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Topic 4.3: Representations of Reactions

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 representation, what each one shows, and the conservation checks every diagram must pass. Section B builds the skill: describing before-and-after boxes in exact words and counts, translating between equations and diagrams, and reading leftovers. Section C combines translation, limiting reactants and error-hunting in exam style.

Every diagram in this worksheet is described completely in words, with exact particle counts. Where an equation is needed, it is stated in the question, so each question can be answered from the text alone. In your answers, describe diagrams the same way: name every species, give its count, and say where it is.

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

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Section A: Recall and Concepts

A1. (a) Name the three levels at which a chemical reaction can be represented. (b) State one kind of information that each level shows best. (c) Which level states the mole ratios of reactants and products, and through what feature of that representation? (d) State one thing a chemical equation cannot show about a reaction.

A2. A diagram uses this key: a small circle is a hydrogen atom, a large circle is an oxygen atom, and joined circles are one molecule. The before box holds 6 H_2 molecules and 3 O_2 molecules. The after box holds 6 H_2O molecules, each drawn as one large circle joined to two small circles. (a) Count the hydrogen atoms and the oxygen atoms in the before box. (b) Count the hydrogen atoms and the oxygen atoms in the after box, and state what the comparison shows. (c) Write the balanced chemical equation that the diagram represents. (d) Describe what has happened to the connections between the atoms.

A3. For each case, describe exactly what the particulate diagram should show. Water molecules are present throughout and every dissolved species is spread evenly. (a) Sodium chloride dissolving in water. (b) Glucose, $C_6H_{12}O_6$, dissolving in water. (c) Hydrochloric acid, a strong acid, in water. (d) Hydrofluoric acid, HF, a weak acid, in water. (e) A precipitate of AgCl forming from its ions, with spectator ions omitted from the drawing.

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A4. (a) At the particulate level, what is a spectator ion? (b) Why are spectator ions often omitted from a reaction diagram? (c) A diagram keeps the spectator ions in the picture: after mixing, it shows a solid cluster plus separated Na^+ and NO_3^- ions. Which level of equation also keeps every species in this way, and which level deletes the unchanged separated ions? (d) A mixing diagram shows the same separated ions, in the same counts and the same groupings, before and after. State the conclusion and justify it.

A5. (a) State the two conservation checks that a before-and-after diagram must pass. (b) A student draws one fewer Cl^- in the after box of a precipitation diagram, explaining that the missing ion "became part of the solid". Explain the error, and state where the missing particle should be drawn. (c) Explain why a solid product is drawn as a cluster rather than as particles spread evenly through the liquid. (d) A diagram passes both checks in part (a), but the atoms appear in new groupings in the after box. State what kind of change the diagram represents, and why.

Section B: Core Practice

B1. A reaction is represented by $2Al(s) + 3Cu^{2+}(aq) \rightarrow 2Al^{3+}(aq) + 3Cu(s)$. A before box holds 4 Al atoms and 6 Cu^{2+} ions, and the reaction goes to completion. (a) Describe the after box exactly, with counts. (b) Show that the atoms balance, and that the total charge of the solution is the same before and after. (c) State, in words, what the diagram shows happening to the aluminium and to the copper. (d) A student's after box shows 4 Al^{3+} ions but only 4 Cu atoms. Use the counts to identify the error.

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B2. A before box for a neutralisation holds 4 H^+ ions, 4 OH^- ions, 4 Na^+ ions and 4 Cl^- ions, all separated. (a) Describe the after box exactly, with counts. (b) Write the net ionic equation for the change. (c) Describe the before and after diagrams if the spectator ions are omitted. (d) A different before box, with spectators omitted, holds 5 H^+ ions and 3 OH^- ions. Describe its after box, and name the limiting ion.

B3. Beaker 1 holds 3 Ba^{2+} ions and 6 Cl^- ions, all separated. Beaker 2 holds 6 Na^+ ions and 3 SO_4^{2-} ions, all separated. The beakers are mixed and the reaction goes to completion. (a) Describe the after picture exactly, with counts. (b) Write the net ionic equation for the change. (c) Show that the total charge dissolved before mixing equals the total charge in the after picture. (d) Beaker 2 instead holds 4 Na^+ ions and 2 SO_4^{2-} ions. Describe the after picture now, and name the limiting ion.

