

(ii) The electrolyte paste contains OH^- ions. On the diagram of the cell above, draw an arrow to indicate the direction of migration of OH^- ions through the electrolyte as the cell operates.

(b) A fresh zinc-air cell is weighed on an analytical balance before being placed in a hearing aid for use.

(i) As the cell operates, does the mass of the cell increase, decrease, or remain the same?

(ii) Justify your answer to part (b)(i) in terms of the equation for the overall cell reaction.

(c) The zinc-air cell is taken to the top of a mountain where the air pressure is lower.

(i) Will the cell potential be higher, lower, or the same as the cell potential at the lower elevation?

(ii) Justify your answer to part (c)(i) based on the equation for the overall cell reaction and the information above.

(d) Metal-air cells need to be lightweight for many applications. In order to transfer more electrons with a smaller mass, Na and Ca are investigated as potential anodes. A 1.0 g anode of which of these metals would transfer more electrons, assuming that the anode is totally consumed during the lifetime of a cell? Justify your answer with calculations.

(e) The only common oxide of zinc has the formula ZnO.

(i) Write the electron configuration for a Zn atom in the ground state.

(ii) From which sublevel are electrons removed when a Zn atom in the ground state is oxidized?

AP CHEMISTRY • EXERCISE SHEET

1.6 Photoelectron Spectroscopy

Name: ______________ Class: __________ Date: ____________ **Total: 12 marks**

KEY WORDS binding energy 结合能 • photoelectron spectroscopy 光电子能谱 • electron configuration 电子排布 • nucleus 原子核

Objective

Build the skills to answer exam questions on **photoelectron spectroscopy (PES)**.

You must be able to:

- describe how **photoelectron spectroscopy 光电子能谱** ejects electrons and measures their **binding energy 结合能**
- interpret a PES spectrum (one peak per subshell)
- read peak position (binding energy) and peak height (number of electrons)
- match a spectrum to an electron configuration

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.

One peak per subshell

Each peak corresponds to one subshell. Its position gives the binding energy; its height is proportional to the number of electrons in that subshell.

Higher binding energy is closer in

Electrons closer to the nucleus are held more tightly, so they have a higher binding energy. The $1s$ peak is always at the highest binding energy.

Reading a ratio

Neon's PES has peaks in the ratio $2 : 2 : 6$, matching $1s^2\ 2s^2\ 2p^6$. A filled $2p$ peak is three times taller than a filled $2s$.

2 Practice

Now apply the methods above.

2.1 State what the height of a PES peak is proportional to. [1]

2.2 Which electrons have the highest binding energy — those closest to or farthest from the nucleus? [1]

2.3 Neon's PES shows peaks in the height ratio 2 : 2 : 6. Identify the subshells. [2]

2.4 How many times taller is a filled $2p$ peak than a filled $2s$ peak? [1]

3 Exam-style questions

3.1 In PES, a higher binding energy means the electron is [1]

- **A** farther from the nucleus
- **B** closer to the nucleus
- **C** more numerous
- **D** at a lower energy shell that is easier to remove

3.2 A PES spectrum with three peaks of relative height 2 : 2 : 6 belongs to an atom with configuration [1]

- **A** $1s^2\ 2s^2\ 2p^6$
- **B** $1s^2\ 2s^2\ 2p^4$
- **C** $1s^2\ 2p^6\ 3s^2$
- **D** $1s^6\ 2s^2\ 2p^2$

3.3 Sodium's PES has peaks in the ratio 2 : 2 : 6 : 1.

(a) Write the electron configuration this represents. [2]

(b) State which peak is at the highest binding energy. [1]

3.4 A PES spectrum has a small peak and a larger peak, with the small peak at a higher binding energy.

(a) State which peak is closer to the nucleus. [1]

(b) Explain what a taller peak tells you. [1]

Solutions

2.1 The number of electrons in that subshell.

2.2 Those closest to the nucleus.

2.3 $1s$, $2s$, and $2p$.

2.4 Three times ($2p$ holds 6, $2s$ holds 2).

3.1 **B** — a higher binding energy means closer to the nucleus.

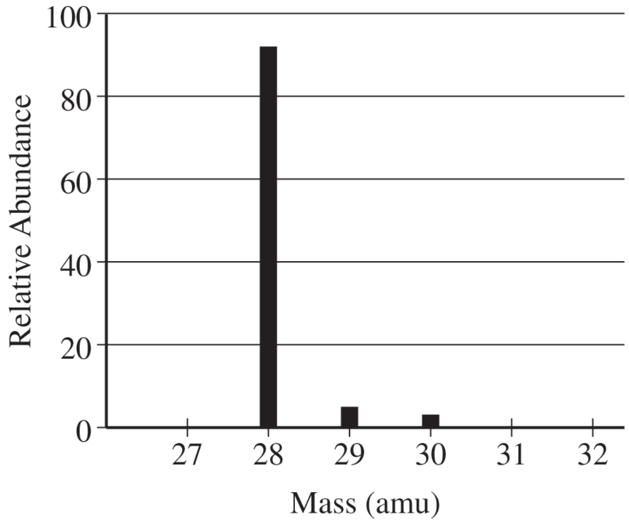
3.2 **A** — $2 : 2 : 6$ matches $1s^2\ 2s^2\ 2p^6$.

3.3 (a) $1s^2\ 2s^2\ 2p^6\ 3s^1$. (b) The $1s$ peak.

3.4 (a) The small peak (higher binding energy). (b) It has more electrons in that subshell.

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.

GO ON TO THE NEXT PAGE.

