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Topic 4.1: Introduction to 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: what a chemical reaction is, the signs that one has occurred, and how physical and chemical changes differ at the particle level. Section B builds the skills: balancing equations, reading coefficients, and using conservation of mass in calculations. Section C combines observations, equations and mass calculations 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 happens to the atoms during a chemical reaction. (b) Define the terms reactant and product. (c) State the law of conservation of mass. (d) Explain, in terms of atoms, why the law of conservation of mass holds for every chemical reaction.

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A2. (a) State four observations that suggest a chemical reaction has occurred. (b) When a precipitate forms during a reaction, explain what has happened at the particle level. (c) A student heats a liquid in an open beaker and sees bubbles forming vigorously. Explain why these bubbles are not, by themselves, evidence of a chemical reaction. (d) Two solutions are mixed and no change is observed. State whether a reaction can be ruled out, and justify your answer.

A3. Classify each change as physical or chemical, justifying each answer in terms of the particles involved. (a) Ice melting to form liquid water. (b) Solid sodium chloride dissolving in water. (c) An iron nail rusting in damp air. (d) Ethanol evaporating from an open dish. (e) Magnesium ribbon burning in air to form a white ash.

A4. (a) State the difference between a subscript and a coefficient in a chemical equation. (b) In the equation $2H_2 + O_2 \rightarrow 2H_2O$, state what the coefficient 2 in front of H_2O represents, and what the subscript 2 in H_2O represents. (c) A student tries to balance an equation by changing H_2O into H_2O_2. Explain the error.

A5. (a) Describe, at the particle level, what happens when solid sodium chloride dissolves in water. (b) Describe, at the particle level, what happens when solid glucose, $C_6H_{12}O_6$, dissolves in water. (c) Explain why dissolving a solid, on its own, is not taken as evidence of a chemical reaction. (d) State how dissolved sodium chloride can be recovered from its solution, and what this shows about the change.

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Section B: Core Practice

B1. Methane burns in oxygen to form carbon dioxide and water. The unbalanced equation is $CH_4 + O_2 \rightarrow CO_2 + H_2O$. Molar masses: CH_4 = 16 g/mol, O_2 = 32 g/mol, CO_2 = 44 g/mol, H_2O = 18 g/mol. (a) Balance the equation. (b) Count the atoms of each element on both sides of your balanced equation to show that it is balanced. (c) State the mole ratio of methane to oxygen in the balanced equation. (d) Calculate the mass of oxygen needed to burn 16 g of methane completely. (e) Calculate the mass of water formed in part (d), and check that the total mass of products equals the total mass of reactants.

B2. When calcium carbonate is heated it decomposes into calcium oxide and carbon dioxide: $CaCO_3 \rightarrow CaO + CO_2$. A student heats 25.0 g of calcium carbonate and obtains 14.0 g of calcium oxide. (a) Calculate the mass of carbon dioxide produced. (b) The crucible is open to the air and the solid contents are weighed before and after heating. Predict the change in the mass of the solid contents, and explain it. (c) Use molar masses ($CaCO_3$ = 100 g/mol, CO_2 = 44 g/mol) to check your answer to part (a).

B3. A reaction between two solutions produces a gas. In a sealed flask, the total mass before the reaction is 152.4 g. (a) State the total mass after the reaction in the sealed flask. (b) The same reaction is run in an open beaker, and afterwards the beaker and its contents have a mass 1.5 g less than before. Calculate the mass of gas that escaped. (c) Explain why the result in part (b) does not break the law of conservation of mass. (d) State one way the experiment could be modified so that no mass appears to be lost.

B4. Balance each equation. (a) $Mg + HCl \rightarrow MgCl_2 + H_2$ (b) $N_2 + H_2 \rightarrow NH_3$ (c) $C_3H_8 + O_2 \rightarrow CO_2 + H_2O$ (d) $Fe + O_2 \rightarrow Fe_2O_3$

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B5. For each scenario, state whether a chemical reaction has occurred and justify your answer. (a) A clear solution of silver nitrate is mixed with a clear solution of sodium chloride. The mixture turns cloudy and a white solid settles out. (b) A sealed bottle of fizzy drink is opened and gas rushes out with a hiss. (c) Two colourless solutions are mixed in a flask held in a student's hand. The flask feels noticeably warmer after mixing. (d) A blue solution is diluted with water and becomes a paler blue.

