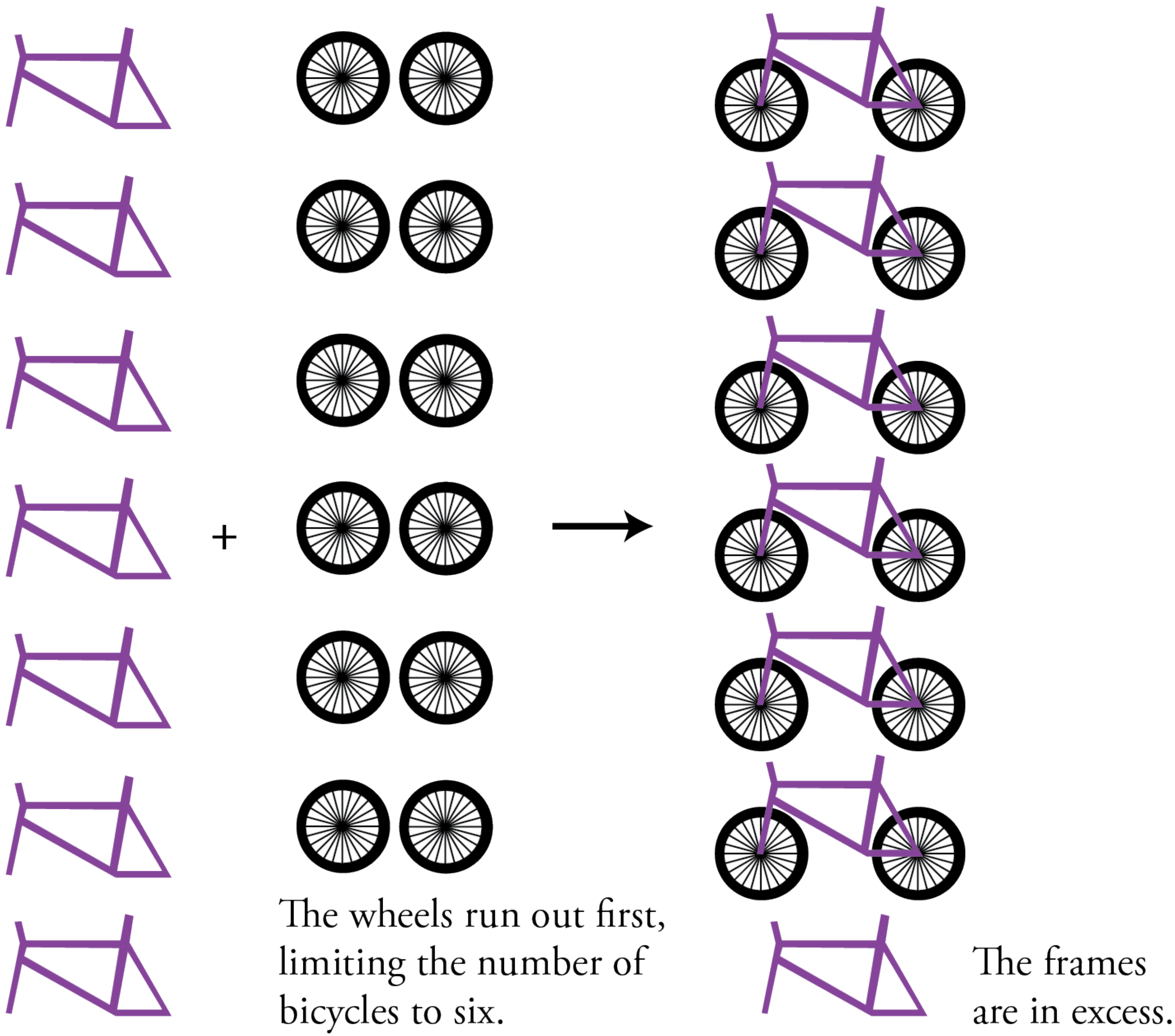
Questions to Ask When Designing a Process for Making a Substance

- How much of each reactant should be added to the reaction vessel?
- What level of purity is desired for the final product? If the product is mixed with other substances (such as excess reactants), how will this purity be achieved?