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

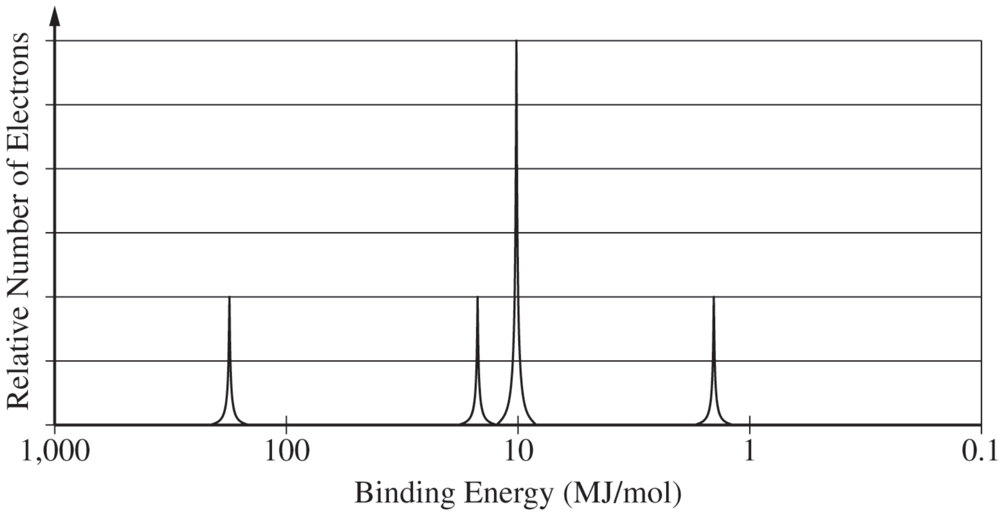
(d) Explain why the absolute molar entropy of $Si(s)$ is less than that of $H_2(g)$.

(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.

GO ON TO THE NEXT PAGE.

(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.

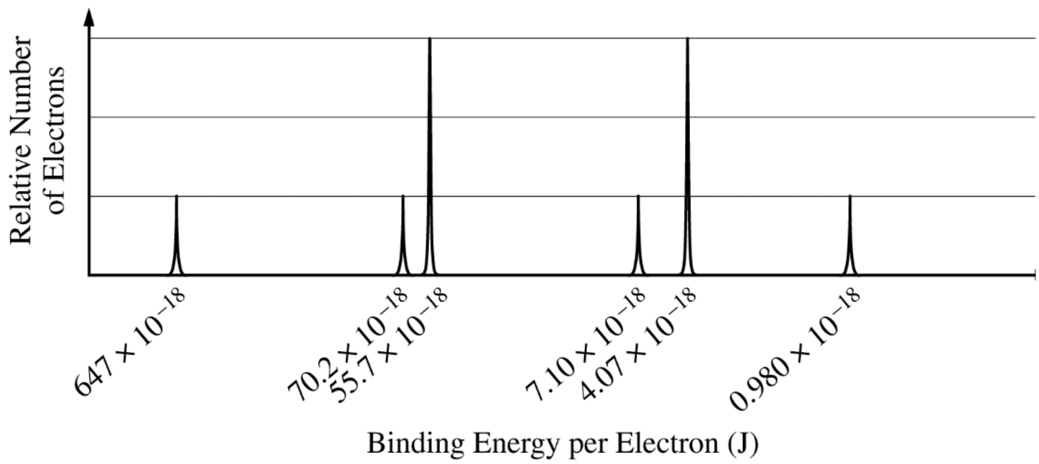


(h) Using principles of atomic structure, explain why the first ionization energy of Ge is lower than that of Si.

(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.

GO ON TO THE NEXT PAGE.

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

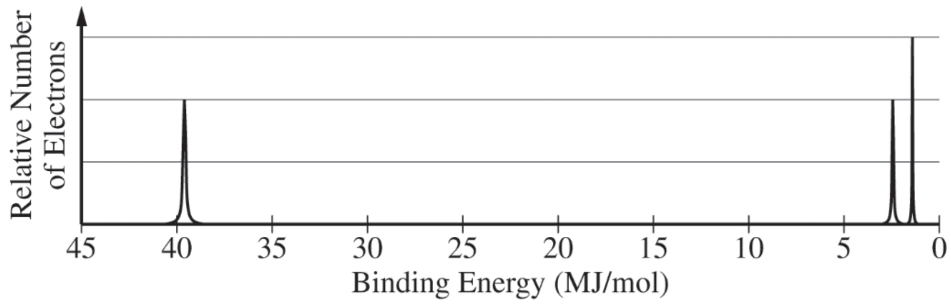


(a) Based on the spectrum,

(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.



7. The complete photoelectron spectrum of an element is represented above.

   (a) Identify the element.

   A radioactive isotope of the element decays with a half-life of 10. minutes.

   (b) Calculate the value of the rate constant, k, for the radioactive decay. Include units with your answer.

   (c) If 64 atoms of the radioactive isotope are originally present in a sample, what is the expected amount of time that will pass until only one atom of the isotope remains? Show how you arrived at your answer.

STOP

END OF EXAM

AP CHEMISTRY • EXERCISE SHEET

1.7 Periodic Trends

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

KEY WORDS atomic radius 原子半径 • ionization energy 电离能 • electronegativity 电负性

Objective

Build the skills to answer exam questions on **periodic trends**.

You must be able to:

- describe the trend in **atomic radius 原子半径** (shrinks across a period, grows down a group)
- describe the trend in **ionization energy 电离能** (rises across, falls down)
- describe the trend in **electronegativity 电负性** (highest at the top right)
- explain the trends using nuclear charge and shielding

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.

