Making Phosphoric Acid

- Furnace Process for making H_3PO_4 to be used to make fertilizers, detergents, and pharmaceuticals.
  - React phosphate rock with sand and coke at 2000 ºC.

$$2Ca_3(PO_4)_2 + 6SiO_2 + 10C \rightarrow 4P + 10CO + 6CaSiO_3$$

  - React phosphorus with oxygen to get tetraphosphorus decoxide.

$$4P + 5O_2 \rightarrow P_4O_{10}$$

  - React tetraphosphorus decoxide with water to make phosphoric acid.

$$P_4O_{10} + 6H_2O \rightarrow 4H_3PO_4$$

Sample Calculation

- What is the minimum mass of water that must be added to 2.50×10^4 kg P_4O_{10} to form phosphoric acid in the following reaction?

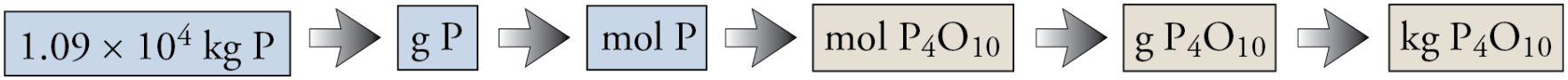
$$P_4O_{10} + 6H_2O \rightarrow 4H_3PO_4$$

Goal: To develop conversion factors that will convert between a measurable property (mass) and number of particles

Measurable Property 1	Mass 1
↓	↓
Number of Particles 1	Moles 1
↓	↓
Number of Particles 2	Moles 2
↓	↓
Measurable Property 2	Mass 2

Two Very Similar Calculations

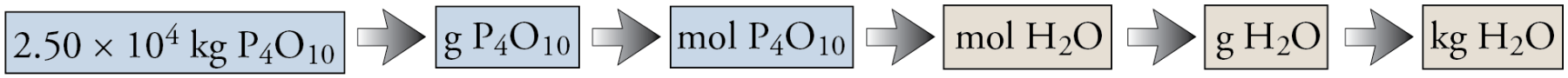
- Conversion between amount of compound and amount of element in that compound (from Section 6.7 of the atoms-first version of the text and Section 9.4 of the chemistry-first version).



$$? \text{ kg } P_4O_{10} = 1.09 \times 10^4 \cancel{\text{kg P}} \left(\frac{10^3 \cancel{\text{g}}}{1 \cancel{\text{kg}}}\right)\left(\frac{1 \cancel{\text{mol P}}}{30.9738 \cancel{\text{g P}}}\right)\left(\frac{1 \cancel{\text{mol } P_4O_{10}}}{4 \cancel{\text{mol P}}}\right)\left(\frac{283.889 \cancel{\text{g}}\ P_4O_{10}}{1 \cancel{\text{mol } P_4O_{10}}}\right)\left(\frac{1 \text{ kg}}{10^3 \cancel{\text{g}}}\right)$$

$$= 2.50 \times 10^4 \text{ kg } P_4O_{10}$$

- Conversion between units of one substance and units of another substance, both involved in a chemical reaction.



$$? \text{ kg } H_2O = 2.50 \times 10^4 \cancel{\text{kg } P_4O_{10}} \left(\frac{10^3 \cancel{\text{g}}}{1 \cancel{\text{kg}}}\right)\left(\frac{1 \cancel{\text{mol } P_4O_{10}}}{283.889 \cancel{\text{g } P_4O_{10}}}\right)\left(\frac{6 \cancel{\text{mol } H_2O}}{1 \cancel{\text{mol } P_4O_{10}}}\right)\left(\frac{18.0153 \cancel{\text{g}}\ H_2O}{1 \cancel{\text{mol } H_2O}}\right)\left(\frac{1 \text{ kg}}{10^3 \cancel{\text{g}}}\right)$$

$$= 9.52 \times 10^3 \text{ kg } H_2O$$

Molar Ratio from Coefficients in Balanced Equations

$$P_4O_{10} + 6H_2O \rightarrow 4H_3PO_4$$

1 molecule P_4O_{10}	6 molecules H_2O	4 molecules H_3PO_4
1 dozen P_4O_{10} molecules	6 dozen H_2O molecules	4 dozen H_3PO_4 molecules
6.022×10^{23} molecules P_4O_{10}	$6(6.022\times10^{23})$ molecules H_2O	$4(6.022\times10^{23})$ molecules H_3PO_4
1 mole P_4O_{10}	6 moles H_2O	4 moles H_3PO_4