B6. Aluminium reacts with oxygen to form aluminium oxide: $4Al + 3O_2 \rightarrow 2Al_2O_3$. (a) State how many moles of oxygen react with 4 mol of aluminium. (b) Calculate how many moles of aluminium oxide form when 6 mol of oxygen reacts completely. (c) Calculate how many moles of aluminium are needed to produce 6 mol of aluminium oxide. (d) A student writes: "the equation shows 4 atoms of aluminium reacting with 3 atoms of oxygen." Correct the errors in this statement.

Section C: Exam Style

C1. A zinc strip is placed in blue copper(II) sulfate solution and left for an hour. The blue colour fades, a reddish-brown solid forms on the strip, and the temperature of the solution rises slightly. The equation for the reaction is $Zn + CuSO_4 \rightarrow ZnSO_4 + Cu$. (a) Give three observations from the description and state what each one indicates. (b) Show that the equation is balanced by counting the atoms of each element on both sides. (c) Explain, at the particle level, why the blue colour fades. (d) The sealed flask and its contents are weighed before and after the hour. State whether the total mass changes, and explain your answer.

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C2. A student adds excess dilute hydrochloric acid to 5.0 g of calcium carbonate in a flask standing on a balance. Bubbles form rapidly and the balance reading falls by 2.2 g. The equation is $CaCO_3 + 2HCl \rightarrow CaCl_2 + H_2O + CO_2$. Molar masses: $CaCO_3$ = 100 g/mol, CO_2 = 44 g/mol. (a) Identify the gas produced, and state the evidence that a gas is formed. (b) Explain why the balance reading falls even though mass is conserved. (c) Use the molar masses to show that the 2.2 g fall is consistent with all of the calcium carbonate reacting. (d) The student repeats the experiment with a balloon fitted tightly over the neck of the flask. Predict the change in the balance reading and explain the prediction.

C3. Two white solids are investigated. Solid X is heated strongly in an open crucible: its mass falls from 12.5 g to 7.0 g, and a gas is given off that turns limewater cloudy. Solid Y is heated gently in a second crucible: it melts, and when it cools it solidifies again with its mass unchanged. (a) Classify the change in each solid as physical or chemical, justifying each classification at the particle level. (b) Calculate the mass of gas given off by solid X, and identify the gas. (c) Explain why the mass loss for solid X does not violate the law of conservation of mass. (d) State one observation or measurement that would confirm the solid formed when Y cools is the same substance as the original Y.

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Answer Key

A1. (a) The atoms are rearranged: bonds joining them in the reactants break and new bonds form, grouping the same atoms into new substances. None are created or destroyed. (b) A reactant is a starting substance that is consumed in a reaction; a product is a new substance formed by the reaction. (c) In a chemical reaction, the total mass of the products equals the total mass of the reactants. (d) The mass of a sample is the total mass of its atoms. A reaction only moves atoms between substances, so the count of atoms of each element, and with it the total mass, cannot change.

A2. (a) Any four of: a solid precipitate forms; a gas is evolved, shown by bubbles or fizzing not caused by boiling; a colour change occurs; the temperature changes as heat is released or absorbed; light or sound is produced. (b) Ions dissolved in the two solutions have combined into an insoluble compound. Its particles lock together into a solid instead of remaining separated and surrounded by water, so the new substance separates out. (c) The bubbles are vapour of the same liquid, formed inside it as it boils. The particles are unchanged, passing from liquid to gas in a physical change, so no new substance is forming. (d) No, a reaction cannot be ruled out. Some reactions produce colourless, dissolved products with little or no temperature change, so a reaction may have occurred with no observable sign.