■ Atomic radius

Across a period, more protons pull the same shell in, so the radius shrinks. Down a group, each new shell sits farther out, so the radius grows.

■ Ionization energy

The energy to remove an electron rises across a period (stronger pull) and falls down a group (electrons farther out and shielded) – the opposite trend to radius.

■ Electronegativity

An atom's pull on shared electrons is highest at the top right (fluorine, ignoring noble gases) and lowest at the bottom left.

2 Practice

Now apply the methods above.

2.1 State how atomic radius changes across a period from left to right. [1]

2.2 Which element is more electronegative, fluorine or sodium? [1]

2.3 State how ionization energy changes down a group. [1]

2.4 Order Na, Si, and Cl (period 3) from largest to smallest atomic radius. [2]

3 Exam-style questions

3.1 Across a period from left to right, the atomic radius [1]

- **A** increases
- **B** decreases
- **C** stays the same
- **D** doubles

3.2 Which element has the highest electronegativity? [1]

- **A** fluorine
- **B** sodium
- **C** helium
- **D** caesium

3.3 Compare sodium (Na) and chlorine (Cl), both in period 3.

(a) State which has the larger atomic radius. [1]

(b) Explain your answer in terms of nuclear charge. [2]

3.4 Consider ionization energy down group 1 (Li, Na, K).

(a) State the trend. [1]

(b) Explain it in terms of shielding and distance. [2]

Solutions

2.1 It decreases.

2.2 Fluorine.

2.3 It decreases.

2.4 Na > Si > Cl.

3.1 B — the atomic radius decreases across a period.

3.2 A — fluorine is the most electronegative.

3.3 (a) Sodium. (b) Chlorine has more protons pulling the same shell in more tightly, so it is smaller.

3.4 (a) Ionization energy decreases down the group. (b) Outer electrons are farther out and shielded by inner shells, so they are easier to remove.

Question 1

1. A student performs a calorimetry experiment with KCl.

Part A

Consider the K^+ ion in KCl.

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

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

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

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

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

Part B

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

Part C

Use the data in the table to do the following.

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

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

Part D

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

Part E

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

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

Part F

RbCl has a K_{sp} of 57 at 20°C.

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

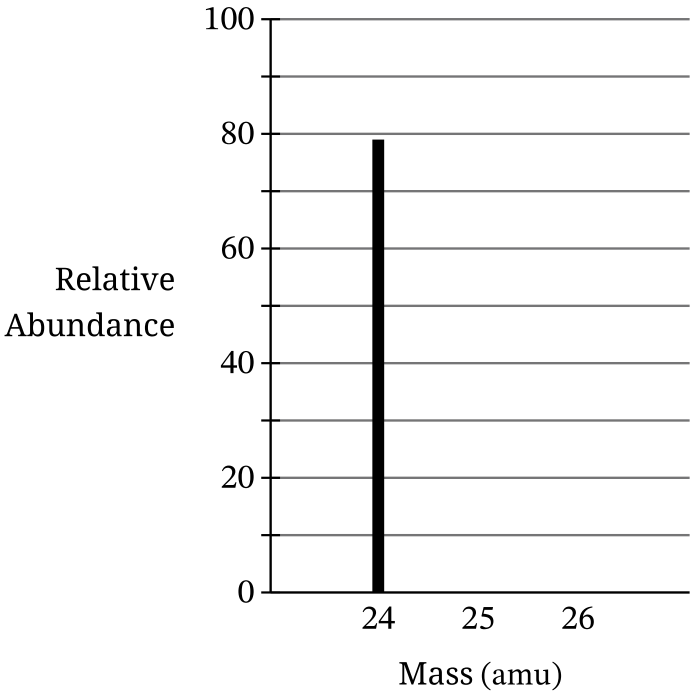
ii. **Calculate** the molar solubility of RbCl in a saturated solution at 20°C. Show the work that leads to your answer.

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

AP Chemistry: **2025**

1. Answer the following questions about magnesium.

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

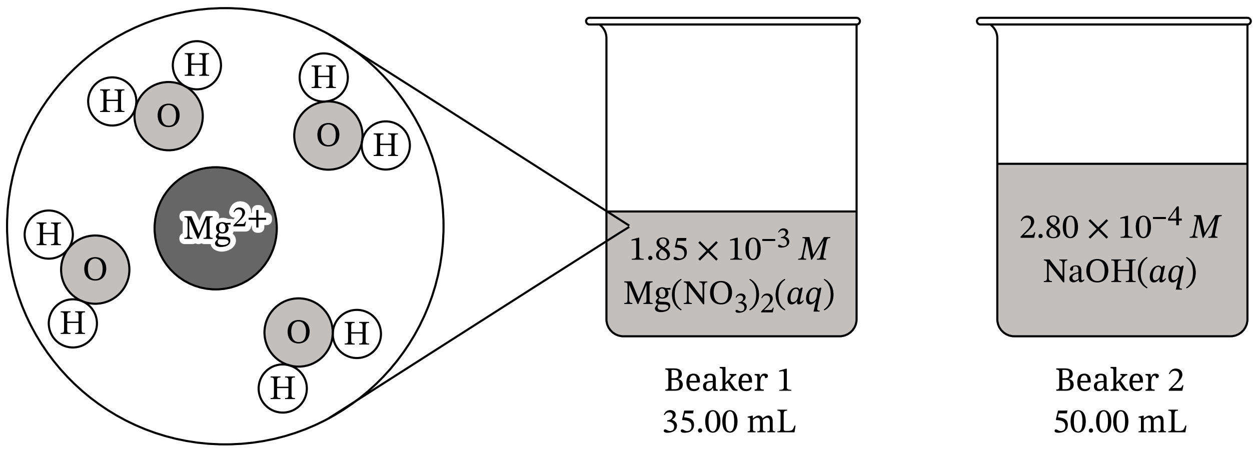


The percent abundance of magnesium-24 is 79%. The percent abundances of the other two natural isotopes of magnesium, magnesium-25 and magnesium-26, are approximately equal.