B4. Methane burns according to $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$. A before box holds 3 CH_4 molecules and 8 O_2 molecules, and the reaction runs until one reactant is used up. (a) Decide which reactant is limiting, showing your counting. (b) Describe the after box exactly, with counts. (c) Verify the atom counts for carbon, hydrogen and oxygen. (d) State what the leftover O_2 molecules in the after box tell you about the starting mixture.

B5. Two boxes represent 10 acid units each in the same volume of water. Box X holds only 10 H^+ ions and 10 Cl^- ions. Box Y holds 9 intact HF molecules, 1 H^+ ion and 1 F^- ion. (a) Which box represents the strong acid? Justify your answer. (b) Calculate the percentage of the HF molecules in Box Y that have ionised. (c) A student redraws Box Y showing 10 H^+ ions and 10 F^- ions. State the error, and what the redrawn box claims about HF. (d) Box X is diluted by adding more water. State what changes in the drawing and what stays the same.

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B6. A sample of solid calcium chloride contains 3 $CaCl_2$ formula units. (a) Describe the particle picture of the solid. (b) Describe the picture after the sample dissolves in water. (c) Show that the dissolved ions balance charge. (d) A sample of 3 glucose units dissolves instead. Describe that picture, and state the difference in what breaks apart in the two cases.

Section C: Exam Style

C1. A before box shows a solid block of 5 Zn atoms in a solution holding 3 Cu^{2+} ions and 3 SO_4^{2-} ions, all separated. The reaction $Zn + Cu^{2+} \rightarrow Zn^{2+} + Cu$ runs until one reactant is used up. (a) Describe the after box completely: every species, its count, and where it is. (b) Identify the limiting reactant, justifying your answer with the counts. (c) Verify the totals of zinc and of copper, and the total charge of the solution, before and after. (d) A classmate claims the after box should show 5 Zn^{2+} ions, because all of the zinc was in contact with the solution. Use the counts to explain the error.

C2. The reaction $2H_2 + O_2 \rightarrow 2H_2O$ starts from a box holding 4 H_2 molecules and 3 O_2 molecules, and runs to completion. (a) Describe the correct after box, with counts. (b) Diagram P shows 4 H_2O molecules and 3 O_2 molecules. Show, with counts, which element fails to be conserved. (c) Diagram Q shows 6 H_2O molecules and nothing else. Show, with counts, which element fails to be conserved, and state what Q claims that the starting box cannot supply. (d) State the two checks that would have caught both errors immediately.

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C3. A before box shows a solid block of 3 Mg atoms in a solution holding 4 H^+ ions and 4 Cl^- ions, all separated. The reaction $Mg + 2H^+ \rightarrow Mg^{2+} + H_2$ runs until one reactant is used up. (a) Decide which reactant is limiting, showing your counting. (b) Describe the after box exactly, including any product that leaves as a gas. (c) Verify the counts of magnesium, hydrogen and chlorine, and the total charge of the solution, before and after. (d) Write the net ionic equation, and state the role of Cl^-.

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Answer Key

A1. (a) The macroscopic level, the symbolic level and the particulate level. (b) Macroscopic: the observations, such as a precipitate forming, a colour change, a gas or a temperature change. Symbolic: the mole ratios and the phases of every species. Particulate: which particles are present, how they are grouped, and what is left over. (c) The symbolic level, through the coefficients of the balanced equation. (d) The arrangement of the particles: where they are, how they are grouped, how they are spaced, or which particles are touching. An equation also cannot show, by itself, what a particular mixture leaves over.

A2. (a) Hydrogen: 6 × 2 = 12 atoms. Oxygen: 3 × 2 = 6 atoms. (b) Hydrogen: 6 × 2 = 12 atoms. Oxygen: 6 × 1 = 6 atoms. The totals are identical, so the atoms are conserved between the two boxes. (c) $2H_2 + O_2 \rightarrow 2H_2O$. (d) Before, every hydrogen atom was joined to another hydrogen atom and every oxygen atom to another oxygen atom. After, each oxygen atom is joined to two hydrogen atoms. Bonds have broken and new bonds have formed, regrouping the same atoms into a new substance.