Limiting Component



Why substance limiting? (1)

- To ensure that one reactant is converted to products most completely.
  - Expense

$P_4(s) + 5O_2(g) \rightarrow P_4O_{10}(s) + \text{excess } O_2(g)$

  - Importance

$SiO_2(s) + 2C(s)$
$\rightarrow Si(l) + 2CO(g) + \text{excess } C(s)$

Why substance limiting? (2)

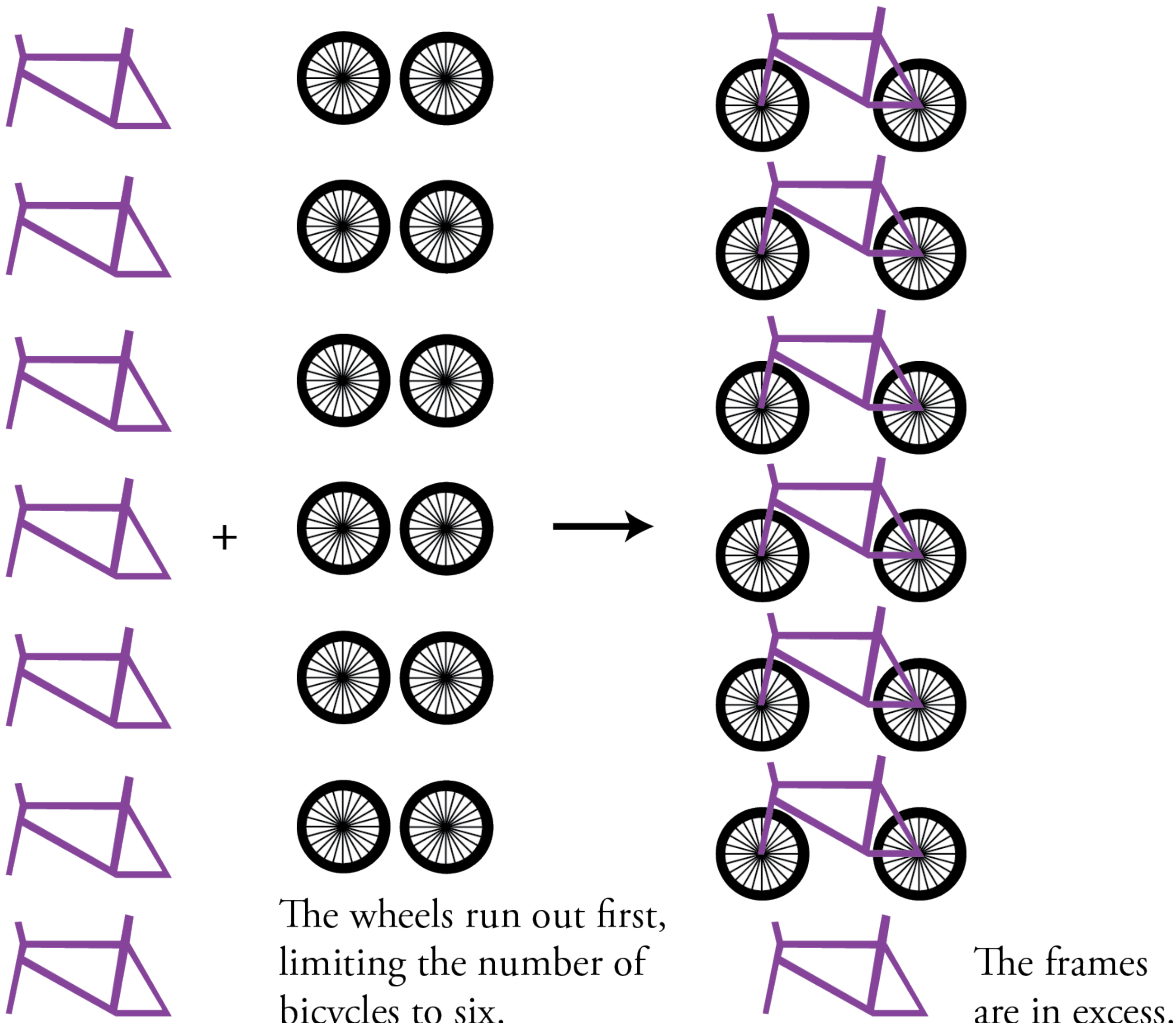
- Concern for excess reactant that remains
  - danger

$$P_4(s) + 5O_2(g) \rightarrow P_4O_{10}(s) + \text{excess } O_2(g)$$

  - ease of separation

$$SiO_2(s) + 2C(s) \rightarrow Si(l) + 2CO(g) + \text{excess } C(s)$$

Limiting Component



Limiting Component (2)