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.



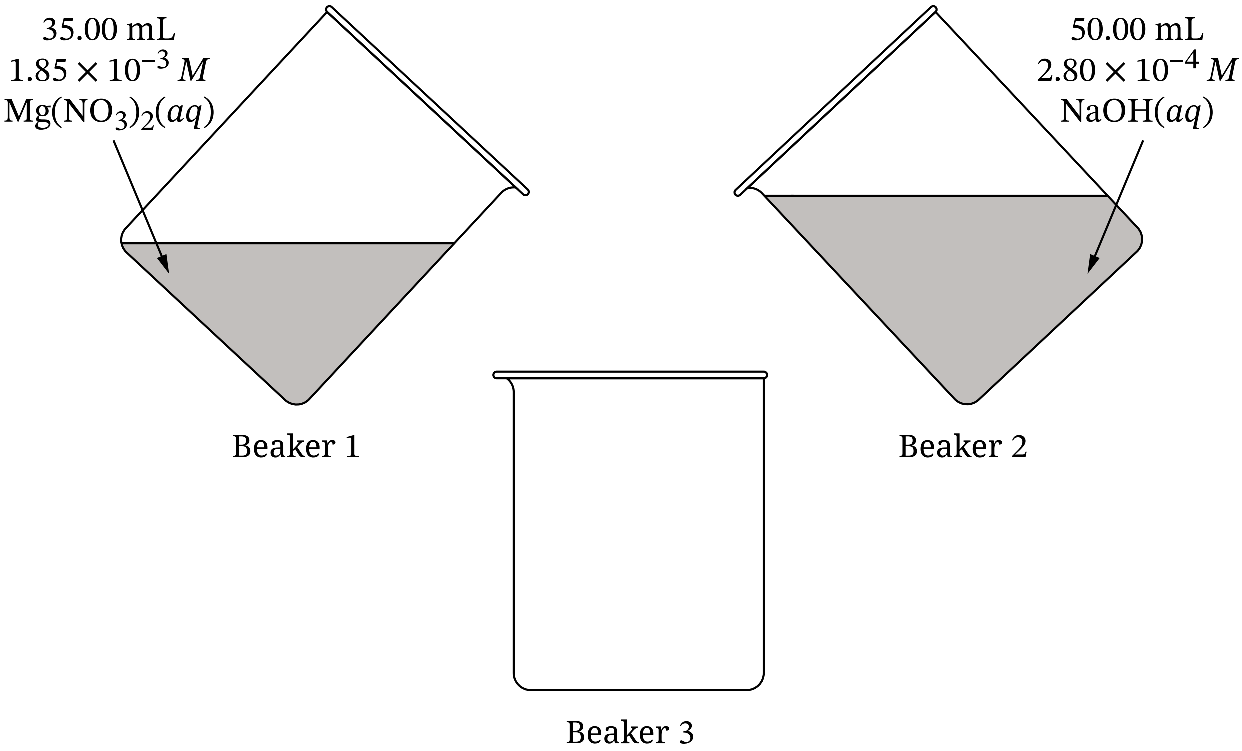
B. The particle diagram shown represents a magnesium ion, Mg^{2+}, in beaker 1. A sodium ion, Na^{+}, in beaker 2 has a weaker attraction to water than the Mg^{2+} does. Explain this phenomenon using Coulomb's law and each of the following.

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 $\left[Mg^{2+}\right]$ 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, $\left[OH^-\right] = 1.65\times10^{-4}\ M$. 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.

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

3. Sterling silver is an alloy that is commonly used to make jewelry and consists of 92.5% silver and 7.5% other metals, such as copper, by mass. Over time, the alloy can form a tarnish of $Ag_2S(s)$ when it reacts with hydrogen sulfide, as represented by the following equation.

$$2\ Ag(s) + H_2S(g) \rightarrow Ag_2S(s) + H_2(g)$$

(a) What are the oxidation numbers of silver in $Ag(s)$ and $Ag_2S(s)$?

$Ag(s)$__________ $Ag_2S(s)$__________

(b) The following table contains the atomic radii for silver and copper.

Element	Silver (Ag)	Copper (Cu)
Atomic radius (pm)	165	145

(i) Explain why sterling silver is better classified as a substitutional alloy than as an interstitial alloy.

(ii) Using principles of atomic structure and Coulomb's law, explain why silver has a larger atomic radius than copper does.

GO ON TO THE NEXT PAGE.

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

The Ag_2S tarnish on sterling silver can be removed until only sterling silver remains. A student weighs a tarnished sterling silver sample both before and after removing the $Ag_2S(s)$ (molar mass 247.80 g / mol) and records the data in the following table.

	Before Tarnish Removal	After Tarnish Removal
Mass	409.21 g	398.94 g

(c) Assuming that only $Ag_2S(s)$ is removed, calculate the number of moles of silver atoms removed.

Rhodium plating is a process used to protect sterling silver from tarnishing. This involves electroplating (depositing) solid rhodium, $Rh(s)$, onto the surface of the metal from an acidified solution of $Rh_2(SO_4)_3(aq)$. Oxygen gas is produced during this process.

(d) A table of half-reactions related to the overall reaction is provided.

