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Topic 4.2: Net Ionic Equations

Worksheet · AP Chemistry

UNIT 4 · CHEMICAL REACTIONS

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How to Use This Worksheet

Work in order. Section A checks the ideas: the three levels of equation, spectator ions, and which species split into ions and which stay whole. Section B builds the skill: writing molecular, complete ionic and net ionic equations for precipitation, acid-base, weak acid and gas-forming reactions. Section C combines prediction, counting and calculation in exam style.

Every value you need is stated in the question. Where a molar mass is needed, it is given in the question, so each question can be answered from the text alone.

Do not look at the answer key until you have attempted every question.

Section A: Recall and Concepts

A1. (a) State what a molecular equation shows. (b) State what a complete ionic equation shows, and which compounds are written as separated ions in it. (c) State what a net ionic equation shows. (d) For the reaction between $AgNO_3(aq)$ and NaCl(aq), state which of the three levels shows that Na^+ takes no part in the reaction.

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A2. The complete ionic equation for the reaction between $BaCl_2(aq)$ and $Na_2SO_4(aq)$ is: $Ba^{2+}(aq) + 2Cl^-(aq) + 2Na^+(aq) + SO_4^{2-}(aq) \rightarrow BaSO_4(s) + 2Na^+(aq) + 2Cl^-(aq)$ (a) Define the term spectator ion. (b) Identify the spectator ions in this equation. (c) Write the net ionic equation. (d) Show that the net ionic equation is balanced for charge.

A3. For each species, state whether it is written as separated ions or as an intact formula in a complete ionic equation, and give the reason. (a) $KNO_3(aq)$ (b) $AgCl(s)$ (c) $CH_3COOH(aq)$ (d) $H_2O(l)$ (e) $CO_2(g)$ (f) $HNO_3(aq)$ (g) $C_6H_{12}O_6(aq)$ (h) $NH_3(aq)$ (i) $Ba(OH)_2(aq)$

A4. Use the solubility anchors to classify each compound as soluble or insoluble in water, justifying each answer with the anchor that decides it. (a) $PbCl_2$ (b) K_2SO_4 (c) $CaCO_3$ (d) $(NH_4)_2S$ (e) $BaSO_4$ (f) $NaNO_3$

A5. (a) Explain why a net ionic equation is said to show the actual chemical change in a reaction. (b) Solutions of KNO_3 and NaCl are mixed. List the ions present in the mixture, and explain why no net ionic equation can be written for it. (c) State the three kinds of product whose formation removes ions from solution and allows a reaction between two solutions to proceed. (d) A student claims that because the mixture in part (b) contains four different ions, a chemical reaction must have taken place. Explain the error in the claim.

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Section B: Core Practice

B1. Silver nitrate solution reacts with sodium bromide solution to form a pale yellow precipitate of silver bromide: $AgNO_3(aq) + NaBr(aq) \rightarrow AgBr(s) + NaNO_3(aq)$. (a) Write the complete ionic equation. (b) Identify the spectator ions. (c) Write the net ionic equation. (d) Show that the net ionic equation is balanced for atoms and for charge.

B2. Calcium chloride solution reacts with sodium carbonate solution: $CaCl_2(aq) + Na_2CO_3(aq) \rightarrow CaCO_3(s) + 2NaCl(aq)$. (a) Write the complete ionic equation. (b) Write the net ionic equation, and name the precipitate. (c) Count the dissolved ion units on the left of the complete ionic equation, and state how many of them are spectators.

B3. Hydrochloric acid reacts with potassium hydroxide solution: $HCl(aq) + KOH(aq) \rightarrow KCl(aq) + H_2O(l)$. (a) Write the complete ionic equation. (b) Write the net ionic equation. (c) Nitric acid is reacted with sodium hydroxide solution instead. Explain why the net ionic equation is the same, naming the spectators in this second reaction. (d) Write the molecular equation for the reaction in part (c).

B4. Acetic acid reacts with sodium hydroxide solution: $CH_3COOH(aq) + NaOH(aq) \rightarrow CH_3COONa(aq) + H_2O(l)$. (a) Write the complete ionic equation. (b) Write the net ionic equation. (c) Explain why CH_3COOH is not split into ions, and state how this net ionic equation differs from the one for HCl with NaOH.

