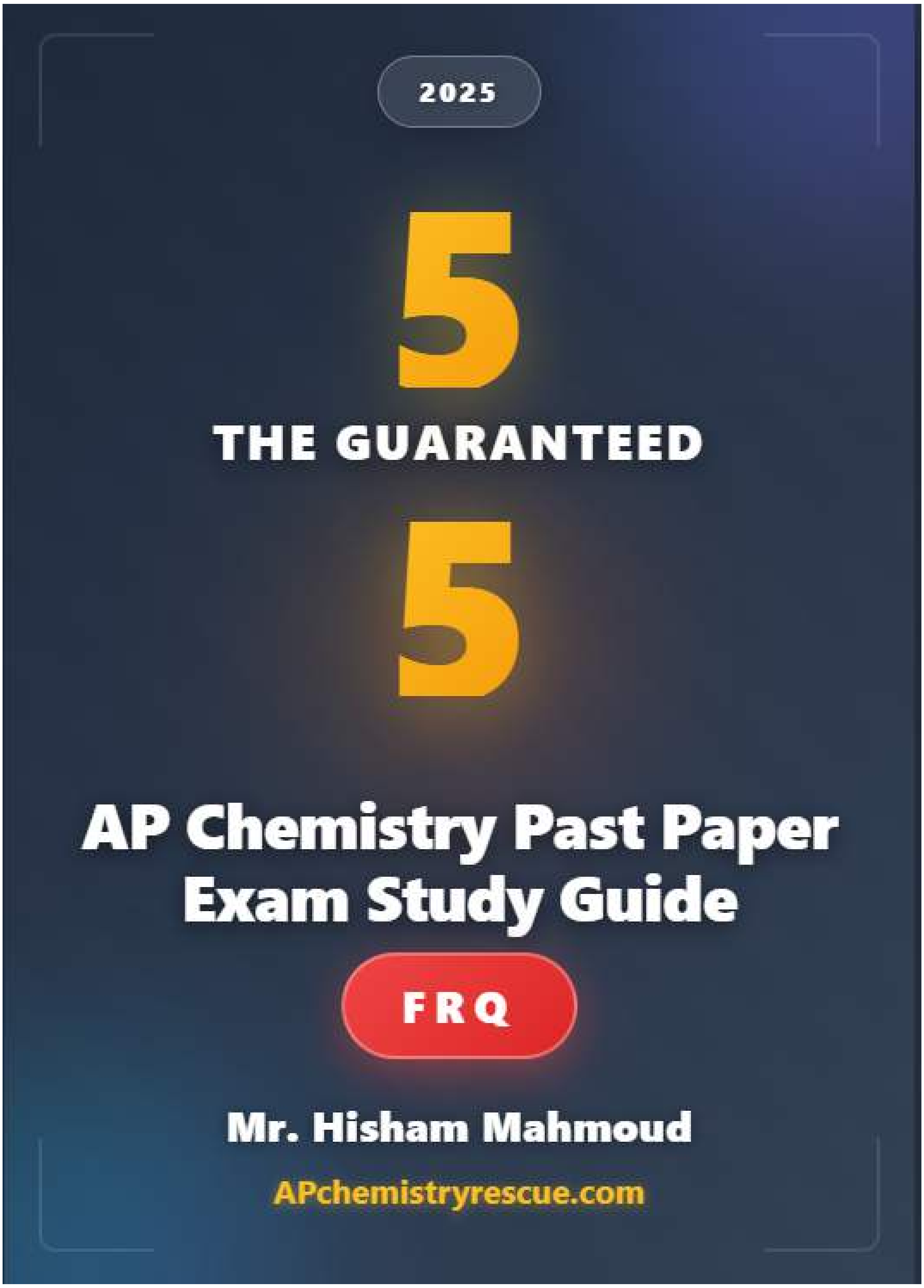


AP Chemistry Exam 2025

Free Response Section

Unofficial Answer Document (Not Endorsed by College Board)

Free-Response Section - Answer Key & Explanations

📚 How This Document is Organized

This answer document is divided into THREE clear sections for each question part:

1️⃣ ORIGINAL EXAM QUESTION

The actual question from the AP® Chemistry 2025 exam with all diagrams, data, and instructions.

2️⃣ OFFICIAL SCORING GUIDELINES

The official answer from College Board with point values and acceptable responses.

3️⃣ DETAILED EXPLANATION

Step-by-step breakdown with analogies, concepts, and why the answer works.

4️⃣ PRACTICE EXERCISES

Additional practice problems for each concept with complete solutions (at the end of each question part).

Each question part (A, B, C, D) follows this same structure!

📊 AP Chemistry Syllabus Alignment Table

This table shows how each question part aligns with the official AP Chemistry Course Framework

Question Part	Unit & Topic	Subtopic / Learning Objective	Key Concepts
Part A	**Unit 1:** Atomic Structure and Properties	**Topic 1.1-1.2:** Moles and Molar Mass, Mass Spectroscopy of Elements	Isotopes, atomic mass, neutrons, mass spectra interpretation
Part B	**Unit 2:** Molecular and Ionic Compound Structure and Properties	**Topic 2.1:** Types of Chemical Bonds / Coulomb's Law (SPQ-2.B)	Coulomb's law, ionic charge, ionic radius, ion-dipole interactions
Part C	**Unit 8:** Acids and Bases	**Topic 8.2:** pH and pOH of Strong Acids and Bases (SAP-9.A)	pH calculation, pOH, strong bases, -log calculations
Part D	**Unit 4:** Chemical Reactions	**Topic 4.1-4.8:** Solution Stoichiometry, Dilution (SPQ-4.A)	Molarity, dilution formula ($M_1V_1 = M_2V_2$), concentration calculations

Part E(i)	**Unit 7:** Equilibrium	**Topic 7.13:** Solubility Equilibria (SPQ-5.D)	Ksp expression, solubility product constant
Part E(ii)	**Unit 7:** Equilibrium	**Topic 7.13:** Solubility Equilibria / Reaction Quotient (SPQ-5.D, TRA-7.A)	Reaction quotient (Q), Q vs Ksp comparison
Part E(iii)	**Unit 7:** Equilibrium	**Topic 7.13:** Predicting Precipitation (SPQ-5.D)	Q > Ksp prediction, precipitate formation, equilibrium direction
Part F	**Unit 7:** Equilibrium	**Topic 7.8 & 7.13:** Le Chatelier's Principle / Common Ion Effect (TRA-7.D, SPQ-5.D)	Le Chatelier's principle, acid-base equilibrium shift, dissolving precipitates

Note: The Learning Objectives shown (e.g., SPQ-2.B, SAP-9.A) are from the official AP Chemistry Course and Exam Description. Each question part tests multiple science practices including mathematical routines, argumentation, and data analysis.

Q1 - PART A: Mass Spectrum Analysis

1 ORIGINAL EXAM QUESTION

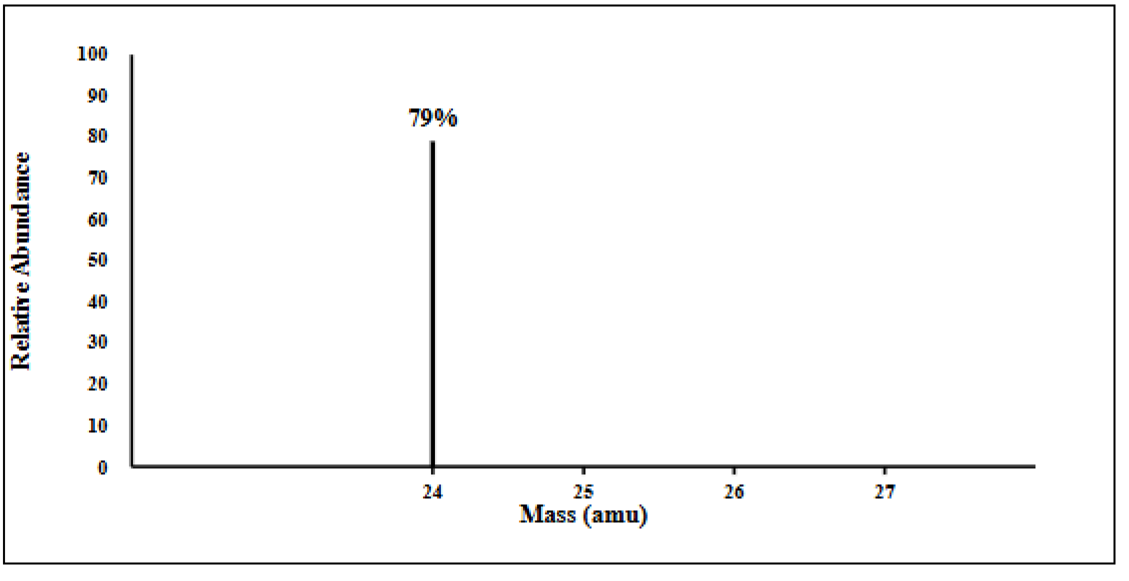
A. A student analyzed a sample of magnesium and obtained the following mass spectrum data. The sample contains two isotopes with the following abundances:

Isotope at 24 amu: 79% abundance

Isotope at 25 amu: 10% abundance

Isotope at 26 amu: 11% abundance

(i) On the axes below, draw vertical lines to represent the mass spectrum for the two less abundant isotopes (at 25 amu and 26 amu).



(ii) Explain why magnesium-26 has a different mass than magnesium-25.

2️⃣ OFFICIAL SCORING GUIDELINES

AP College Board Official AP® Chemistry 2025 Scoring Guidelines:
(i) For the correct plotted lines: 1 point - The abundance for the two lines should be between 10 and 11.
(ii) For the correct answer: 1 point - Magnesium-26 has one more neutron than magnesium-25 does.

3️⃣ DETAILED EXPLANATION

Part (i) Answer:

You need to draw two vertical lines on the graph:

At 25 amu: Draw a vertical line from the x-axis up to the 10% mark on the y-axis

At 26 amu: Draw a vertical line from the x-axis up to the 11% mark on the y-axis

Think of it like a bar graph where each line shows how much of each isotope is present. The line at 24 amu is already drawn for you at 79% (the tallest one). You're adding the two shorter lines for the less common isotopes.

Why this matters:

A mass spectrum is like a fingerprint for elements. It shows all the different versions (isotopes) of an element and how common each one is. The height of each line tells you the percentage of that isotope in the sample.

Part (ii) Answer:

Magnesium-26 has a different mass than magnesium-25 because it has one more neutron.

Here's what's happening:

All magnesium atoms have 12 protons (that's what makes them magnesium)

Magnesium-25 has: 12 protons + 13 neutrons = 25 total

Magnesium-26 has: 12 protons + 14 neutrons = 26 total

Think of atoms like LEGO structures. All magnesium atoms have the same number of red blocks (protons), but they can have different numbers of blue blocks (neutrons). Adding one more blue block makes the whole structure heavier by 1 amu.

The key concept:

Isotopes are atoms of the same element with different numbers of neutrons. Same protons, different neutrons = different masses.

4️⃣ PRACTICE EXERCISES - Part A

Exercise A1:
A student analyzed a sample of neon and found three isotopes:
Neon-20: 90% abundance

Neon-21: 0.3% abundance

Neon-22: 9.7% abundance

(i) Draw vertical lines on a mass spectrum to represent all three isotopes (x-axis: 20-23 amu, y-axis: 0-100%).
(ii) Explain why neon-22 has a different mass than neon-20.

> **Answer (i):** Draw three vertical lines: at 20 amu reaching 90%, at 21 amu reaching 0.3%, and at 22 amu reaching 9.7%. The line at 20 amu is the tallest since neon-20 is the most abundant.
>
> **Answer (ii):** Neon-22 has two more neutrons than neon-20. Both have 10 protons (which makes them neon), but neon-20 has 10 neutrons (10 + 10 = 20) while neon-22 has 12 neutrons (10 + 12 = 22). The extra two neutrons make neon-22 heavier by 2 amu.

Exercise A2:
A mass spectrum of boron shows two peaks:
One peak at 10 amu with 20% abundance

One peak at 11 amu with 80% abundance

(i) Draw the complete mass spectrum on properly labeled axes.
(ii) Explain the difference in mass between boron-10 and boron-11.

> **Answer (i):** Draw y-axis labeled "Relative Abundance" (0-100%) and x-axis labeled "Mass (amu)" (9-12 amu). Draw a vertical line at 10 amu reaching 20% and another at 11 amu reaching 80%.
>
> **Answer (ii):** Boron-11 has one more neutron than boron-10. Both have 5 protons, but boron-10 has 5 neutrons (5 + 5 = 10) while boron-11 has 6 neutrons (5 + 6 = 11). This extra neutron makes boron-11 heavier by 1 amu.

Exercise A3:
A student analyzed a sample of chlorine and found two isotopes:
Chlorine-35: 75.8% abundance

Chlorine-37: 24.2% abundance

(i) On axes labeled from 34-38 amu (x-axis) and 0-100% (y-axis), draw vertical lines to represent both isotopes.
(ii) Explain why chlorine-37 has a different mass than chlorine-35.

> **Answer (i):** Draw two vertical lines: at 35 amu reaching 75.8% and at 37 amu reaching 24.2%. The line at 35 amu should be about three times taller than the line at 37 amu.
>
> **Answer (ii):** Chlorine-37 has two more neutrons than chlorine-35. Both isotopes have 17 protons (which makes them chlorine), but chlorine-35 has 18 neutrons (17 + 18 = 35) while chlorine-37 has 20 neutrons (17 + 20 = 37). The two extra neutrons make chlorine-37 heavier by 2 amu.

Exercise A4:
A student analyzed a sample of carbon and found two isotopes:
Carbon-12: 98.9% abundance

Carbon-13: 1.1% abundance

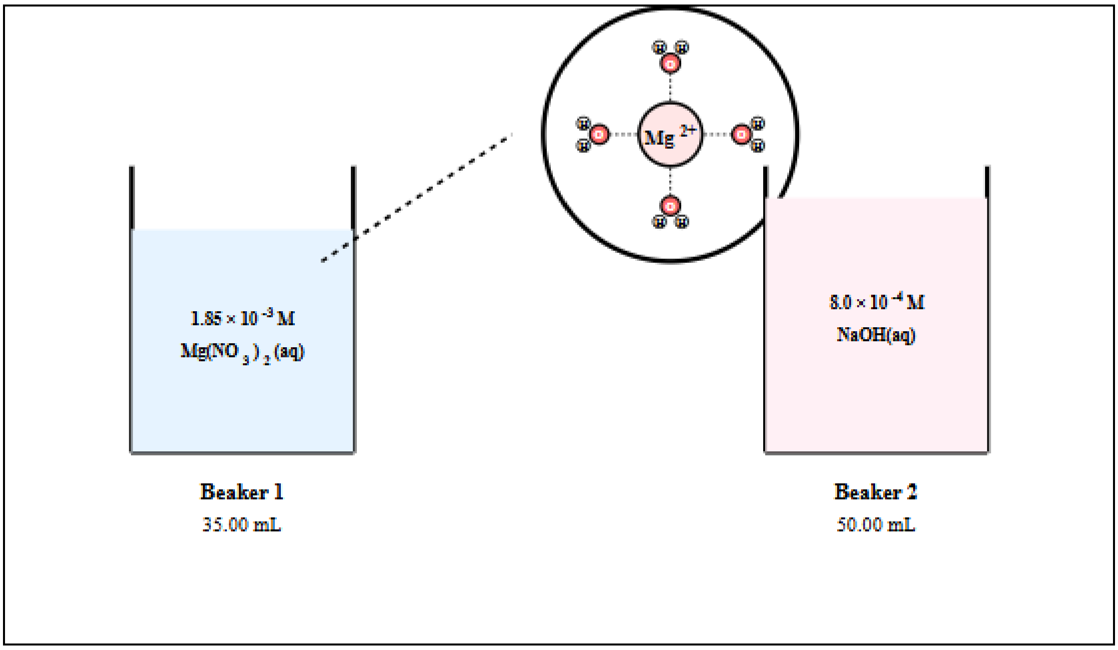
(i) Draw a mass spectrum showing both isotopes with properly labeled axes.
(ii) Explain why these two isotopes have different masses.