Half-Reaction	$E°$ (V)
$Rh^{3+}(aq) + 3\,e^- \rightarrow Rh(s)$	+0.80
$O_2(g) + 4\,H^+(aq) + 4\,e^- \rightarrow 2\,H_2O(l)$	+1.23

(i) Write the balanced net ionic equation for plating $Rh(s)$ from the acidified $Rh_2(SO_4)_3(aq)$ solution.

(ii) Calculate the value of E°_{cell} for the reaction in part (d)(i).

GO ON TO THE NEXT PAGE.

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

(iii) Based on your answer to part (d)(ii), explain why this process requires the use of an external power source.

(e) Calculate the length of time, in seconds, required to plate 2.8 g of $Rh(s)$ onto a piece of sterling silver if 2.0 C / s of current is applied.

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CHEMISTRY

SECTION II

Time—1 hour and 45 minutes

7 Questions

irections: Questions 1–3 are long free-response questions that require about 23 minutes each to answer and are orth 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 nvolved in arriving at your answers. You must show your work to receive credit for your answer. Pay attention to ignificant figures.

. Answer the following questions related to manganese compounds.

(a) Manganese has several common oxidation states.

(i) Write the complete electron configuration for an Mn atom in the ground state.

(ii) When manganese forms cations, electrons are lost from which subshell first? Identify both the number and letter associated with the subshell.

A student performs an experiment to produce a manganese salt of unknown composition, $Mn_xCl_y(aq)$, and determine its empirical formula. The student places a sample of $Mn(s)$ in a beaker containing excess $HCl(aq)$, as represented by the following equation.

$$x\ Mn(s) + y\ HCl(aq) \rightarrow Mn_xCl_y(aq) + \frac{y}{2}\ H_2(g)$$

GO ON TO THE NEXT PAGE.

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

The student heats the resulting mixture until only $Mn_xCl_y(s)$ remains in the beaker. The data are given in the following table.

Mass of empty beaker	60.169 g
Mass of beaker and $Mn(s)$	61.262 g
Mass of beaker and Mn_xCl_y after heating to constant mass	62.673 g

(b) Calculate the mass of Cl in the sample of $Mn_xCl_y(s)$ remaining in the beaker.

(c) Calculate the number of moles of Cl in the sample of $Mn_xCl_y(s)$ remaining in the beaker.

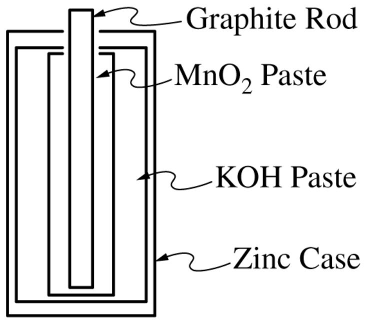
(d) The student determines that 0.0199 mol of Mn was used in the experiment. Use the data to determine the empirical formula of the $Mn_xCl_y(s)$.

(e) The student repeats the experiment using the same amounts of Mn and HCl and notices that some of the Mn_xCl_y splatters out of the beaker as it is heated to dryness. Will the number of moles of Cl calculated for this trial be greater than, less than, or equal to the number calculated in part (c) ? Justify your answer.

GO ON TO THE NEXT PAGE.

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

(f) Another compound of manganese, MnO_2, is used in alkaline batteries, represented by the following diagram. Some half-reactions are given in the table.



Reduction Half-Reaction	$E°$ (V)
$Zn^{2+}(aq) + 2\,e^- \rightarrow Zn(s)$	–0.76
$ZnO(s) + H_2O(l) + 2\,e^- \rightarrow Zn(s) + 2\,OH^-(aq)$	–1.28
$2\,MnO_2(s) + H_2O(l) + 2\,e^- \rightarrow Mn_2O_3(s) + 2\,OH^-(aq)$	0.15

(i) Based on the half-reactions given in the table, write the balanced net ionic equation for the reaction that has the greatest thermodynamic favorability.

(ii) Calculate the value of E°_{cell} for the overall reaction.

(iii) Calculate the value of $\Delta G°$ in kJ/mol_{rxn}.

(iv) A student claims that the total mass of an alkaline battery decreases as the battery operates because the anode loses mass. Do you agree with the student's claim? Justify your answer.

GO ON TO THE NEXT PAGE.

. 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 $HF(l)$.

GO ON TO THE NEXT PAGE.

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.

GO ON TO THE NEXT PAGE.