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B5. Zinc metal reacts with dilute hydrochloric acid: $Zn(s) + 2HCl(aq) \rightarrow ZnCl_2(aq) + H_2(g)$. (a) Write the complete ionic equation. (b) Write the net ionic equation, and identify the spectator ion. (c) State what is observed as the reaction proceeds, and which product each observation comes from. (d) Describe the change that each zinc atom undergoes as it becomes a Zn^{2+} ion, and state what the hydrogen ions gain.

B6. For each pair of solutions, predict whether a precipitate forms. Where a reaction occurs, write the net ionic equation. (a) $KNO_3(aq)$ and $NaCl(aq)$ (b) $Pb(NO_3)_2(aq)$ and $NaCl(aq)$ (c) $Na_2S(aq)$ and $CdCl_2(aq)$ (d) $NH_4Cl(aq)$ and $NaNO_3(aq)$ (e) $(NH_4)_2SO_4(aq)$ and $BaCl_2(aq)$

Section C: Exam Style

C1. A student mixes 50.0 mL of 0.200 M $Pb(NO_3)_2(aq)$ with excess $KI(aq)$. A yellow precipitate of PbI_2 forms. The molar mass of PbI_2 is 461 g/mol. (a) Write the balanced molecular equation. (b) Write the complete ionic equation, and state the total number of dissolved ion units on its left side and how many of them are spectators. (c) Write the net ionic equation, and show that it is balanced for charge. (d) Calculate the moles of Pb^{2+} in the 50.0 mL sample, the moles of PbI_2 formed, and the mass of precipitate produced. (e) The precipitate is filtered off. State which ions remain in the filtrate, and explain why no Pb^{2+} is among them.

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C2. A colourless solution is known to be either sodium sulfate solution or sodium chloride solution. A student adds barium chloride solution to a sample and a white precipitate forms. (a) Identify the solution, and name the precipitate. (b) Write the net ionic equation for the test reaction. (c) Explain why the other candidate solution would give no precipitate with barium chloride solution. (d) The student adds $Pb(NO_3)_2(aq)$ to a fresh sample of the identified solution. Predict whether a precipitate forms, and write the net ionic equation if one does. (e) Name the spectator ions in the test reaction of part (b).

C3. Excess dilute hydrochloric acid is added to two separate test tubes. Tube 1 holds $Na_2CO_3(aq)$. Tube 2 holds solid $CaCO_3$. Both tubes fizz vigorously. (a) For Tube 1, write the molecular equation, the complete ionic equation and the net ionic equation, and identify the gas. (b) For Tube 2, write the molecular equation and the net ionic equation. (c) Explain why CO_3^{2-} appears as a free ion in the net ionic equation for Tube 1, while $CaCO_3$ appears as a whole formula in the net ionic equation for Tube 2. (d) State the driving force that both reactions share, and explain how it helps the reactions go to completion.

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Answer Key

A1. (a) All reactants and products as complete formulas, with state symbols: it shows what is mixed and what forms, but not that dissolved compounds exist as ions. (b) Every dissolved species, with soluble ionic compounds and other strong electrolytes written as their separated ions; solids, liquids, gases, weak electrolytes and nonelectrolytes stay as intact formulas. (c) Only the species that undergo chemical change, with spectator ions removed. (d) The net ionic equation: Na^+ is absent from it precisely because it does not react, while the complete ionic equation still shows it on both sides.

A2. (a) An ion that appears identically on both sides of a complete ionic equation, dissolved and unchanged throughout, taking no part in the reaction. (b) Na^+ and Cl^-: both appear on the left and the right, unchanged. (c) $Ba^{2+}(aq) + SO_4^{2-}(aq) \rightarrow BaSO_4(s)$. (d) Left side charge: (+2) + (-2) = 0. Right side: $BaSO_4$ is a neutral solid, charge 0. The charges match, and the atoms, one Ba, one S and four O on each side, match as well.

A3. (a) Separated ions, K^+ and NO_3^-: a soluble ionic salt is a strong electrolyte and dissociates completely. (b) Intact formula: it is a solid, and solids are not separated into ions. (c) Intact formula: acetic acid is a weak acid, a weak electrolyte that ionizes only slightly. (d) Intact formula: water is a pure liquid and is written whole, never as H^+ and OH^-. (e) Intact formula: it is a gas, written as CO_2 molecules. (f) Separated ions, H^+ and NO_3^-: nitric acid is one of the strong acids and dissociates completely. (g) Intact formula: glucose is a nonelectrolyte, dissolving as whole molecules and forming no ions. (h) Intact formula: ammonia is a weak base, a weak electrolyte that ionizes only slightly. (i) Separated ions, one Ba^{2+} and two OH^-: barium hydroxide is a strong base and dissociates completely.

