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General Chemistry

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Reaction Stoichiometry and Percent Yield

قياس التفاعل ونسبة المردود

Introduction: **مقدمة**

Stoichiometry calculations are about calculating the amounts of substances that react and form in a chemical reaction. The word “stoichiometry” comes from the Greek stoikheion "element" and metriā "measure. “Based on the balanced chemical equation, we can calculate the amount of a product substance that will form if we begin with a specific amount of one or more reactants. Or, you may have a target amount of product to prepare. How much starting compounds are needed to prepare this amount? These are practical calculations that are done frequently by chemists.

تُعنى حسابات القياس الكمي بحساب كميات المواد التي تتفاعل وتتكون في التفاعل الكيميائي. كلمة "قياس كمي" مشتقة من الكلمتين اليونانيتين "stoikheion" بمعنى "عنصر" و"metriā" بمعنى "قياس". بناءً على المعادلة الكيميائية الموزونة، يمكننا حساب كمية المادة الناتجة التي ستتكون إذا بدأنا بكمية محددة من مادة متفاعلة واحدة أو أكثر. أو قد يكون لديك كمية محددة من الناتج المراد تحضيره. ما هي كمية المركبات الأولية اللازمة لتحضير هذه الكمية؟ هذه حسابات عملية يجريها الكيميائيون بشكل متكرر.

Calculation Method: **طريقة الحساب**

For practically all stoichiometry calculations, we want to use these steps:

بالنسبة لجميع حسابات القياس الكمي تقريبًا، نريد استخدام هذه الخطوات

<u>Step 1:</u> Write the balanced chemical equation for the reaction.

اكتب المعادلة الكيميائية المتوازنة للتفاعل

<u>Step 2:</u> Calculate the moles of "given" substance. If more than one reactant amount is given, calculate the moles of each reactant to determine which is the **limiting reactant**. (*The limiting reactant: the substance that is totally consumed when the chemical reaction is complete)*

احسب عدد مولات المادة المعطاة. إذا عُلمت كمية أكثر من مادة متفاعلة، فاحسب عدد مولات كل مادة لتحديد المادة المتفاعلة المحددة. (المادة المتفاعلة المحددة: هي المادة التي تُستهلك بالكامل عند اكتمال التفاعل الكيميائي)

<u>Step 3:</u> Calculate the moles of "desired" substance from your answer in Step 2 using the coefficients from the balanced chemical equation. If more than one reactant was given, then you have to calculate the moles of product based on the moles of limiting reactant. Keep this answer for Step 4.

احسب عدد مولات المادة "المطلوبة" من إجابتك في الخطوة 2 باستخدام المعاملات من المعادلة الكيميائية الموزونة. إذا تم إعطاء أكثر من متفاعل واحد، فعليك حساب عدد مولات الناتج بناءً على عدد مولات المتفاعل المحدد. احتفظ بهذه الإجابة للخطوة 4

Step 4: Convert your answer in Step 3 to the units the problem asks for. Usually this is grams, but it could be volume (for gases or liquid solutions) or concentration (such as molarity, for solutions).

حوّل إجابتك في الخطوة 3 إلى الوحدات المطلوبة في المسألة. عادةً ما تكون هذه الوحدات بالجرام، ولكن قد تكون بالحجم (للغازات أو المحاليل السائلة) أو بالتركيز (مثل المولارية، للمحاليل)

Present Yield: **المردود المئوي**

The percent yield of a reaction tells us how well the reaction worked in terms of forming a desired product.

نسبة المردود في التفاعل تخبرنا بمدى نجاح التفاعل من حيث تكوين المنتج المطلوب

$$Percent\ Yield = \frac{Actual\ (Experimental) Yield\ of\ Product}{Theoretical\ (Calculated)\ Yield\ of\ Product} X\ 100$$

∗ *The unit of the amounts may be in grams or moles.*

<u>EXAMPLE 1.</u> How many grams of iron (III) oxide (ferric oxide), Fe_2O_3, are formed from the reaction of 5.00 g of iron metal with excess oxygen gas?