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

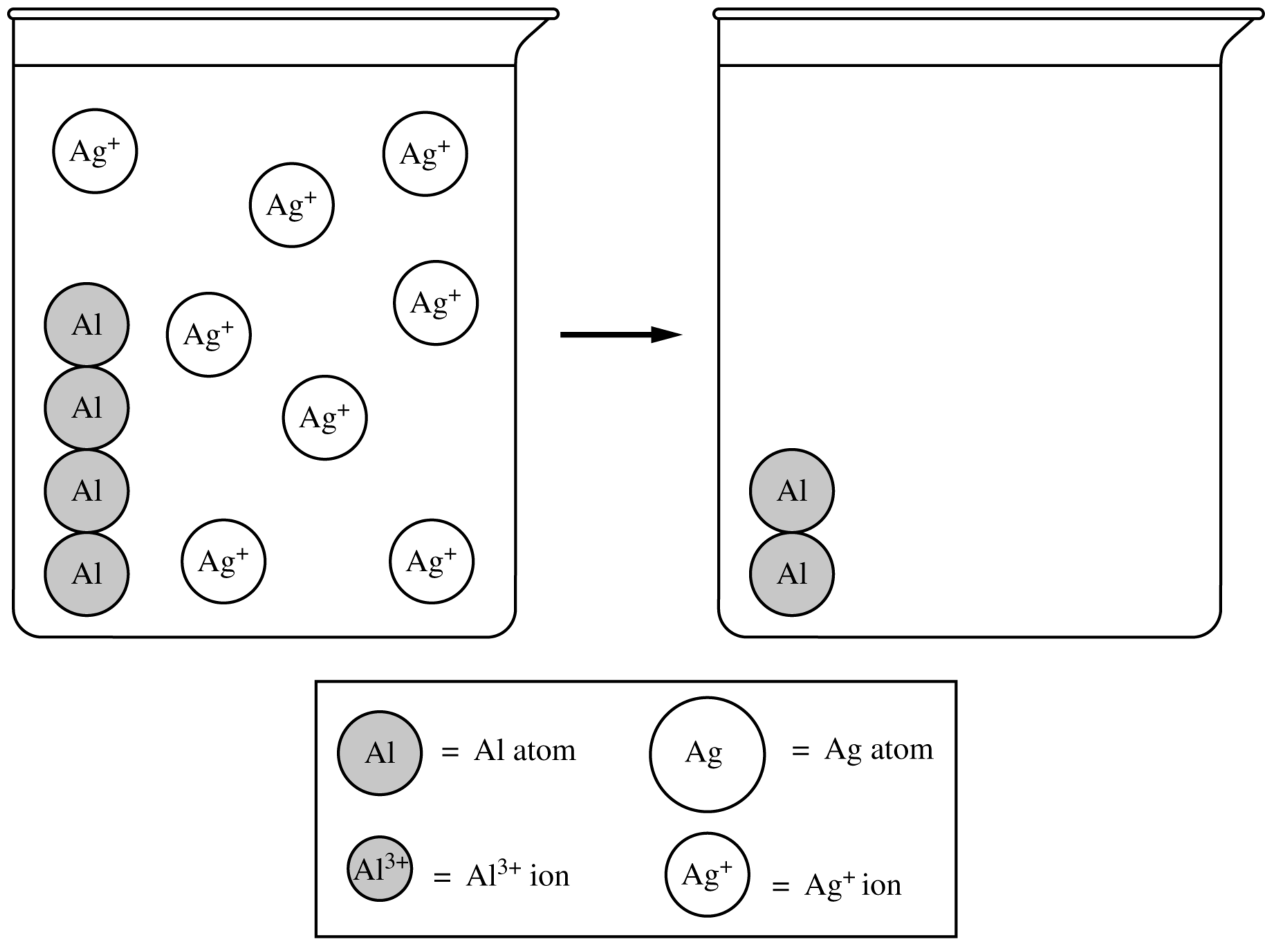
Step	Step Description
1.	Use weighing paper to measure the determined mass of solid $AgNO_3$ on a balance.
2.	

GO ON TO THE NEXT 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

GO ON TO THE NEXT PAGE.

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

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

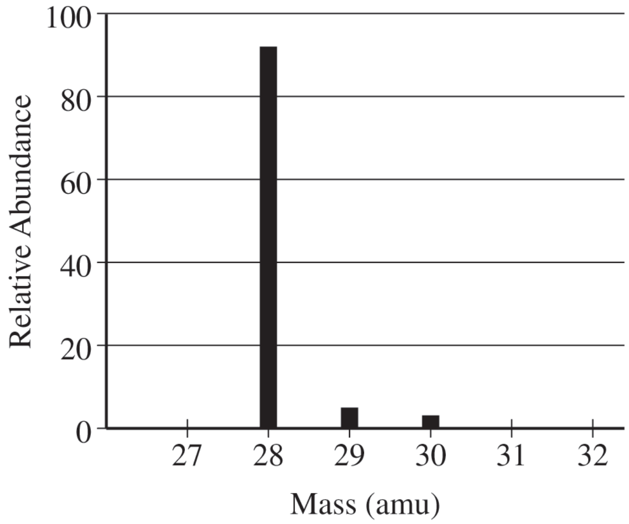
(f) Based on the value of $E°$, would the standard free energy change of the reaction under standard conditions, $\Delta G°$, be positive, negative, or zero? Justify your answer.

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

GO ON TO THE NEXT PAGE.

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.

GO ON TO THE NEXT PAGE.

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

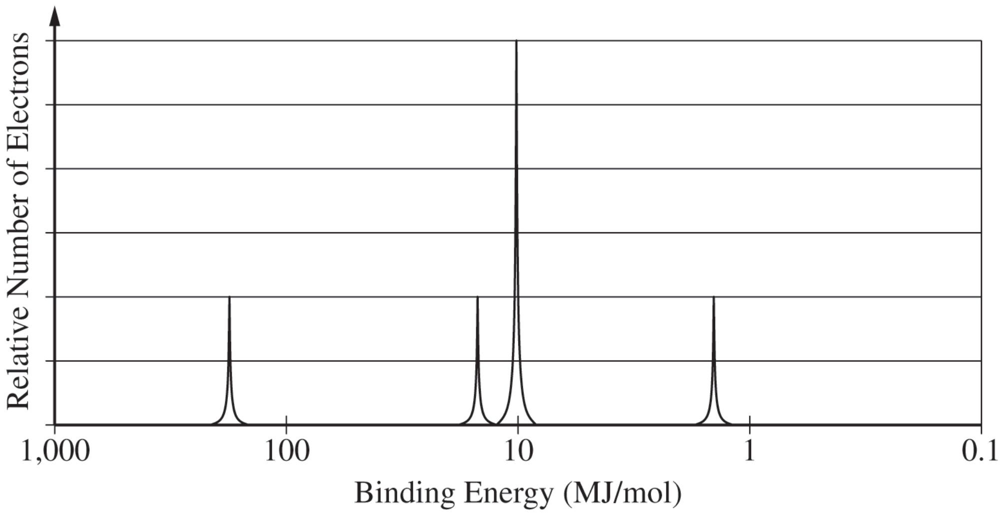
(d) Explain why the absolute molar entropy of $Si(s)$ is less than that of $H_2(g)$.