A4. (a) Insoluble: chlorides are soluble except those of Ag^+ and Pb^{2+}, and $PbCl_2$ is the named exception. (b) Soluble: it is a Group 1 salt, and potassium sulfate has no insoluble partner among the sulfate exceptions. (c) Insoluble: carbonates are insoluble except those of Group 1 and NH_4^+, and Ca^{2+} is neither. (d) Soluble: sulfides are usually insoluble, but ammonium salts are always soluble, and the NH_4^+ anchor overrides the sulfide one. (e) Insoluble: $BaSO_4$ is the standard sulfate exception. (f) Soluble: all nitrates are soluble, with no exceptions.

A5. (a) Because it deletes every species that passes through unchanged and keeps only the particles that are consumed and formed: the precipitate, gas or water being made, and the ions used up in making it. (b) The mixture contains K^+, Na^+, NO_3^- and Cl^-. The possible products, KCl and $NaNO_3$, are both soluble, so a complete ionic equation would show the same four ions on both sides; everything cancels, leaving nothing, which means no reaction has occurred. (c) An insoluble solid (a precipitate), a gas, and water, the weak electrolyte formed in neutralisation. (d) The claim confuses presence with change. The same four ions exist before and after mixing; none is

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consumed and no new substance forms. A reaction requires species to change, not merely to be present together in one solution.

B1. (a) $Ag^+(aq) + NO_3^-(aq) + Na^+(aq) + Br^-(aq) \rightarrow AgBr(s) + Na^+(aq) + NO_3^-(aq)$. (b) Na^+ and NO_3^-. (c) $Ag^+(aq) + Br^-(aq) \rightarrow AgBr(s)$. (d) Atoms: one Ag and one Br on each side. Charge: left (+1) + (-1) = 0; right, a neutral solid, 0. Both balance.

B2. (a) $Ca^{2+}(aq) + 2Cl^-(aq) + 2Na^+(aq) + CO_3^{2-}(aq) \rightarrow CaCO_3(s) + 2Na^+(aq) + 2Cl^-(aq)$. (b) $Ca^{2+}(aq) + CO_3^{2-}(aq) \rightarrow CaCO_3(s)$: the precipitate is calcium carbonate. (c) Six dissolved ion units on the left: one Ca^{2+}, two Cl^-, two Na^+ and one CO_3^{2-}. Four are spectators: the two Na^+ and the two Cl^-.

B3. (a) $H^+(aq) + Cl^-(aq) + K^+(aq) + OH^-(aq) \rightarrow K^+(aq) + Cl^-(aq) + H_2O(l)$. (b) $H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$. (c) Every strong acid supplies H^+ and every strong base supplies OH^-, and those are the only species that change; the rest are spectators. In the second reaction the spectators are Na^+ and NO_3^-, so cancelling them leaves the same net equation, $H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$. (d) $HNO_3(aq) + KOH(aq) \rightarrow KNO_3(aq) + H_2O(l)$.

B4. (a) $CH_3COOH(aq) + Na^+(aq) + OH^-(aq) \rightarrow Na^+(aq) + CH_3COO^-(aq) + H_2O(l)$. (b) $CH_3COOH(aq) + OH^-(aq) \rightarrow CH_3COO^-(aq) + H_2O(l)$. (c) Acetic acid is a weak electrolyte: only a small fraction of its molecules ionize, so it is written whole rather than as H^+ and CH_3COO^- ions that are barely present. The difference is that the weak acid molecule itself appears in the net equation, in place of the H^+ that a strong acid would supply.

B5. (a) $Zn(s) + 2H^+(aq) + 2Cl^-(aq) \rightarrow Zn^{2+}(aq) + 2Cl^-(aq) + H_2(g)$. (b) $Zn(s) + 2H^+(aq) \rightarrow Zn^{2+}(aq) + H_2(g)$; the spectator is Cl^-. (c) Bubbles of gas form on the metal and the zinc gradually dissolves away. The bubbles are the hydrogen gas product; the shrinking metal is zinc atoms leaving the solid as Zn^{2+} ions entering the solution. (d) Each zinc atom loses two electrons as it becomes a Zn^{2+} ion. Each hydrogen ion gains one electron, and two hydrogen atoms together form the H_2 molecule that leaves as gas.