$$\left(\frac{1 \text{ bicycle}}{1 \text{ frame}}\right) \quad \text{and} \quad \left(\frac{1 \text{ bicycle}}{2 \text{ wheels}}\right)$$

$$? \text{ bicycles} = 7 \cancel{\text{frames}} \left(\frac{1 \text{ bicycle}}{1 \cancel{\text{frame}}}\right) = 7 \text{ bicycles}$$

$$? \text{ bicycles} = 12 \cancel{\text{wheels}} \left(\frac{1 \text{ bicycle}}{2 \cancel{\text{wheels}}}\right) = 6 \text{ bicycles}$$

Limiting Reactant

- The reactant that runs out first in a chemical reaction limits the amount of product that can form. This reactant is called the ***limiting reactant***.

Limiting Reactant Problems

- **Tip-off -** You are given amounts of two or more reactants in a chemical reaction, and you are asked to calculate the maximum amount of a product that can form from the combination of the reactants.
- **General Steps**

1. Do separate calculations of the maximum amount of product that can form from each reactant.
2. The lowest of the values calculated in the step above is your answer. It is the maximum amount of product that can be formed from the given amounts of reactants.

Example

- The uranium(IV) oxide, UO_2, used as fuel in nuclear power plants has a higher percentage of the fissionable isotope uranium-235 than is present in the UO_2 found in nature. To make fuel grade UO_2, chemists first convert uranium oxides to uranium hexafluoride, UF_6, whose concentration of uranium-235 can be increased by a process described in my online lecture for Section 16.3 of the atoms-first version of my text and Section 18.3 of the chemistry-first version. The enriched UF_6 is then converted back to UO_2 in a series of reactions, beginning with

$$UF_6 + 2H_2O \rightarrow UO_2F_2 + 4HF$$

a. How many megagrams of UO_2F_2 can be formed from the reaction of 24.543 Mg UF_6 with 8.0 Mg of water?

b. Why do you think the reactant in excess was chosen to be in excess?

Example

$$UF_6 + 2H_2O \rightarrow UO_2F_2 + 4HF$$

How many megagrams of UO_2F_2 can be formed from the reaction of 24.543 Mg UF_6 with 8.0 Mg of water?

- Limiting reactant tip-off – We are given amounts of two reactants and asked to calculate an amount of product.
- Steps
  - Calculate amount of UO_2F_2 from 24.543 Mg UF_6.
  - Calculate amount of UO_2F_2 from 8.0 Mg of H_2O.
  - Smaller value is answer.

Example

$$UF_6 + 2H_2O \rightarrow UO_2F_2 + 4HF$$

How many megagrams of UO_2F_2 can be formed from the reaction of 24.543 Mg UF_6 with 8.0 Mg of water?

$$? \text{ Mg } UO_2F_2 = 24.543 \text{ Mg } UF_6$$

$$? \text{ Mg } UO_2F_2 = 24.543 \text{ Mg } UF_6 \left(\frac{1 \times}{1 \times} \right)$$

$$? \text{ Mg } UO_2F_2 = 24.543 \text{ Mg } UF_6 \left(\frac{1 \times 308.0245}{1 \times 352.019} \right)$$

Example

$$UF_6 + 2H_2O \rightarrow UO_2F_2 + 4HF$$

How many megagrams of UO_2F_2 can be formed from the reaction of 24.543 Mg UF_6 with 8.0 Mg of water?

$$? \text{ Mg } UO_2F_2 = 24.543 \text{ Mg } UF_6 \left(\frac{1 \times 308.0245 \text{ Mg}}{1 \times 352.019 \text{ Mg}} \right)$$

$$? \text{ Mg } UO_2F_2 = 24.543 \cancel{\text{Mg } UF_6} \left(\frac{1 \times 308.0245 \text{ Mg } UO_2F_2}{1 \times 352.019 \cancel{\text{Mg } UF_6}} \right)$$

$$? \text{ Mg } UO_2F_2 = 24.543 \cancel{\text{Mg } UF_6} \left(\frac{1 \times 308.0245 \text{ Mg } UO_2F_2}{1 \times 352.019 \cancel{\text{Mg } UF_6}} \right)$$

$$= 21.476 \text{ Mg } UO_2F_2$$

Example

$$UF_6 + 2H_2O \rightarrow UO_2F_2 + 4HF$$

How many megagrams of UO_2F_2 can be formed from the reaction of 24.543 Mg UF_6 with 8.0 Mg of water?