(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.

GO ON TO THE NEXT PAGE.

(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.

GO ON TO THE NEXT PAGE.

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	?

3. Answer the following questions relating to Fe and its ions, Fe^{2+} and Fe^{3+}.

(a) Write the ground-state electron configuration of the Fe^{2+} ion.

Ion	Ionic Radius (pm)
Fe^{2+}	92
Fe^{3+}	79

(b) The radii of the ions are given in the table above. Using principles of atomic structure, explain why the radius of the Fe^{2+} ion is larger than the radius of the Fe^{3+} ion.

(c) Fe^{3+} ions interact more strongly with water molecules in aqueous solution than Fe^{2+} ions do. Give one reason for this stronger interaction, and justify your answer using Coulomb's law.

A student obtains a solution that contains an unknown concentration of $Fe^{2+}(aq)$. To determine the concentration of $Fe^{2+}(aq)$ in the solution, the student titrates a sample of the solution with $MnO_4^-(aq)$, which converts $Fe^{2+}(aq)$ to $Fe^{3+}(aq)$, as represented by the following equation.

$$5\ Fe^{2+}(aq) + MnO_4^-(aq) + 8\ H^+(aq) \rightarrow 5\ Fe^{3+}(aq) + Mn^{2+}(aq) + 4\ H_2O(l)$$

(d) Write the balanced equation for the half-reaction for the oxidation of $Fe^{2+}(aq)$ to $Fe^{3+}(aq)$.

(e) The student titrates a 10.0 mL sample of the $Fe^{2+}(aq)$ solution. Calculate the value of $[Fe^{2+}]$ in the solution if it takes 17.48 mL of added 0.0350 M $KMnO_4(aq)$ to reach the equivalence point of the titration.

To deliver the 10.0 mL sample of the $Fe^{2+}(aq)$ solution in part (e), the student has the choice of using one of the pieces of glassware listed below.

- 25 mL buret
- 25 mL graduated cylinder
- 25 mL beaker
- 25 mL volumetric flask

(f) Explain why the 25 mL volumetric flask would be a poor choice to use for delivering the required volume of the $Fe^{2+}(aq)$ solution.

In a separate experiment, the student is given a sample of powdered $Fe(s)$ that contains an inert impurity. The student uses a procedure to oxidize the $Fe(s)$ in the sample to $Fe_2O_3(s)$. The student collects the following data during the experiment.

Mass of $Fe(s)$ with inert impurity	6.724 g
Mass of $Fe_2O_3(s)$ produced	7.531 g

(g) Calculate the number of moles of Fe in the $Fe_2O_3(s)$ produced.

(h) Calculate the percent by mass of Fe in the original sample of powdered $Fe(s)$ with the inert impurity.

(i) If the oxidation of the $Fe(s)$ in the original sample was incomplete so that some of the 7.531 g of product was $FeO(s)$ instead of $Fe_2O_3(s)$, would the calculated mass percent of $Fe(s)$ in the original sample be higher, lower, or the same as the actual mass percent of $Fe(s)$? Justify your answer.

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.

1. A student investigates the enthalpy of solution, ΔH_{soln}, for two alkali metal halides, $LiCl$ and $NaCl$. In addition to the salts, the student has access to a calorimeter, a balance with a precision of ±0.1 g, and a thermometer with a precision of ±0.1°C.

   (a) To measure ΔH_{soln} for $LiCl$, the student adds 100.0 g of water initially at 15.0°C to a calorimeter and adds 10.0 g of $LiCl(s)$, stirring to dissolve. After the $LiCl$ dissolves completely, the maximum temperature reached by the solution is 35.6°C.

   (i) Calculate the magnitude of the heat absorbed by the solution during the dissolution process, assuming that the specific heat capacity of the solution is 4.18 J/(g·°C). Include units with your answer.

   (ii) Determine the value of ΔH_{soln} for $LiCl$ in kJ/mol_{rxn}.

   To explain why ΔH_{soln} for $NaCl$ is different than that for $LiCl$, the student investigates factors that affect ΔH_{soln} and finds that ionic radius and lattice enthalpy (which can be defined as the ΔH associated with the separation of a solid crystal into gaseous ions) contribute to the process. The student consults references and collects the data shown in the table below.

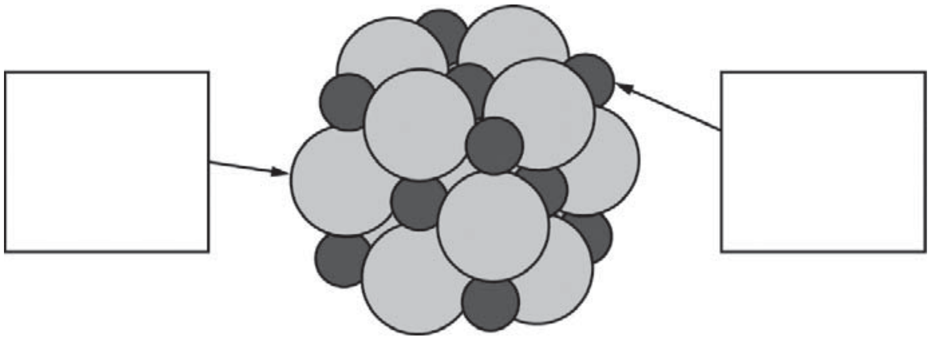
Ion	Ionic Radius (pm)
Li^+	76
Na^+	102

(b) Write the complete electron configuration for the Na^{+} ion in the ground state.