> **Answer (i):** Draw y-axis labeled "Relative Abundance" (0-100%) and x-axis labeled "Mass (amu)" (11-14 amu). Draw a very tall vertical line at 12 amu reaching 98.9% and a very short line at 13 amu reaching 1.1%.
>
> **Answer (ii):** Carbon-13 has one more neutron than carbon-12. Both have 6 protons (which defines them as carbon), but carbon-12 has 6 neutrons (6 + 6 = 12) while carbon-13 has 7 neutrons (6 + 7 = 13). This additional neutron makes carbon-13 heavier by 1 amu.

Q1 - PART B: Coulomb's Law & Ion Hydration

1️⃣ ORIGINAL EXAM QUESTION

B. The particle diagram shown below 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

2 OFFICIAL SCORING GUIDELINES

AP College Board Official AP® Chemistry 2025 Scoring Guidelines:
B(i): Point 03 - The charge on the sodium ion is less than the charge on the magnesium ion. A smaller charge results in a weaker Coulombic attraction between Na^{+} and water.
B(ii): Point 04 - The Na^{+} ion is larger than the Mg^{2+} ion, so the distance between the Na^{+} and the oxygen on the water molecule will be greater. As distance increases, Coulombic attraction decreases.

3 DETAILED EXPLANATION

Part B(i) Answer - Relative Charge:

Mg^{2+} has a stronger attraction to water than Na^{+} because it has a greater positive charge.

Coulomb's Law Connection:

According to Coulomb's law, the force of attraction is directly proportional to the charge:

Mg^{2+} has a charge of +2

Na^{+} has a charge of +1

Since Mg^{2+} has twice the charge, it attracts water molecules with twice the force

Think of it like magnets: A stronger magnet (higher charge) pulls metal objects (water molecules) more strongly. The +2 charge on magnesium acts like a double-strength magnet compared to sodium's +1 charge.

Part B(ii) Answer - Relative Radii:

Mg^{2+} has a stronger attraction to water than Na^{+} because it has a smaller ionic radius.

Coulomb's Law Connection:

According to Coulomb's law, the force of attraction is inversely proportional to the square of the distance:

Mg^{2+} ionic radius: ~72 pm (smaller)

Na^{+} ionic radius: ~102 pm (larger)

Water molecules can get closer to Mg^{2+}, increasing the electrostatic attraction

Think of it like a campfire: The closer you stand to the fire, the more heat you feel. Water molecules can get closer to the smaller Mg^{2+} ion, so they feel a stronger attraction. The larger Na^{+} ion keeps water molecules farther away, weakening the attraction.

Combined Effect:

Mg^{2+} has BOTH higher charge AND smaller size, making it attract water molecules much more strongly than Na^{+} does. This is why Mg^{2+} is more strongly hydrated.

4️⃣ PRACTICE EXERCISES - Part B

Exercise B1:

Compare the attraction to water molecules between Al^{3+} and Na^{+} ions. Explain using Coulomb's law and:

(i) The relative charge of the ions

(ii) The relative radii of the ions (Al^{3+} radius: ~54 pm; Na^{+} radius: ~102 pm)

> **Answer (i):** Al^{3+} has a stronger attraction to water than Na^{+} because it has a greater positive charge. According to Coulomb's law, force is directly proportional to charge. Al^{3+} has a charge of +3 while Na^{+} has a charge of +1. The higher charge on Al^{3+} creates a stronger Coulombic attraction to the partial negative charge on water's oxygen atom.
>
> **Answer (ii):** Al^{3+} has a stronger attraction to water than Na^{+} because it has a smaller ionic radius. According to Coulomb's law, force is inversely proportional to the square of the distance. Al^{3+} (54 pm) is much smaller than Na^{+} (102 pm), so water molecules can get closer to Al^{3+}, increasing the electrostatic attraction. The smaller distance results in stronger Coulombic attraction.

Exercise B2:
Compare the attraction to water molecules between Ca^{2+} and K^{+} ions. Explain using Coulomb's law and:
(i) The relative charge of the ions
(ii) The relative radii of the ions (Ca^{2+} radius: ~100 pm; K^{+} radius: ~138 pm)

> **Answer (i):** Ca^{2+} has a stronger attraction to water than K^{+} because it has a greater positive charge. According to Coulomb's law, the force of attraction is directly proportional to charge. Ca^{2+} has a charge of +2 while K^{+} has a charge of +1. This means Ca^{2+} has twice the charge, creating a stronger Coulombic attraction to water molecules.
>
> **Answer (ii):** Ca^{2+} has a stronger attraction to water than K^{+} because it has a smaller ionic radius. According to Coulomb's law, force is inversely proportional to the square of the distance. Ca^{2+} (100 pm) is smaller than K^{+} (138 pm), allowing water molecules to get closer to the Ca^{2+} ion. The shorter distance increases the electrostatic attraction.

Exercise B3:
Compare the attraction to water molecules between Fe^{3+} and Fe^{2+} ions. Explain using Coulomb's law and:
(i) The relative charge of the ions
(ii) The relative radii of the ions (Fe^{3+} radius: ~65 pm; Fe^{2+} radius: ~78 pm)

> **Answer (i):** Fe^{3+} has a stronger attraction to water than Fe^{2+} because it has a greater positive charge. According to Coulomb's law, the force of attraction is directly proportional to charge. Fe^{3+} has a charge of +3 while Fe^{2+} has a charge of +2. The higher charge on Fe^{3+} creates a stronger Coulombic attraction to water's partial negative oxygen atoms.
>
> **Answer (ii):** Fe^{3+} has a stronger attraction to water than Fe^{2+} because it has a smaller ionic radius. According to Coulomb's law, force is inversely proportional to the square of the distance. Fe^{3+} (65 pm) is smaller than Fe^{2+} (78 pm), so water molecules can approach closer to Fe^{3+}. The shorter distance increases the electrostatic attraction between the ion and water molecules.

Exercise B4:
Compare the attraction to water molecules between Li^+ and Cs^+ ions. Both have +1 charges. Explain using Coulomb's law and:
(i) The relative charge of the ions
(ii) The relative radii of the ions (Li^+ radius: ~76 pm; Cs^+ radius: ~167 pm)

> **Answer (i):** Based on charge alone, Li^+ and Cs^+ would have equal attraction to water since both have the same +1 charge. According to Coulomb's law, the force of attraction is directly proportional to charge. Since both ions have identical charges (+1), this factor does not contribute to any difference in their attraction to water.
>
> **Answer (ii):** Li^+ has a much stronger attraction to water than Cs^+ because it has a smaller ionic radius. According to Coulomb's law, force is inversely proportional to the square of the distance. Li^+ (76 pm) is much smaller than Cs^+ (167 pm), so water molecules can get significantly closer to Li^+. The much shorter distance dramatically increases the electrostatic attraction to water molecules.

Q1 - PART C: pH Calculation

1️⃣ ORIGINAL EXAM QUESTION

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

2️⃣ OFFICIAL SCORING GUIDELINES

AP College Board Official AP® Chemistry 2025 Scoring Guidelines:
C: Point 05 - pOH = -log(8.0 × 10^{-4}) = 3.097; pH = 14 - 3.097 = 10.903 (accept 10.9, 10.90, or 11.0)

3 DETAILED EXPLANATION

Part C Answer - pH Calculation:

Step 1: Identify the base concentration

NaOH is a strong base that completely dissociates:

$[OH^-] = 8.0 \times 10^{-4}$ M

Step 2: Calculate pOH

pOH = $-\log[OH^-]$

pOH = $-\log(8.0 \times 10^{-4})$

pOH = 3.097

Step 3: Calculate pH

pH + pOH = 14

pH = 14 - 3.097

pH = 10.903 or 10.9

What this means:

A pH of 10.9 indicates a basic (alkaline) solution. Since NaOH is a strong base, it completely breaks apart in water to produce OH^- ions, making the solution basic. The pH is above 7, confirming it's not acidic.