$$? \text{ Mg } UO_2F_2 = 24.543 \cancel{\text{Mg } UF_6} \left(\frac{1 \times 308.0245 \text{ Mg } UO_2F_2}{1 \times 352.019 \cancel{\text{Mg } UF_6}} \right)$$

$$= \mathbf{21.476 \text{ Mg } UO_2F_2}$$

$$? \text{ Mg } UO_2F_2 = 8.0 \cancel{\text{Mg } H_2O} \left(\frac{1 \times 308.0245 \text{ Mg } UO_2F_2}{2 \times 18.0153 \cancel{\text{Mg } H_2O}} \right)$$

$$= 68 \text{ Mg } UO_2F_2$$

Example

b. Why do you think the reactant in excess was chosen to be in excess?

- Water is much less expensive than the rare uranium compound.
- It is important to carry as much uranium through the process as possible.
- It is better to have the nontoxic water in the final mixture than the radioactive UF_6.
- Water is also easy to separate from the solid product mixture.

Why not 100% Yield?

- Reversible reactions
- Side reactions
- Slow reactions
- Loss during separation/purification

Percent Yield

$$\text{Percent Yield} = \frac{\text{Actual Yield}}{\text{Theoretical Yield}} \times 100\%$$

- **Actual yield** is measured. It is given in the problem.
- **Theoretical yield** is the maximum yield that you calculate.

Example Calculation for Percent Yield

- Sodium chromate, Na_2CrO_4, is made by roasting chromite, $FeCr_2O_4$, with sodium carbonate, Na_2CO_3. (Roasting means heating in the presence of air or oxygen.) A simplified version of the net reaction is

$$4FeCr_2O_4 + 8Na_2CO_3 + 7O_2 \rightarrow 8Na_2CrO_4 + 2Fe_2O_3 + 8CO_2$$

- What is the percent yield if 1.2 kg of Na_2CrO_4 is produced from ore that contains 1.0 kg of $FeCr_2O_4$?

Example Calculation for Percent Yield

$4FeCr_2O_4 + 8Na_2CO_3 + 7O_2 \rightarrow 8Na_2CrO_4 + 2Fe_2O_3 + 8CO_2$

What is the percent yield if 1.2 kg of Na_2CrO_4 is produced from ore that contains 1.0 kg of $FeCr_2O_4$?

$$\text{Percent Yield} = \frac{\text{Actual Yield}}{\text{Theoretical Yield}} \times 100\%$$

- Na_2CrO_4 is a product, so 1.2 kg Na_2CrO_4 is the *actual yield*.
- $FeCr_2O_4$ is a reactant, so 1.0 kg $FeCr_2O_4$ is used to calculate the maximum amount of Na_2CrO_4 that could be formed (the *theoretical yield*).

Example Calculation for Percent Yield

$$4FeCr_2O_4 + 8Na_2CO_3 + 7O_2 \rightarrow 8Na_2CrO_4 + 2Fe_2O_3 + 8CO_2$$

- What is the percent yield if 1.2 kg of Na_2CrO_4 is produced from ore that contains 1.0 kg of $FeCr_2O_4$?

$$? \text{ kg } Na_2CrO_4 = 1.0 \cancel{\text{kg } FeCr_2O_4} \left(\frac{10^3 \cancel{\text{g}}}{1 \cancel{\text{kg}}}\right)\left(\frac{1 \cancel{\text{mol } FeCr_2O_4}}{223.835 \cancel{\text{g } FeCr_2O_4}}\right)\left(\frac{8 \cancel{\text{mol } Na_2CrO_4}}{4 \cancel{\text{mol } FeCr_2O_4}}\right)\left(\frac{161.9733 \cancel{\text{g}} \text{ } Na_2CrO_4}{1 \cancel{\text{mol } Na_2CrO_4}}\right)\left(\frac{1 \text{ kg}}{10^3 \cancel{\text{g}}}\right)$$

$$= 1.4 \text{ kg } Na_2CrO_4$$

$$\text{Percent yield} = \frac{\text{Actual yield}}{\text{Theoretical yield}} \times 100\%$$

$$= \frac{1.2 \text{ kg } Na_2CrO_4}{1.4 \text{ kg } Na_2CrO_4} \times 100\% = \mathbf{86\% \text{ yield}}$$