Step 1: Balanced reaction.

$$4\ Fe_{(s)} + 3\ O_{2\ (g)} \longrightarrow 2\ Fe_2O_{3\ (s)}$$

Step 2: Moles of "given" substance.

The given substance is the iron metal, since its amount is given.

$$moles\ of\ Fe = \frac{grams\ of\ Fe}{molar\ mass\ of\ Fe} = \frac{5.00\ g}{55.845\ \frac{g}{mol}} = 0.08953353\ mol$$

($not\ rounding\ yet$). Note that gram units cancel, leaving the unit of moles for the answer

$$moles\ of\ Fe = \frac{5.00\ g\ Fe}{1}\ X\ \frac{1\ mol\ Fe}{55.847\ g\ Fe} = 0.08953353\ mol\ Fe$$

Step 3: Moles of "desired" substance.

This is the product, ferric oxide. Here is where the balanced reaction comes in. The coefficients in the balanced reaction represent the moles of the substances that react and form. As such, balanced reactions are "in" moles by default. This is why we always have to convert amounts to moles when working stoichiometry problems.

$$moles\ of\ Fe_2O_3 = \frac{0.08953353\ mol\ Fe}{1}\ X\ \frac{2\ mol\ Fe_2O_3}{4\ mol\ Fe} = 0.044766765\ mol\ Fe_2O_3$$

Step 4: Grams of Fe_2O_3.

$$Grams\ of\ Fe_2O_3 = moles\ of\ Fe_2O_3\ X\ molar\ mass\ of\ Fe_2O_3$$

$$Grams\ of\ Fe_2O_3 = 0.044766765\ mol\ \ X\ \ 159.6882\ \frac{g}{mol}$$

$Grams\ of\ Fe_2O_3 = \mathbf{7.15\ g}$ rounded to 3 significant figures.

And that's it! We can also do steps 2 through 4 like a conversion problem. Once you are familiar with the steps, you can work these problems more quickly this way:

$$\frac{5.00\ g\ Fe}{1}\ X\ \frac{1\ mol\ Fe}{55.845\ g\ Fe}\ X\ \frac{2\ mol\ Fe_2O_3}{4\ mol\ Fe}\ X\ \frac{159.6882\ g\ Fe_2O_3}{1\ mol\ Fe_2O_3} = \mathbf{7.15\ g}\ of\ Fe_2O_3$$

$$\boldsymbol{Percent\ Yield\ of\ Fe_2O_3} = \frac{6.75\ g}{7.15\ g}\ X\ 100 = \mathbf{94.4}\%$$

Experiment: تجربة

In this experiment, you will prepare copper metal from the reaction of aluminum metal with a solution of copper (II) sulfate (cupric sulfate). From the amounts of the reactants, you will determine which reactant is the limiting reactant, and from this amount, calculate the theoretical yield of copper metal. From the actual amount of copper obtained, you can then calculate your percent yield of copper.

في هذه التجربة، ستقوم بتحضير فلز النحاس من تفاعل فلز الألومنيوم مع محلول كبريتات النحاس الثنائي (كبريتات النحاس). من خلال كميات المواد المتفاعلة، ستحدد المادة المتفاعلة المحددة، ومن ثم ستحسب الناتج النظري لفلز النحاس. ومن خلال الكمية الفعلية للنحاس الناتج، يمكنك حساب النسبة المئوية للناتج

Chemical Equation: المعادلة الكيميائية

$$3CuSO_{4\,(aq)} + 2Al_{(s)} \rightarrow 3Cu_{(s)} + Al_2(SO_4)_{3\,(aq)}$$

Materials and Equipment's المواد والمعدات

Cupric Sulfate solid ($CuSO_4 \cdot 5\,H_2O$), Hydrochloric Acid (6 M HCl), Dry Aluminum Foil, Deionized Water, Methanol or Ethanol, 200 mL Beaker, 10 mL Graduated Cylinder, Glass Stirrer Rob, Electrical Hot Plate.