A3. (a) Separate Na^+ ions and separate Cl^- ions, spread evenly among the water molecules, with no joined NaCl pairs anywhere. (b) Whole glucose molecules, each one intact, spread evenly among the water molecules: no ions and no separated atoms. (c) Only H^+ ions and Cl^- ions, separated, with no intact HCl molecules at all. (d) Mostly intact HF molecules, with a small number of separated H^+ and F^- ions among them. (e) Before: separated Ag^+ and Cl^- ions only. After: those ions locked together in one clustered lattice block, the AgCl solid, with no other solute species drawn.

A4. (a) An ion that is drawn identically before and after the reaction: dissolved and unchanged throughout, taking no part in the change. (b) They do not participate in forming the product, so leaving them out keeps the diagram focused on the species that actually change. (c) The complete ionic equation keeps every dissolved species, spectators included. The net ionic equation deletes the unchanged separated ions. (d) No reaction took place. No particle has changed its grouping, so no new substance has formed; the species have only mixed.

A5. (a) The total number of atoms of each element must be the same in both boxes, and the total charge must be the same in both boxes. (b) The chloride ion has not stopped existing: it is inside the precipitate. It should be drawn within the solid cluster, as part of the lattice. Ions change their location and grouping in a reaction; they never vanish. (c) A solid consists of particles held together in a fixed, bonded arrangement in one place. Particles spread evenly through a liquid are dissolved by definition, so a spread-out drawing would describe a solution, not a solid. (d) A chemical change. The atoms are all still present, but regrouped into new substances with different properties, which is exactly what a reaction is.

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B1. (a) 4 Al^{3+} ions in solution and 6 Cu atoms as solid metal. No Al atoms and no Cu^{2+} ions remain. (b) Aluminium: 4 before, 4 after. Copper: 6 before, 6 after. Solution charge: before, 6 × (+2) = +12; after, 4 × (+3) = +12. The charges match. (c) The aluminium atoms decrease, leaving the solid as Al^{3+} ions entering the solution, while the copper ions become copper atoms: copper metal forms as aluminium metal is consumed. (d) Copper fails to balance: 6 Cu^{2+} ions went in, so 6 Cu atoms must come out. Drawing only 4 loses 2 copper atoms and breaks conservation of atoms.

B2. (a) 4 H_2O molecules have formed, and the 4 Na^+ and 4 Cl^- ions are still separated and unchanged. (b) $H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$. (c) Before: only 4 H^+ and 4 OH^- ions, separated. After: only the 4 H_2O molecules. (d) 3 H_2O molecules and 2 H^+ ions left over. The OH^- is limiting: each OH^- consumes one H^+ to make one H_2O, so 3 OH^- use 3 of the 5 H^+, forming 3 H_2O and leaving 2 H^+.

B3. (a) A solid cluster of 3 $BaSO_4$ units, that is 3 Ba^{2+} ions locked together with 3 SO_4^{2-} ions, and 6 Na^+ and 6 Cl^- ions still separated in solution. (b) $Ba^{2+}(aq) + SO_4^{2-}(aq) \rightarrow BaSO_4(s)$. (c) Before: Beaker 1 carries 3(+2) + 6(-1) = 0 and Beaker 2 carries 6(+1) + 3(-2) = 0, a total of 0. After: the separated spectators carry 6(+1) + 6(-1) = 0 and the cluster is neutral, a total of 0. Charge is conserved. (d) A cluster of 2 $BaSO_4$ units forms; 1 Ba^{2+} ion remains dissolved, alongside 4 Na^+ and 6 Cl^- ions. SO_4^{2-} is limiting: only 2 of the 3 Ba^{2+} ions have a sulfate partner to precipitate with.

B4. (a) Each CH_4 consumes 2 O_2, so 3 CH_4 need 3 × 2 = 6 O_2. There are 8 O_2, more than enough, so CH_4 is limiting and 2 O_2 will be left over. (b) 3 CO_2 molecules, 6 H_2O molecules and 2 unchanged O_2 molecules. (c) Carbon: 3 before, 3 after. Hydrogen: 3 × 4 = 12 before, 6 × 2 = 12 after. Oxygen: 8 × 2 = 16 before; after, 3 × 2 + 6 × 1 + 2 × 2 = 16. All three balance. (d) Oxygen was present in excess. The reaction stopped because the methane ran out, not the oxygen, so the starting mixture held more O_2 than the fuel could use.