4 PRACTICE EXERCISES - Part C

Exercise C1:
Calculate the pH of a 5.0×10^{-3} M solution of KOH(aq).

Answer:
Step 1: KOH is a strong base that completely dissociates: $[OH^-] = 5.0 \times 10^{-3}$ M
Step 2: Calculate pOH: pOH = $-\log(5.0 \times 10^{-3}) = 2.301$
Step 3: Calculate pH: pH = 14 - 2.301 = 11.699 or 11.7
The solution is basic with a pH of 11.7.

Exercise C2:
Calculate the pH of a 2.5×10^{-5} M solution of $Ba(OH)_2$(aq).

Answer:
Step 1: $Ba(OH)_2$ is a strong base that completely dissociates: $Ba(OH)_2 \rightarrow Ba^{2+} + 2OH^-$
$[OH^-] = 2 \times 2.5 \times 10^{-5}$ M $= 5.0 \times 10^{-5}$ M (note: 2 moles of OH^- per mole of $Ba(OH)_2$)
Step 2: Calculate pOH: pOH = $-\log(5.0 \times 10^{-5}) = 4.301$
Step 3: Calculate pH: pH = 14 - 4.301 = 9.699 or 9.7
The solution is basic with a pH of 9.7.

Exercise C3:
Calculate the pH of a 1.2×10^{-2} M solution of LiOH(aq).

Answer:
Step 1: LiOH is a strong base that completely dissociates: $[OH^-] = 1.2 \times 10^{-2}$ M
Step 2: Calculate pOH: pOH = $-\log(1.2 \times 10^{-2}) = 1.921$
Step 3: Calculate pH: pH = 14 - 1.921 = 12.079 or 12.1
The solution is strongly basic with a pH of 12.1.

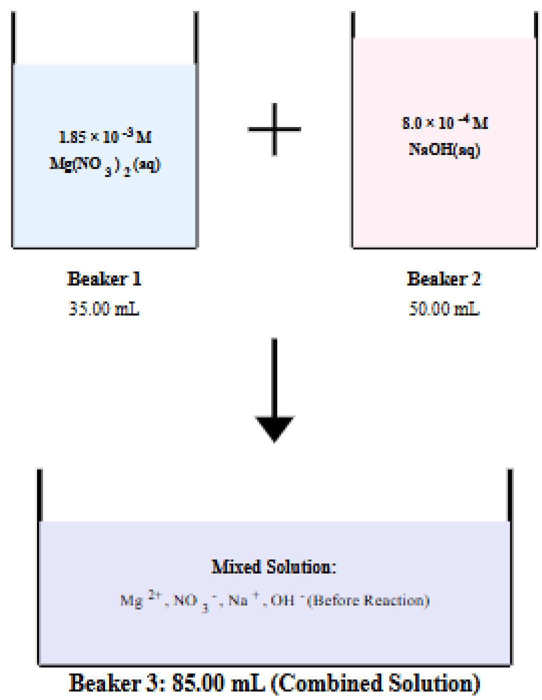
Exercise C4:
Calculate the pH of a 6.8×10^{-4} M solution of $Sr(OH)_2$(aq).

Answer:
Step 1: $Sr(OH)_2$ is a strong base that completely dissociates: $Sr(OH)_2 \rightarrow Sr^{2+} + 2OH^-$
$[OH^-] = 2 \times 6.8 \times 10^{-4}$ M $= 1.36 \times 10^{-3}$ M (note: each $Sr(OH)_2$ produces 2 OH^- ions)
Step 2: Calculate pOH: pOH = $-\log(1.36 \times 10^{-3}) = 2.866$
Step 3: Calculate pH: pH = 14 - 2.866 = 11.134 or 11.1
The solution is basic with a pH of 11.1.

Q1 - PART D: Dilution Calculation

1️⃣ ORIGINAL EXAM QUESTION

D. A student combines 35.00 mL of 1.85×10^{-3} M $Mg(NO_3)_2(aq)$ with 50.00 mL of 8.0×10^{-4} M NaOH(aq), as shown in the diagram below. Calculate [Mg^{2+}] after the two solutions are combined but before any reaction takes place. (Assume that volumes are additive.)



2 OFFICIAL SCORING GUIDELINES

AP College Board Official AP® Chemistry 2025 Scoring Guidelines:
D: Point 06 - [Mg^{2+}] = (1.85×10^{-3} M)(35.00 mL) / (85.00 mL) = 7.62×10^{-4} M (accept 7.6×10^{-4} M or 0.000762 M)

3️⃣ DETAILED EXPLANATION

Part D Answer - Dilution Calculation:

Mg^{2+} has a stronger attraction to water than Na^{+} because it has a greater positive charge.

Coulomb's Law Connection:

According to Coulomb's law, the force of attraction is directly proportional to the charge:
Mg^{2+} has a charge of +2

Na^{+} has a charge of +1

Since Mg^{2+} has twice the charge, it attracts water molecules with twice the force

Think of it like magnets: A stronger magnet (higher charge) pulls metal objects (water molecules) more strongly. The +2 charge on magnesium acts like a double-strength magnet compared to sodium's +1 charge.

Part B(ii) Answer - Relative Radii:

Mg^{2+} has a stronger attraction to water than Na^{+} because it has a smaller ionic radius.

Coulomb's Law Connection:
According to Coulomb's law, the force of attraction is inversely proportional to the square of the distance:
Mg^{2+} ionic radius: ~72 pm (smaller)

Na^{+} ionic radius: ~102 pm (larger)

Water molecules can get closer to Mg^{2+}, increasing the electrostatic attraction

Think of it like a campfire: The closer you stand to the fire, the more heat you feel. Water molecules can get closer to the smaller Mg^{2+} ion, so they feel a stronger attraction. The larger Na^{+} ion keeps water molecules farther away, weakening the attraction.

Combined Effect:
Mg^{2+} has BOTH higher charge AND smaller size, making it attract water molecules much more strongly than Na^{+} does. This is why Mg^{2+} is more strongly hydrated.

Part C Answer - pH Calculation:

Step 1: Identify the base concentration
NaOH is a strong base that completely dissociates:
$[OH^{-}] = 8.0 \times 10^{-4}$ M

Step 2: Calculate pOH
$pOH = -\log[OH^{-}]$

$pOH = -\log(8.0 \times 10^{-4})$

$pOH = 3.097$

Step 3: Calculate pH
$pH + pOH = 14$

pH = 14 - 3.097

pH = 10.903 or 10.9

What this means:

A pH of 10.9 indicates a basic (alkaline) solution. Since NaOH is a strong base, it completely breaks apart in water to produce OH^- ions, making the solution basic. The pH is above 7, confirming it's not acidic.

Part D Answer - Dilution Calculation:

Official Dilution Formula: $M_1V_1 = M_2V_2$

Step 1: Identify the values

• $M_1 = 1.85 \times 10^{-3}$ M (initial $[Mg^{2+}]$ from Beaker 1)

• V_1 = 0.03500 L = 35.00 mL

• V_2 = 0.03500 L + 0.05000 L = 0.08500 L = 85.00 mL (total volume)

• M_2 = ? (final $[Mg^{2+}]$ after mixing)

Step 2: Apply $M_1V_1 = M_2V_2$

Remember: $Mg(NO_3)_2$ dissociates to give 1 Mg^{2+} ion per formula unit

Moles of Mg^{2+} = Molarity × Volume

Moles of Mg^{2+} = $(1.85 \times 10^{-3}$ M)(35.00 mL)

Moles of Mg^{2+} = 6.475×10^{-2} mmol

Step 3: Calculate the new concentration in Beaker 3

When you combine the solutions, the Mg^{2+} ions spread out into a larger volume, making them more dilute.