Sample Calculations (2)

- What is the minimum mass of water that must be added to 2.50×10^4 kg P_4O_{10} to form phosphoric acid in the following reaction?

$$P_4O_{10} + 6H_2O \rightarrow 4H_3PO_4$$

- The coefficients in the balanced equation provide us with a conversion factor that converts from units of P_4O_{10} to units of H_2O.

$$\left(\frac{1 \text{ mol } P_4O_{10}}{6 \text{ mol } H_2O}\right) \quad \left(\frac{1 \text{ mol } P_4O_{10}}{4 \text{ mol } H_3PO_4}\right) \quad \left(\frac{6 \text{ mol } H_2O}{4 \text{ mol } H_3PO_4}\right)$$

Sample Calculation

- What is the minimum mass of water that must be added to 2.50×10^4 kg P_4O_{10} to form phosphoric acid in the following reaction?

$$P_4O_{10} + 6H_2O \rightarrow 4H_3PO_4$$

$$? \text{ kg } H_2O = 2.50 \times 10^4 \cancel{\text{kg } P_4O_{10}} \left(\frac{10^3 \text{ g}}{1 \cancel{\text{kg}}}\right)\left(\frac{1 \cancel{\text{mol } P_4O_{10}}}{283.889 \cancel{\text{g } P_4O_{10}}}\right)\left(\frac{6 \cancel{\text{mol } H_2O}}{1 \cancel{\text{mol } P_4O_{10}}}\right)\left(\frac{18.0153 \cancel{\text{g}}\, H_2O}{1 \cancel{\text{mol } H_2O}}\right)\left(\frac{1 \text{ kg}}{10^3 \cancel{\text{g}}}\right)$$

$$= 9.52 \times 10^3 \text{ kg } H_2O$$

Equation Stoichiometry

- **Tip-off -** The calculation calls for you to convert from amount of one substance to amount of another, both of which are involved in a chemical reaction.
- **General Steps**