B5. (a) Box X. Every one of its acid units exists as separated ions, with no intact molecules at all, which is the picture of a completely ionised, strong acid. Box Y is the weak acid: only 1 of its 10 units has ionised. (b) 1 ÷ 10 × 100 = 10%. (c) The redraw claims HF ionises completely, turning a weak acid into a strong one. It contradicts the fact that most HF molecules stay intact in water. (d) What changes: more water particles are drawn, the box is larger and the ions are more widely spaced. What stays the same: the counts, 10 H^+ and 10 Cl^-, and the complete absence of intact HCl molecules.

B6. (a) The ions locked in a lattice cluster: 3 Ca^{2+} and 6 Cl^- in a 1 to 2 ratio, touching, in one block. (b) 3 Ca^{2+} ions and 6 Cl^- ions, separated from each other and spread among the water molecules. (c) Positive charge: 3 × (+2) = +6. Negative charge: 6 × (-1) = -6. The totals are equal, so the picture is neutral overall, as it must be. (d) 3 intact glucose molecules spread among the water molecules. The difference: dissolving $CaCl_2$ breaks the lattice apart into its ions, so the particles present afterwards are different species from the solid's units; dissolving glucose only separates whole molecules from each other, and the bonds inside each molecule stay intact.

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C1. (a) 2 Zn atoms remain in the solid block; 3 Zn^{2+} ions are in solution; 3 Cu atoms have formed as solid metal; the 3 SO_4^{2-} ions are unchanged in solution. (b) Cu^{2+} is limiting. The ratio is 1 to 1, so 5 Zn atoms would need 5 Cu^{2+} ions; only 3 are present, so the reaction stops after 3 Zn atoms have reacted. (c) Zinc: 5 before; 2 + 3 = 5 after. Copper: 3 before, 3 after. Solution charge: before, 3(+2) + 3(-2) = 0; after, 3(+2) + 3(-2) = 0. All conserved. (d) Each Zn^{2+} ion formed requires one Cu^{2+} ion to become a Cu atom, one for one. The box holds only 3 Cu^{2+} ions, so at most 3 Zn atoms can become ions. The remaining 2 Zn atoms have no copper ions left to react with and must stay in the block, however long they sit in the solution.

C2. (a) 4 H_2O molecules and 1 O_2 molecule left over. (b) Oxygen. Before: 3 × 2 = 6 O atoms. P shows 4 × 1 + 3 × 2 = 10 O atoms. P invents 4 oxygen atoms: it puts oxygen into the water while also leaving every O_2 molecule unreacted. (c) Hydrogen. Before: 4 × 2 = 8 H atoms. Q shows 6 × 2 = 12 H atoms. Q claims 6 H_2O molecules, which would need 6 H_2 molecules as a starting material; the starting box holds only 4. (d) Count the atoms of each element in the before and after boxes and require the totals to match; count the total charge in both boxes and require that to match too. Both P and Q fail the atom count at once.

C3. (a) Each Mg atom consumes 2 H^+, so 3 Mg atoms would need 6 H^+. Only 4 H^+ are present, so H^+ is limiting and 2 Mg atoms react. (b) 1 Mg atom remains in the solid block; 2 Mg^{2+} ions are in solution; 2 H_2 molecules have formed and leave as gas bubbles; the 4 Cl^- ions are unchanged in solution. (c) Magnesium: 3 before; 1 + 2 = 3 after. Hydrogen: 4 before; 2 × 2 = 4 after. Chlorine: 4 before, 4 after. Solution charge: before, 4(+1) + 4(-1) = 0; after, 2(+2) + 4(-1) = 0. All conserved. (d) $Mg(s) + 2H^+(aq) \rightarrow Mg^{2+}(aq) + H_2(g)$. Cl^- is a spectator ion: it appears unchanged on both sides of the full equation and is cancelled to give the net ionic equation.

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