$[Mg^{2+}]$ = Moles / Total Volume

$[Mg^{2+}] = (6.475 \times 10^{-2}$ mmol) / (85.00 mL)

OR use the dilution formula directly:

$[Mg^{2+}]_{final} = [Mg^{2+}]_{initial} \times (V_{initial} / V_{final})$

$[Mg^{2+}]_{final} = (1.85 \times 10^{-3}$ M) × (35.00 mL / 85.00 mL)

$[Mg^{2+}]_{final}$ = (1.85 �� 10^{-3}) × (0.4118)

$[Mg^{2+}] = 7.62 \times 10^{-4}$ M

What's happening here:

Think of it like diluting juice concentrate. You start with 35 mL of a concentrated Mg^{2+} solution, then add 50 mL of another solution. The Mg^{2+} ions now have more space to spread out (85 mL total), so their concentration decreases. The calculation shows they're now about 41% as concentrated as before (35/85 = 0.41).

Important Note:

This is the concentration BEFORE any reaction occurs. We're just calculating the effect of mixing (dilution). The problem asks specifically for the concentration after combining but before any chemical reaction takes place between Mg^{2+} and OH^-.

4️⃣ PRACTICE EXERCISES - Part D

Exercise D1:
A student combines 25.00 mL of 3.0×10^{-3} M $CaCl_2$(aq) with 75.00 mL of 1.5×10^{-3} M Na_2CO_3(aq). Calculate [Ca^{2+}] after mixing but before any reaction occurs.

Answer:
Step 1: Calculate moles of Ca^{2+}: (3.0×10^{-3} M)(25.00 mL) = 0.075 mmol
Step 2: Calculate total volume: 25.00 mL + 75.00 mL = 100.00 mL
Step 3: Calculate new [Ca^{2+}]: 0.075 mmol / 100.00 mL = 7.5×10^{-4} M
OR using dilution formula: [Ca^{2+}] = (3.0×10^{-3} M)(25.00 mL / 100.00 mL) = 7.5×10^{-4} M

Exercise D2:
A student mixes 40.00 mL of 2.5×10^{-2} M $AgNO_3$(aq) with 60.00 mL of 1.2×10^{-2} M KCl(aq). Calculate [Ag^{+}] immediately after mixing.

Answer:
Step 1: Calculate moles of Ag^{+}: (2.5×10^{-2} M)(40.00 mL) = 1.0 mmol
Step 2: Calculate total volume: 40.00 mL + 60.00 mL = 100.00 mL
Step 3: Calculate new [Ag^{+}]: 1.0 mmol / 100.00 mL = 1.0×10^{-2} M
OR using dilution formula: [Ag^{+}] = (2.5×10^{-2} M)(40.00 mL / 100.00 mL) = 1.0×10^{-2} M

Exercise D3:

A student combines 50.00 mL of 4.0×10^{-4} M $Pb(NO_3)_2(aq)$ with 30.00 mL of 6.0×10^{-4} M KI(aq). Calculate $[Pb^{2+}]$ after combining the solutions.

Answer:

Step 1: Calculate moles of Pb^{2+}: $(4.0 \times 10^{-4}$ M)(50.00 mL) = 0.02 mmol

Step 2: Calculate total volume: 50.00 mL + 30.00 mL = 80.00 mL

Step 3: Calculate new $[Pb^{2+}]$: 0.02 mmol / 80.00 mL = 2.5×10^{-4} M

OR using dilution formula: $[Pb^{2+}] = (4.0 \times 10^{-4}$ M)(50.00 mL / 80.00 mL) = 2.5×10^{-4} M

Exercise D4:

A student mixes 20.00 mL of 1.5×10^{-3} M $FeCl_3(aq)$ with 80.00 mL of 2.0×10^{-3} M NaOH(aq). Calculate $[Fe^{3+}]$ immediately after mixing.

Answer:

Step 1: Calculate moles of Fe^{3+}: $(1.5 \times 10^{-3}$ M)(20.00 mL) = 0.03 mmol

Step 2: Calculate total volume: 20.00 mL + 80.00 mL = 100.00 mL

Step 3: Calculate new $[Fe^{3+}]$: 0.03 mmol / 100.00 mL = 3.0×10^{-4} M

OR using dilution formula: $[Fe^{3+}] = (1.5 \times 10^{-3}$ M)(20.00 mL / 100.00 mL) = 3.0×10^{-4} M

A student analyzed a sample of neon and found three isotopes:
Neon-20: 90% abundance

Neon-21: 0.3% abundance

Neon-22: 9.7% abundance

(i) Draw vertical lines on a mass spectrum to represent all three isotopes (x-axis: 20-23 amu, y-axis: 0-100%).
(ii) Explain why neon-22 has a different mass than neon-20.

Answer (i): Draw three vertical lines: at 20 amu reaching 90%, at 21 amu reaching 0.3%, and at 22 amu reaching 9.7%. The line at 20 amu is the tallest since neon-20 is the most abundant.

Answer (ii): Neon-22 has two more neutrons than neon-20. Both have 10 protons (which makes them neon), but neon-20 has 10 neutrons (10 + 10 = 20) while neon-22 has 12 neutrons (10 + 12 = 22). The extra two neutrons make neon-22 heavier by 2 amu.

Exercise 2:

A mass spectrum of boron shows two peaks:
One peak at 10 amu with 20% abundance

One peak at 11 amu with 80% abundance

(i) Draw the complete mass spectrum on properly labeled axes.
(ii) Explain the difference in mass between boron-10 and boron-11.

Answer (i): Draw y-axis labeled "Relative Abundance" (0-100%) and x-axis labeled "Mass (amu)" (9-12 amu). Draw a vertical line at 10 amu reaching 20% and another at 11 amu reaching 80%.

Answer (ii): Boron-11 has one more neutron than boron-10. Both have 5 protons, but boron-10 has 5 neutrons (5 + 5 = 10) while boron-11 has 6 neutrons (5 + 6 = 11). This extra neutron makes boron-11 heavier by 1 amu.

Exercise 1

Exercise 2:
A mass spectrum of boron shows two peaks:
One peak at 10 amu with 20% abundance

One peak at 11 amu with 80% abundance

(i) Draw the complete mass spectrum on properly labeled axes.
(ii) Explain the difference in mass between boron-10 and boron-11.

> **Answer (i):** Draw y-axis labeled "Relative Abundance" (0-100%) and x-axis labeled "Mass (amu)" (9-12 amu). Draw a vertical line at 10 amu reaching 20% and another at 11 amu reaching 80%.
>
> **Answer (ii):** Boron-11 has one more neutron than boron-10. Both have 5 protons, but boron-10 has 5 neutrons (5 + 5 = 10) while boron-11 has 6 neutrons (5 + 6 = 11). This extra neutron makes boron-11 heavier by 1 amu.

Exercise 3:
Compare the attraction to water molecules between Al^{3+} and Na^+ ions. Explain using Coulomb's law and:
(i) The relative charge of the ions
(ii) The relative radii of the ions (Al^{3+} radius: ~54 pm; Na^+ radius: ~102 pm)

> **Answer (i):** Al^{3+} has a stronger attraction to water than Na^+ because it has a greater positive charge. According to Coulomb's law, force is directly proportional to charge. Al^{3+} has a charge of +3 while Na^+ has a charge of +1. The higher charge on Al^{3+} creates a stronger Coulombic attraction to the partial negative charge on water's oxygen atom.
>
> **Answer (ii):** Al^{3+} has a stronger attraction to water than Na^+ because it has a smaller ionic radius. According to Coulomb's law, force is inversely proportional to the square of the distance. Al^{3+} (54 pm) is much smaller than Na^+ (102 pm), so water molecules can get closer to Al^{3+}, increasing the electrostatic attraction. The smaller distance results in stronger Coulombic attraction.