A3. (a) Physical. The water molecules are identical before and after melting; only their arrangement and freedom of movement change. (b) Physical. The Na^+ and Cl^- ions separate from the lattice and become surrounded by water molecules, but they are the same ions as in the solid, so no new substance forms. (c) Chemical. Iron atoms combine with oxygen and water to form hydrated iron(III) oxide, a new substance with different properties from iron. (d) Physical. The ethanol molecules leave the liquid unchanged; only their spacing changes, and the vapour condenses back to the same ethanol. (e) Chemical. Magnesium atoms combine with oxygen to form magnesium oxide, $2Mg + O_2 \rightarrow 2MgO$, a new substance, and the heat and bright light released are further evidence of reaction.

A4. (a) A subscript is part of a chemical formula: it states how many atoms of an element are in one unit of the substance, and it is fixed by the substance's identity. A coefficient is placed in front of a formula: it states how many units, or moles, of the substance take part, and it can be adjusted when balancing. (b) The coefficient 2 in front of H_2O represents two units, or two moles, of water formed. The subscript 2 in H_2O represents the two hydrogen atoms in each water molecule. (c) Changing the subscript changes the substance: H_2O_2 is hydrogen peroxide, not water, so the student has written a different reaction. Balancing may change coefficients, which alter amounts, never subscripts, which define each substance.

A5. (a) The ionic lattice breaks apart. The Na^+ and Cl^- ions separate from each other, and each ion becomes surrounded by water molecules, spread evenly through the solution. (b) The glucose

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molecules leave the solid and spread out among the water molecules as whole, intact molecules; no bonds inside a glucose molecule are broken. (c) In both cases the particles present after dissolving are exactly those present before: the same ions, or the same molecules. A chemical reaction requires atoms regrouped into new substances, and dissolving produces none. (d) Evaporate the water, for example by heating the solution until the water boils away. The sodium chloride is recovered unchanged, showing the change was physical and reversible.

B1. (a) $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$. (b) Left side: C = 1, H = 4, O = 2 × 2 = 4. Right side: C = 1 in CO_2; H = 2 × 2 = 4 in $2H_2O$; O = 2 in CO_2 + 2 × 1 = 2 in $2H_2O$, totalling 4. Each element matches on both sides, so it is balanced. (c) 1:2. (d) Moles of CH_4 = 16 ÷ 16 = 1 mol. The mole ratio CH_4:O_2 is 1:2, so 2 mol of O_2 is needed, with mass 2 × 32 = 64 g. (e) The mole ratio CH_4:H_2O is 1:2, so 2 mol of water forms, with mass 2 × 18 = 36 g. Check: carbon dioxide formed is 1 mol, 44 g, so total product mass = 44 + 36 = 80 g. Total reactant mass = 16 + 64 = 80 g. The totals agree, as conservation of mass requires.

B2. (a) Conservation of mass: total product mass equals the 25.0 g of reactant, so mass of CO_2 = 25.0 − 14.0 = 11.0 g. (b) The mass of the solid contents falls by 11.0 g, from 25.0 g of $CaCO_3$ to the 14.0 g of CaO that remains, because the carbon dioxide escapes into the air. (c) Moles of $CaCO_3$ = 25.0 ÷ 100 = 0.250 mol. The equation shows 1 mol of $CaCO_3$ producing 1 mol of CO_2, so moles of CO_2 = 0.250 mol and mass of CO_2 = 0.250 × 44 = 11.0 g, agreeing with part (a).

B3. (a) 152.4 g: the flask is sealed, so nothing enters or leaves and the total mass cannot change. (b) 1.5 g of gas escaped: the fall in mass of the beaker and contents equals the mass of the gas that left. (c) The mass is not destroyed; it left the beaker as gas and is now in the air. Contents plus escaped gas still total the original mass, so the law holds for the complete system. (d) Any one of: run the reaction in a sealed flask; fit a balloon over the vessel to trap the gas; collect the gas in a gas syringe.