B6. (a) No precipitate. Both possible products, KCl and $NaNO_3$, are soluble, so all four ions stay dissolved. (b) Yes: $PbCl_2$ is an insoluble chloride. Net ionic: $Pb^{2+}(aq) + 2Cl^-(aq) \rightarrow PbCl_2(s)$. (c) Yes: CdS is an insoluble sulfide and neither ion is Group 1 or NH_4^+. Net ionic: $Cd^{2+}(aq) + S^{2-}(aq) \rightarrow CdS(s)$. (d) No precipitate. NH_4Cl, $NaNO_3$, and the swapped products NaCl and NH_4NO_3 are all soluble, so nothing forms. (e) Yes: $BaSO_4$ is an insoluble sulfate, even though NH_4^+ is present and the other product, NH_4Cl, is soluble. Net ionic: $Ba^{2+}(aq) + SO_4^{2-}(aq) \rightarrow BaSO_4(s)$.

C1. (a) $Pb(NO_3)_2(aq) + 2KI(aq) \rightarrow PbI_2(s) + 2KNO_3(aq)$. (b) $Pb^{2+}(aq) + 2NO_3^-(aq) + 2K^+(aq) + 2I^-(aq) \rightarrow PbI_2(s) + 2K^+(aq) + 2NO_3^-(aq)$. Left side dissolved ion units: 1 + 2 + 2 + 2 = 7. Spectators: the two K^+ and the two NO_3^-, four units in total. (c) $Pb^{2+}(aq) + 2I^-(aq) \rightarrow PbI_2(s)$. Charge: left (+2) + 2(-1) = 0; right, a neutral solid, 0, so charge balances; Pb and I atoms also balance, one Pb and two I on each side. (d) Moles of Pb^{2+} = 0.0500 L × 0.200 mol/L = 0.0100 mol. The net equation shows one PbI_2 formed per Pb^{2+}, and Pb^{2+} is the limiting ion because KI is in excess, so moles of PbI_2 = 0.0100 mol. Mass = 0.0100 × 461 = 4.61 g of precipitate. (e) The filtrate contains the spectator ions, K^+ and NO_3^-,

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plus the I^- left over from the excess KI. No Pb^{2+} remains: PbI_2 is insoluble and iodide was present in excess, so every Pb^{2+} ion was taken out of solution into the solid.

C2. (a) The solution is sodium sulfate, and the white precipitate is $BaSO_4$. (b) $Ba^{2+}(aq) + SO_4^{2-}(aq) \rightarrow BaSO_4(s)$. (c) Sodium chloride solution contains Cl^-, and $BaCl_2$ is itself soluble: the possible products are $BaCl_2$ and NaCl, both soluble, and chloride is insoluble only with Ag^+ or Pb^{2+}, so no pairing precipitates and nothing is observed. (d) Yes, a precipitate forms: $PbSO_4$ is one of the insoluble sulfates. Net ionic: $Pb^{2+}(aq) + SO_4^{2-}(aq) \rightarrow PbSO_4(s)$. (e) Na^+ and Cl^-: the sodium ions come from the sample and the chloride ions from the barium chloride solution, and both appear unchanged on either side of the complete ionic equation.

C3. (a) Molecular: $2HCl(aq) + Na_2CO_3(aq) \rightarrow 2NaCl(aq) + H_2O(l) + CO_2(g)$. Complete ionic: $2H^+(aq) + 2Cl^-(aq) + 2Na^+(aq) + CO_3^{2-}(aq) \rightarrow 2Na^+(aq) + 2Cl^-(aq) + H_2O(l) + CO_2(g)$. Net ionic: $2H^+(aq) + CO_3^{2-}(aq) \rightarrow H_2O(l) + CO_2(g)$. The gas is carbon dioxide. (b) Molecular: $CaCO_3(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + H_2O(l) + CO_2(g)$. Net ionic: $CaCO_3(s) + 2H^+(aq) \rightarrow Ca^{2+}(aq) + H_2O(l) + CO_2(g)$. (c) Sodium carbonate is soluble, so in Tube 1 the carbonate exists in solution as free CO_3^{2-} ions before the acid is added, and that ion is what reacts. Calcium carbonate is an insoluble solid: it never dissociates into free ions, so the solid itself is the reacting species and is written whole, releasing Ca^{2+} only as the acid consumes it. (d) Both produce a gas that escapes from the mixture. Because the CO_2 leaves, it cannot take part in any reverse reaction, so its escape pulls the reaction forward until the carbonate is used up.

Continue Revising

Topic 4.2 Revision Notes

Topic 4.2 Quiz: Net Ionic Equations

Previous Worksheet: Topic 4.1 Introduction to Reactions

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