Safety Note: ملاحظات السلامة

Hydrochloric acid is a strong acid that is harmful to the skin and especially to your eyes. Wear your safety glasses or goggles during the entire procedure. The reaction also produces flammable hydrogen gas (H_2), so Bunsen burners should not be used while the reaction is in progress.

حمض الهيدروكلوريك حمض قوي ضار بالجلد، وخاصةً بالعينين. ارتدِ نظارات السلامة أو النظارات الواقية طوال فترة التفاعل. ينتج عن التفاعل غاز الهيدروجين ((H2القابل للاشتعال، لذا يُمنع استخدام موقد بنسن أثناء حدوث التفاعل.

Procedure: إجراء

1. Weigh a clean, dry 200 mL beaker and record its weight on the report form.
2. Carefully add 2.00 g of copper (II) sulfate pentahydrate, $CuSO_4 \cdot 5\ H_2O$ inside the beaker and record the weight.
3. Measure 10 mL of deionized water in a small graduated cylinder and add the water to the beaker to dissolve the copper (II) sulfate pentahydrate with the aid of a glass stirring rod.
4. Record the color of the solution on the report sheet.
5. Measure 2.0 mL of 6 M HCl in your graduated cylinder, add it to the solution, and mix well.
6. Weigh 0.25 g of dry aluminum foil in small pieces and record the weight on the report sheet.
7. Add the pieces of Al foil a little at a time. ***Use the stirring rod to mix the solution during the reaction.***

(CAUTION: Exothermic reaction!) Note the color of the solution after the added piece of aluminum no longer darkens on its surface.

8. Add the remaining few pieces of aluminum foil and add an additional 10 mL of (6 M HCl) to facilitate the reaction of any excess aluminum with the hydrochloric acid.
9. After all of the aluminum foil has reacted, allow the solid particles of copper product to settle, and carefully decant the solution from the solid ***(leaving the copper behind in the beaker).***
10. Add 20 mL of deionized water to the solid, stir well with the stirring rod, and decant again.
11. Repeat this washing with 20 mL of water once more.
12. Finally, add 10 mL of methanol to the solid, stir, and decant.
13. Heat the beaker on an electric hot plate at medium heat ***(a setting of about 4 out of 10)*** for about 15 mints until the solid and beaker are thoroughly dry.
14. Allow the beaker and its contents to cool for about 5 mints then weigh the beaker and its contents and record the weight on the report form.
15. On the report sheet, record the moles of Al and $CuSO_4 \cdot 5\ H_2O$ used, and determine which is the limiting reactant.
16. Based on the limiting reactant, calculate the theoretical yield of copper metal product.
17. From your actual yield of copper, calculate the percent yield of copper product obtained from the reaction.
18. Place your copper metal in the collection container on the front desk (do not wash it down the sink!).
19. Rinse your glassware well and return your other equipment to their proper storage locations.

Note:

- **Molar mass for Cu = 63.546 g/mol**
- **Molar mass for Al = 26.981 g/mol**
- **Molar mass for $CuSO_4.H_2O$ = 249.69 g/mol**

Lab Report

1. Mass of empty 150 mL beaker	
2. Mass of beaker plus $CuSO_4 \cdot 5\ H_2O$	
3. Color of solution	
4. Mass of $CuSO_4 \cdot 5\ H_2O$ [2] – [1]	
5. Mass of Al foil used (small pieces)	
6. Color of solution after reaction is complete	
7. Mass of beaker and copper product (after heating and cooling)	
8. Mass of copper metal product [7] – [1]	
9. Moles of Al used (show your calculation)	
10. Moles of $CuSO_4 \cdot 5\ H_2O$ used (show your calculation)	
11. Moles of copper product based on moles of Al (show your calculation)	
12. Moles of copper product based on moles of $CuSO_4 \cdot 5\ H_2O$ (show your calculation)	
13. Limiting reactant	
14. Grams of Cu product based on the limiting reactant (theoretical yield) (show your calculation)	
15. Percent yield of Cu (2 to 3 significant figures) (show your calculation)	