Exercise 4:
Compare the attraction to water molecules between Ca^{2+} and K^+ ions. Explain using Coulomb's law and:
(i) The relative charge of the ions
(ii) The relative radii of the ions (Ca^{2+} radius: ~100 pm; K^+ radius: ~138 pm)

> **Answer (i):** Ca^{2+} has a stronger attraction to water than K^+ because it has a greater positive charge. According to Coulomb's law, the force of attraction is directly proportional to charge. Ca^{2+} has a charge of +2 while K^+ has a charge of +1. This means Ca^{2+} has twice the charge, creating a stronger Coulombic attraction to water molecules.
>
> **Answer (ii):** Ca^{2+} has a stronger attraction to water than K^+ because it has a smaller ionic radius. According to Coulomb's law, force is inversely proportional to the square of the distance. Ca^{2+} (100 pm) is smaller than K^+ (138 pm), allowing water molecules to get closer to the Ca^{2+} ion. The shorter distance increases the electrostatic attraction.

Exercise 5:
Calculate the pH of a 5.0×10^{-3} M solution of KOH(aq).

> **Answer:**
> **Step 1:** KOH is a strong base that completely dissociates: $[OH^-] = 5.0 \times 10^{-3}$ M
> **Step 2:** Calculate pOH: pOH = $-\log(5.0 \times 10^{-3}) = 2.301$
> **Step 3:** Calculate pH: pH = 14 - 2.301 = 11.699 or 11.7
> The solution is basic with a pH of 11.7.

Exercise 6:
Calculate the pH of a 2.5×10^{-5} M solution of $Ba(OH)_2$(aq).

> **Answer:**
> **Step 1:** $Ba(OH)_2$ is a strong base that completely dissociates: $Ba(OH)_2 \rightarrow Ba^{2+} + 2OH^-$
> $[OH^-] = 2 \times 2.5 \times 10^{-5}$ M $= 5.0 \times 10^{-5}$ M (note: 2 moles of OH^- per mole of $Ba(OH)_2$)
> **Step 2:** Calculate pOH: pOH = $-\log(5.0 \times 10^{-5}) = 4.301$
> **Step 3:** Calculate pH: pH = 14 - 4.301 = 9.699 or 9.7
> The solution is basic with a pH of 9.7.

Exercise 7:
A student analyzed a sample of chlorine and found two isotopes:
Chlorine-35: 75.8% abundance

Chlorine-37: 24.2% abundance

(i) On axes labeled from 34-38 amu (x-axis) and 0-100% (y-axis), draw vertical lines to represent both isotopes.
(ii) Explain why chlorine-37 has a different mass than chlorine-35.

> **Answer (i):** Draw two vertical lines: at 35 amu reaching 75.8% and at 37 amu reaching 24.2%. The line at 35 amu should be about three times taller than the line at 37 amu.
>
> **Answer (ii):** Chlorine-37 has two more neutrons than chlorine-35. Both isotopes have 17 protons (which makes them chlorine), but chlorine-35 has 18 neutrons (17 + 18 = 35) while chlorine-37 has 20 neutrons (17 + 20 = 37). The two extra neutrons make chlorine-37 heavier by 2 amu.

Exercise 8:
A student analyzed a sample of carbon and found two isotopes:
Carbon-12: 98.9% abundance

Carbon-13: 1.1% abundance

(i) Draw a mass spectrum showing both isotopes with properly labeled axes.
(ii) Explain why these two isotopes have different masses.

Answer (i): Draw y-axis labeled "Relative Abundance" (0-100%) and x-axis labeled "Mass (amu)" (11-14 amu). Draw a very tall vertical line at 12 amu reaching 98.9% and a very short line at 13 amu reaching 1.1%.

Answer (ii): Carbon-13 has one more neutron than carbon-12. Both have 6 protons (which defines them as carbon), but carbon-12 has 6 neutrons (6 + 6 = 12) while carbon-13 has 7 neutrons (6 + 7 = 13). This additional neutron makes carbon-13 heavier by 1 amu.

Exercise 9:
Compare the attraction to water molecules between Fe^{3+} and Fe^{2+} ions. Explain using Coulomb's law and:
(i) The relative charge of the ions
(ii) The relative radii of the ions (Fe^{3+} radius: ~65 pm; Fe^{2+} radius: ~78 pm)

Answer (i): Fe^{3+} has a stronger attraction to water than Fe^{2+} because it has a greater positive charge. According to Coulomb's law, the force of attraction is directly proportional to charge. Fe^{3+} has a charge of +3 while Fe^{2+} has a charge of +2. The higher charge on Fe^{3+} creates a stronger Coulombic attraction to water's partial negative oxygen atoms.

Answer (ii): Fe^{3+} has a stronger attraction to water than Fe^{2+} because it has a smaller ionic radius. According to Coulomb's law, force is inversely proportional to the square of the distance. Fe^{3+} (65 pm) is smaller than Fe^{2+} (78 pm), so water molecules can approach closer to Fe^{3+}. The shorter distance increases the electrostatic attraction between the ion and water molecules.

Exercise 10:
Compare the attraction to water molecules between Li^{+} and Cs^{+} ions. Both have +1 charges. Explain using Coulomb's law and:
(i) The relative charge of the ions
(ii) The relative radii of the ions (Li^{+} radius: ~76 pm; Cs^{+} radius: ~167 pm)

Answer (i): Based on charge alone, Li^{+} and Cs^{+} would have equal attraction to water since both have the same +1 charge. According to Coulomb's law, the force of attraction is directly proportional to charge. Since both ions have identical charges (+1), this factor does not contribute to any difference in their attraction to water.

Answer (ii): Li^{+} has a much stronger attraction to water than Cs^{+} because it has a smaller ionic radius. According to Coulomb's law, force is inversely proportional to the square of the distance. Li^{+} (76 pm) is much smaller than Cs^{+} (167 pm), so water molecules can get significantly closer to Li^{+}. The much shorter distance dramatically increases the electrostatic attraction to water molecules.

Exercise 11:
Calculate the pH of a 1.2 ��� 10^{-2} M solution of LiOH(aq).

Answer:
Step 1: LiOH is a strong base that completely dissociates: $[OH^-] = 1.2 \times 10^{-2}$ M
Step 2: Calculate pOH: $pOH = -\log(1.2 \times 10^{-2}) = 1.921$
Step 3: Calculate pH: $pH = 14 - 1.921 = 12.079$ or 12.1
The solution is strongly basic with a pH of 12.1.

Exercise 12:
Calculate the pH of a 6.8×10^{-4} M solution of $Sr(OH)_2$(aq).

Answer:
Step 1: $Sr(OH)_2$ is a strong base that completely dissociates: $Sr(OH)_2 \rightarrow Sr^{2+} + 2OH^-$
$[OH^-] = 2 \times 6.8 \times 10^{-4}$ M $= 1.36 \times 10^{-3}$ M (note: each $Sr(OH)_2$ produces 2 OH^- ions)
Step 2: Calculate pOH: $pOH = -\log(1.36 \times 10^{-3}) = 2.866$
Step 3: Calculate pH: $pH = 14 - 2.866 = 11.134$ or 11.1
The solution is basic with a pH of 11.1.

Q1 - PART E: Solubility Product & Precipitation

1 ORIGINAL EXAM QUESTION

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

$$Mg(OH)_2(s) \rightleftharpoons Mg^{2+}(aq) + 2OH^-(aq) \quad K_{sp} = 5.61 \times 10^{-12}$$

(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, $[OH^-] = 1.65 \times 10^{-4}$ 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.

2 OFFICIAL SCORING GUIDELINES

AP College Board Official AP® Chemistry 2025 Scoring Guidelines:

E(i): Point 07 - $K_{sp} = [Mg^{2+}][OH^-]^2$

E(ii): Point 08 - $Q = [Mg^{2+}][OH^-]^2 = (7.62 \times 10^{-4})(1.65 \times 10^{-4})^2 = 2.07 \times 10^{-11}$

E(iii): Point 09 - $Q > K_{sp}$, so a precipitate will form. The concentration of the ions in solution (represented by Q) is greater than that of a saturated solution, so a precipitate will form.