B4. (a) $Mg + 2HCl \rightarrow MgCl_2 + H_2$. (b) $N_2 + 3H_2 \rightarrow 2NH_3$. (c) $C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$. (d) $4Fe + 3O_2 \rightarrow 2Fe_2O_3$.

B5. (a) A chemical reaction. Silver ions and chloride ions from the two solutions combine to form silver chloride, an insoluble new substance: the white solid. (b) No reaction; a physical change. The gas was dissolved in the drink under pressure and comes out of solution when the pressure is released; its particles are unchanged. (c) A chemical reaction has very likely occurred. The temperature rise, with no heating applied, means the mixing released heat, which happens when atoms are rearranged into new substances. (d) No reaction; a physical change. The same coloured particles are spread through more water, so the colour is weaker, but no new substance has formed.

B6. (a) 3 mol. (b) The ratio O_2:Al_2O_3 is 3:2, so moles of Al_2O_3 = 6 × 2/3 = 4 mol. (c) The ratio Al:Al_2O_3 is 4:2, or 2:1, so moles of Al = 6 × 2 = 12 mol. (d) Two corrections. Oxygen is present as O_2 molecules, not loose atoms, so the equation shows 3 mol of oxygen molecules, containing 6 mol of oxygen

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atoms. And coefficients count amounts in moles, so the equation reads: 4 mol of aluminium reacts with 3 mol of oxygen molecules to form 2 mol of aluminium oxide.

C1. (a) The blue colour fades: the Cu^{2+} ions that give the colour are leaving the solution. A reddish-brown solid forms on the strip: copper, a new substance, is being produced. The temperature rises: the reaction releases heat. Together these show a chemical reaction forming new substances. (b) Left side: Zn = 1, Cu = 1, S = 1, O = 4. Right side: Zn = 1 in $ZnSO_4$, S = 1, O = 4, Cu = 1. Every element matches, so the equation is balanced as written. (c) The blue colour comes from Cu^{2+} ions dissolved in the solution. At the strip's surface, Cu^{2+} ions gain electrons and become copper atoms in the solid coating, while zinc atoms lose electrons and enter solution as Zn^{2+} ions. As Cu^{2+} ions are removed, the blue fades. (d) The total mass does not change. The flask is sealed, so every atom present at the start remains inside at the end, rearranged into zinc sulfate and copper; the same atoms give the same total mass.

C2. (a) Carbon dioxide. The evidence is the rapid bubbling, or effervescence, as the gas forms and escapes. (b) The carbon dioxide escapes into the air, so it is no longer part of what the balance weighs. The reading falls by the mass of the gas that left, but that mass still exists in the air; conservation applies to flask and escaped gas together. (c) Moles of $CaCO_3$ = 5.0 ÷ 100 = 0.050 mol. The equation shows 1 mol of CO_2 formed per 1 mol of $CaCO_3$, so moles of CO_2 = 0.050 mol, and mass of CO_2 = 0.050 × 44 = 2.2 g. This matches the observed fall exactly, consistent with all the carbonate reacting. (d) The reading stays constant. The carbon dioxide is trapped in the balloon, so it remains part of what the balance weighs; the balloon inflates, but the total mass of flask, contents and trapped gas is unchanged.

C3. (a) Solid X: chemical change. A gas is driven off and the remaining solid has lost part of its substance: its particles have been regrouped, with some atoms leaving in the gas. Solid Y: physical change. Melting alters only the arrangement and motion of the same particles, and on cooling the original solid returns with its mass unchanged, so no new substance formed. (b) Mass of gas = 12.5 − 7.0 = 5.5 g. The gas is carbon dioxide, identified by its turning limewater cloudy. (c) The 5.5 g has not vanished; it is the mass of the carbon dioxide now in the air. Remaining solid, 7.0 g, plus escaped gas, 5.5 g, totals the original 12.5 g, so mass is conserved for the whole system. (d) Any one of: measure its melting point and find it identical to the original solid's; check that it has the same appearance and properties; confirm it behaves the same in a simple test, such as dissolving.

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