(c) Using principles of atomic structure, explain why the Na^{+} ion is larger than the Li^{+} ion.

(d) Which salt, $LiCl$ or $NaCl$, has the greater lattice enthalpy? Justify your answer.

(e) Below is a representation of a portion of a crystal of $LiCl$. Identify the ions in the representation by writing the appropriate formulas (Li^{+} or Cl^{-}) in the boxes below.



(f) The lattice enthalpy of $LiCl$ is positive, indicating that it takes energy to break the ions apart in $LiCl$. However, the dissolution of $LiCl$ in water is an exothermic process. Identify all particle-particle interactions that contribute significantly to the dissolution process being exothermic. For each interaction, include the particles that interact and the specific type of intermolecular force between those particles.

Nonmetal	C	N	O	Ne	Si	P	S	Ar
Formula of Compound	CF_4	NF_3	OF_2	No compound	SiF_4	PF_3	SF_2	No compound

5. Some binary compounds that form between fluorine and various nonmetals are listed in the table above. A student examines the data in the table and poses the following hypothesis: the number of F atoms that will bond to a nonmetal is always equal to 8 minus the number of valence electrons in the nonmetal atom.

(a) Based on the student's hypothesis, what should be the formula of the compound that forms between chlorine and fluorine?

(b) In an attempt to verify the hypothesis, the student researches the fluoride compounds of the other halogens and finds the formula ClF_3. In the box below, draw a complete Lewis electron-dot diagram for a molecule of ClF_3.

(c) Two possible geometric shapes for the ClF_3 molecule are trigonal planar and T-shaped. The student does some research and learns that the molecule has a dipole moment. Which of the two shapes is consistent with the fact that the ClF_3 molecule has a dipole moment? Justify your answer in terms of bond polarity and molecular structure.

In an attempt to resolve the existence of the ClF_3 molecule with the hypothesis stated above, the student researches the compounds that form between halogens and fluorine, and assembles the following list.

Halogen	Formula(s)
F	F_2
Cl	
Br	BrF, BrF_3, BrF_5
I	IF, IF_3, IF_5, IF_7

(d) Based on concepts of atomic structure and periodicity, propose a modification to the student's previous hypothesis to account for the compounds that form between halogens and fluorine.

1.8 Valence Electrons and Ionic Compounds

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

KEY WORDS ionic compound 离子化合物 • cations 阳离子 • anions 阴离子 • valence electrons 价电子 • nucleus 原子核

Objective

Build the skills to answer exam questions on **valence electrons and ionic compounds**.

You must be able to:

- identify **valence electrons 价电子** as the outermost electrons that drive bonding
- describe how metals form **cations 阳离子** and nonmetals form **anions 阴离子**
- write the formula of an **ionic compound 离子化合物** by balancing charges
- apply the octet rule to predict common ion charges

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.

Valence electrons and ions

Metals lose valence electrons to form positive cations; nonmetals gain electrons to form negative anions, each reaching a full octet.

Balancing charges

An ionic compound is neutral overall. Combine ions so the charges cancel:

$$Na^+ + Cl^- \to NaCl, \qquad Mg^{2+} + 2\,Cl^- \to MgCl_2.$$

Criss-cross

The magnitude of each ion's charge becomes the other's subscript. Al^{3+} with O^{2-} gives Al_2O_3.

2 Practice

Now apply the methods above.

2.1 State where valence electrons are located in an atom. [1]

2.2 A metal atom loses electrons. State the sign of the ion it forms. [1]

2.3 Write the neutral formula from Mg^{2+} and Cl^{-}. [2]

2.4 How many Cl^{-} ions balance one Al^{3+} ion? [1]

3 Exam-style questions

3.1 Valence electrons are found in the [1]

- **A** nucleus
- **B** innermost shell
- **C** outermost shell
- **D** neutrons

3.2 The neutral formula from Ca^{2+} and Cl^{-} is [1]

- **A** CaCl
- **B** $CaCl_2$
- **C** Ca_2Cl
- **D** $CaCl_3$

3.3 Consider aluminium (Al^{3+}) and oxide (O^{2-}).

(a) Write the neutral ionic formula. [2]

(b) State the method you used to balance the charges. [1]

3.4 A metal M forms M^{2+} and a nonmetal X forms X^{-}.

(a) Write the formula of the compound they make. [1]

(b) State whether M is more likely a metal or a nonmetal, and why. [2]

Solutions

2.1 In the outermost shell.

2.2 Positive (a cation).

2.3 $MgCl_2$ (one 2+ needs two 1−).

2.4 Three.

3.1 **C** — the outermost shell.

3.2 **B** — $CaCl_2$.

3.3 (a) Al_2O_3. (b) Criss-cross the charge magnitudes into subscripts (so total + equals total −).

3.4 (a) MX_2. (b) A metal — metals lose electrons to form positive cations like M^{2+}.

Compound	Melting Point (°C)
LiI	449
KI	686
LiF	845
NaF	993

6. A student learns that ionic compounds have significant covalent character when a cation has a polarizing effect on a large anion. As a result, the student hypothesizes that salts composed of small cations and large anions should have relatively low melting points.

(a) Select two compounds from the table and explain how the data support the student's hypothesis.

(b) Identify a compound from the table that can be dissolved in water to produce a basic solution. Write the net ionic equation for the reaction that occurs to cause the solution to be basic.