3 DETAILED EXPLANATION

Part E(i) Answer - K_{sp} Expression:

The K_{sp} expression is:

$$K_{sp} = [Mg^{2+}][OH^-]^2$$

How to write K_{sp} expressions:

Rule 1: Only include aqueous ions (products), NEVER include solids or liquids

Rule 2: Raise each concentration to the power of its coefficient in the balanced equation

Rule 3: For $Mg(OH)_2 \rightarrow Mg^{2+} + 2OH^-$, the coefficient of OH^- is 2, so we square it

Think of it like a recipe:

When $Mg(OH)_2$ dissolves, it produces 1 magnesium ion and 2 hydroxide ions. The K_{sp} expression shows this relationship: one $[Mg^{2+}]$ term and $[OH^-]$ squared (because there are 2 of them).

Part E(ii) Answer - Reaction Quotient Q:

Step 1: Recall the Q expression (same form as K_{sp})

> $Q = [Mg^{2+}][OH^-]^2$

Step 2: Identify the concentrations from the problem

> • $[Mg^{2+}] = 7.62 \times 10^{-4}$ M (from Part D)
> • $[OH^-] = 1.65 \times 10^{-4}$ M (given in the problem)

Step 3: Substitute values into Q expression

> $Q = (7.62 \times 10^{-4})(1.65 \times 10^{-4})^2$

Step 4: Calculate $[OH^-]^2$ first

> $(1.65 \times 10^{-4})^2 = 2.7225 \times 10^{-8}$

Step 5: Multiply by $[Mg^{2+}]$

> $Q = (7.62 \times 10^{-4}) \times (2.7225 \times 10^{-8})$
> $Q = 2.074 \times 10^{-11}$
> $\mathbf{Q = 2.07 \times 10^{-11}}$

What is Q?

The reaction quotient (Q) tells you the current state of the system BEFORE equilibrium is reached. It has the same mathematical form as K_{sp}, but uses current concentrations instead of equilibrium concentrations.

Part E(iii) Answer - Predicting Precipitation:

Step 1: Compare Q to K_{sp}

$Q = 2.07 \times 10^{-11}$

$K_{sp} = 5.61 \times 10^{-12}$

$Q > K_{sp}$ (because $2.07 \times 10^{-11} > 5.61 \times 10^{-12}$)

Step 2: Apply the precipitation rule

Precipitation Rules:

- If **$Q > K_{sp}$** → Too many ions → Precipitate FORMS
- If **$Q < K_{sp}$** → Too few ions → Solid DISSOLVES
- If **$Q = K_{sp}$** → Just right → System at EQUILIBRIUM

Step 3: Make the prediction

YES, a precipitate will form.

Justification:

Since $Q > K_{sp}$, the solution currently contains MORE dissolved ions than it can hold at equilibrium (it's supersaturated). To reach equilibrium, the system must decrease the ion concentrations by forming solid $Mg(OH)_2$ precipitate. The reaction will shift to the left (toward reactants) until Q decreases to equal K_{sp}.

Think of it like a bathtub:

K_{sp} is like the maximum water capacity of the tub. Q is the current water level. If $Q > K_{sp}$, you have too much water (overflow = precipitate forms). The water (ions) must leave the tub (solution) to reach the normal level (equilibrium).

4 PRACTICE EXERCISES - Part E

Exercise E1:

Silver chloride dissolves according to the equation: $AgCl(s) \rightleftharpoons Ag^{+}(aq) + Cl^{-}(aq)$, $K_{sp} = 1.8 \times 10^{-10}$

(i) Write the K_{sp} expression for AgCl.

(ii) A solution has $[Ag^{+}] = 2.0 \times 10^{-5}$ M and $[Cl^{-}] = 3.0 \times 10^{-5}$ M. Calculate Q.

(iii) Will a precipitate form? Justify your answer.

Answer (i): $K_{sp} = [Ag^{+}][Cl^{-}]$
(Both ions have coefficient of 1, so neither is raised to a power)

Answer (ii):
$Q = [Ag^{+}][Cl^{-}]$
$Q = (2.0 \times 10^{-5})(3.0 \times 10^{-5})$
$Q = 6.0 \times 10^{-10}$

Answer (iii): YES, a precipitate will form.
Justification: $Q = 6.0 \times 10^{-10}$ and $K_{sp} = 1.8 \times 10^{-10}$. Since $Q > K_{sp}$, the solution contains more dissolved ions than can exist at equilibrium. The system must form solid AgCl precipitate to decrease the ion concentrations until Q equals K_{sp}.

Exercise E2:

Calcium fluoride dissolves according to: $CaF_2(s) \rightleftharpoons Ca^{2+}(aq) + 2F^-(aq)$, $K_{sp} = 3.9 \times 10^{-11}$

(i) Write the K_{sp} expression for CaF_2.

(ii) A solution has $[Ca^{2+}] = 1.5 \times 10^{-4}$ M and $[F^-] = 5.0 \times 10^{-4}$ M. Calculate Q.

(iii) Will a precipitate form? Justify your answer.

Answer (i): $K_{sp} = [Ca^{2+}][F^-]^2$

(F^- has coefficient of 2 in the balanced equation, so it's squared)

Answer (ii):

$Q = [Ca^{2+}][F^-]^2$

$Q = (1.5 \times 10^{-4})(5.0 \times 10^{-4})^2$

$Q = (1.5 \times 10^{-4})(2.5 \times 10^{-7})$

$Q = 3.75 \times 10^{-11}$

Answer (iii): NO, a precipitate will NOT form.

Justification: $Q = 3.75 \times 10^{-11}$ and $K_{sp} = 3.9 \times 10^{-11}$. Since $Q < K_{sp}$ (Q is slightly less than K_{sp}), the solution is not yet saturated. The system can hold more dissolved ions without forming a precipitate. The solution is unsaturated.

Exercise E3:

Lead(II) iodide dissolves according to: $PbI_2(s) \rightleftharpoons Pb^{2+}(aq) + 2I^-(aq)$, $K_{sp} = 7.9 \times 10^{-9}$

(i) Write the K_{sp} expression for PbI_2.

(ii) A solution has $[Pb^{2+}] = 3.0 \times 10^{-3}$ M and $[I^-] = 1.0 \times 10^{-3}$ M. Calculate Q.

(iii) Will a precipitate form? Justify your answer.

Answer (i): $K_{sp} = [Pb^{2+}][I^-]^2$

(I^- has coefficient of 2, so it's squared)

Answer (ii):

$Q = [Pb^{2+}][I^-]^2$

$Q = (3.0 \times 10^{-3})(1.0 \times 10^{-3})^2$

$Q = (3.0 \times 10^{-3})(1.0 \times 10^{-6})$

$Q = 3.0 \times 10^{-9}$

Answer (iii): NO, a precipitate will NOT form.

Justification: $Q = 3.0 \times 10^{-9}$ and $K_{sp} = 7.9 \times 10^{-9}$. Since $Q < K_{sp}$, the current ion concentrations are below saturation. More solid could dissolve before reaching equilibrium. No precipitate will form because the solution is unsaturated.

Exercise E4:

Iron(III) hydroxide dissolves according to: $Fe(OH)_3(s) \rightleftharpoons Fe^{3+}(aq) + 3OH^{-}(aq)$, $K_{sp} = 6.3 \times 10^{-38}$

(i) Write the K_{sp} expression for $Fe(OH)_3$.

(ii) A solution has $[Fe^{3+}] = 2.0 \times 10^{-10}$ M and $[OH^{-}] = 5.0 \times 10^{-10}$ M. Calculate Q.

(iii) Will a precipitate form? Justify your answer.

> **Answer (i):** $K_{sp} = [Fe^{3+}][OH^{-}]^3$
> (OH^{-} has coefficient of 3, so it's cubed)
>
> **Answer (ii):**
> $Q = [Fe^{3+}][OH^{-}]^3$
> $Q = (2.0 \times 10^{-10})(5.0 \times 10^{-10})^3$
> $Q = (2.0 \times 10^{-10})(1.25 \times 10^{-28})$
> $Q = 2.5 \times 10^{-38}$
>
> **Answer (iii):** NO, a precipitate will NOT form.
> **Justification:** $Q = 2.5 \times 10^{-38}$ and $K_{sp} = 6.3 \times 10^{-38}$. Since $Q < K_{sp}$, the solution is unsaturated and can hold more dissolved ions before reaching equilibrium. The system would need higher ion concentrations to form a precipitate.

Q1 - PART F: Le Chatelier's Principle & Solubility

1 ORIGINAL EXAM QUESTION

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.

Context: Recall the equilibrium:

$$Mg(OH)_2(s) \rightleftharpoons Mg^{2+}(aq) + 2OH^{-}(aq)$$

2 OFFICIAL SCORING GUIDELINES

AP College Board Official AP® Chemistry 2025 Scoring Guidelines:

F: Point 10 - Decrease. The H^+ from $HNO_3(aq)$ will react with OH^-, decreasing $[OH^-]$ and causing $Q < K_{sp}$. As a result, more $Mg(OH)_2(s)$ will dissolve until equilibrium is reestablished, resulting in less $Mg(OH)_2(s)$.

3 DETAILED EXPLANATION

Part F Answer - Effect of Adding Acid:

Answer:

The amount of undissolved $Mg(OH)_2(s)$ will **DECREASE**.

Step-by-Step Justification:

Step 1: Identify what happens when HNO_3 is added

HNO_3 is a strong acid that completely dissociates:

$HNO_3(aq) \rightarrow H^+(aq) + NO_3^-(aq)$

This adds H^+ ions to the solution.

Step 2: Recognize the acid-base neutralization reaction

The H^+ ions react with OH^- ions in solution:

$$\mathbf{H^+(aq) + OH^-(aq) \rightarrow H_2O(l)}$$

This reaction **removes OH^- ions** from solution, decreasing $[OH^-]$.

Step 3: Determine the effect on Q

Since $[OH^-]$ decreases:

$Q = [Mg^{2+}][OH^-]^2$ will DECREASE

The solution was originally at equilibrium ($Q = K_{sp}$), but now:

$Q < K_{sp}$

Step 4: Apply Le Chatelier's Principle

When $Q < K_{sp}$, the solution becomes **unsaturated** (not enough ions).

To restore equilibrium, the reaction shifts **RIGHT** (toward products):

$$Mg(OH)_2(s) \rightarrow Mg^{2+}(aq) + 2OH^-(aq)$$

More solid $Mg(OH)_2$ **dissolves** to replace the OH^- ions that were neutralized.

Step 5: Final conclusion

Since more $Mg(OH)_2(s)$ dissolves, the amount of undissolved solid **DECREASES**.

Think of it like this:

Analogy: Imagine a crowd of people (OH^- ions) at a concert. The solid $Mg(OH)_2$ is like people waiting outside trying to get in. The venue is at capacity (equilibrium).

When you add acid (H^+), it's like people leaving the concert (OH^- being neutralized). Now there's room for more people to enter from outside. The waiting line (solid $Mg(OH)_2$) gets shorter as more people (ions) enter the venue (dissolve into solution).

Common Ion Effect vs. Acid Addition:

Adding OH^- (common ion) → Q increases → More precipitate forms → Solid increases

Adding H^+ (neutralizes OH^-) → Q decreases → More solid dissolves → Solid decreases

🔄 PRACTICE EXERCISES - Part F

Exercise F1:

A saturated solution of calcium carbonate contains undissolved $CaCO_3(s)$:

$$CaCO_3(s) \rightleftharpoons Ca^{2+}(aq) + CO_3^{2-}(aq)$$

A student adds HCl(aq) to the solution. The H^+ ions react with CO_3^{2-} according to:

$$H^+(aq) + CO_3^{2-}(aq) \rightarrow HCO_3^-(aq)$$

Does the amount of undissolved $CaCO_3(s)$ increase, decrease, or remain the same? Justify your answer.

Answer: DECREASE

Justification:

The H^+ from HCl reacts with CO_3^{2-} ions, removing them from solution. This decreases $[CO_3^{2-}]$, causing $Q = [Ca^{2+}][CO_3^{2-}]$ to decrease. Since $Q < K_{sp}$, the system is no longer at equilibrium. To restore equilibrium, the reaction shifts right (toward products), causing more $CaCO_3(s)$ to dissolve. Therefore, the amount of undissolved solid decreases.

Exercise F2:

A saturated solution of iron(II) hydroxide contains undissolved $Fe(OH)_2(s)$:

$$Fe(OH)_2(s) \rightleftharpoons Fe^{2+}(aq) + 2OH^-(aq)$$

A student adds solid NaOH to the solution. Does the amount of undissolved $Fe(OH)_2(s)$ increase, decrease, or remain the same? Justify your answer.

Answer: INCREASE

Justification:

NaOH is a strong base that dissociates completely: $NaOH \rightarrow Na^+ + OH^-$. This adds OH^- ions to the solution, increasing $[OH^-]$. Since $Q = [Fe^{2+}][OH^-]^2$ increases, $Q > K_{sp}$. The solution becomes supersaturated. To restore equilibrium, the reaction shifts left (toward reactants), forming more solid $Fe(OH)_2$ precipitate. Therefore, the amount of undissolved solid increases. This is the common ion effect.

Exercise F3:

A saturated solution of zinc hydroxide contains undissolved $Zn(OH)_2(s)$:

$$Zn(OH)_2(s) \rightleftharpoons Zn^{2+}(aq) + 2OH^-(aq)$$

A student adds $H_2SO_4(aq)$, which provides H^+ ions that neutralize OH^-. Does the amount of undissolved $Zn(OH)_2(s)$ increase, decrease, or remain the same? Justify your answer.

> **Answer: DECREASE**
>
> **Justification:**
> The H^+ ions from H_2SO_4 react with OH^- ions: $H^+ + OH^- \rightarrow H_2O$. This neutralization removes OH^- from solution, decreasing $[OH^-]$. As a result, $Q = [Zn^{2+}][OH^-]^2$ decreases, and $Q < K_{sp}$. The solution becomes unsaturated. To restore equilibrium, the reaction shifts right (toward products), causing more $Zn(OH)_2(s)$ to dissolve. Therefore, the amount of undissolved solid decreases.

Exercise F4:

A saturated solution of silver acetate contains undissolved $AgC_2H_3O_2(s)$:

$$AgC_2H_3O_2(s) \rightleftharpoons Ag^+(aq) + C_2H_3O_2^-(aq)$$

A student adds solid $AgNO_3$, which provides additional Ag^+ ions. Does the amount of undissolved $AgC_2H_3O_2(s)$ increase, decrease, or remain the same? Justify your answer.

> **Answer: INCREASE**
>
> **Justification:**
> $AgNO_3$ dissociates completely: $AgNO_3 \rightarrow Ag^+ + NO_3^-$. This adds Ag^+ ions to the solution, increasing $[Ag^+]$. Since $Q = [Ag^+][C_2H_3O_2^-]$ increases, $Q > K_{sp}$. The solution becomes supersaturated with ions. To restore equilibrium, the reaction shifts left (toward reactants), forming more solid $AgC_2H_3O_2$ precipitate. Therefore, the amount of undissolved solid increases. This demonstrates the common ion effect with Ag^+.

2025 Edition

What's Inside

Four comprehensive components for complete exam preparation

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The actual questions from the AP® Chemistry 2025 exam with all diagrams, data, and instructions.

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OFFICIAL Scoring Guidelines

The official answer from College Board with point values and acceptable responses.

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DETAILED Explanation

Step-by-step breakdown with analogies, concepts, and why the answer works.

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PRACTICE Exercises

Additional practice problems for each concept with complete solutions (at the end of each question part).

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