1. If you are not given it, write and balance the chemical equation for the reaction.

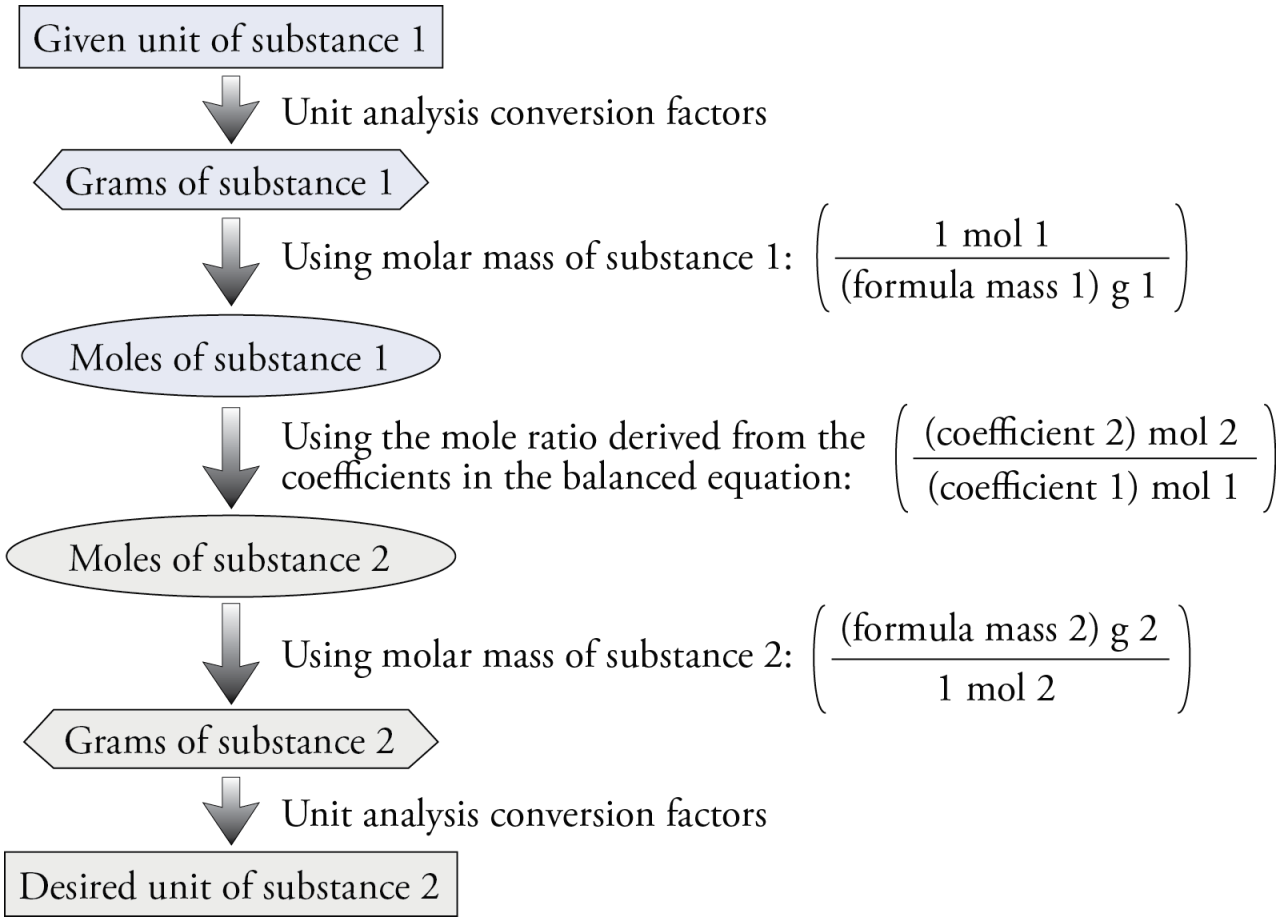
Equation Stoichiometry

2. Start your unit analysis in the usual way.
3. If you are not given grams of substance 1, convert from the unit that you are given to grams. This may take one or more conversion factors.
4. Convert from grams of substance 1 to moles of substance 1.

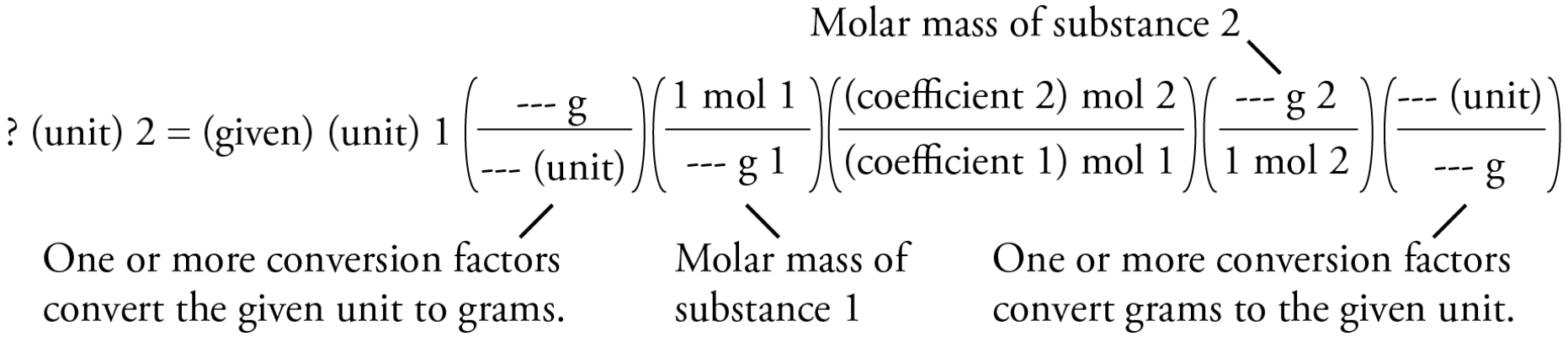
Equation Stoichiometry

5. Convert from moles of substance 1 to moles of substance 2 using the coefficients from the balanced equation to create the molar ratio used as a conversion factor.
6. Convert from moles of substance 2 to grams of substance 2, using its molar mass.
7. If necessary, convert from grams of 2 to the desired unit for 2. This may take one or more conversion factors.

Equation Stoichiometry Steps



Equation Stoichiometry Steps



Sample Calculation

- Tetrachloroethene, C_2Cl_4, often called perchloroethylene (perc), is a colorless liquid used in dry cleaning. It can be formed in several steps from the reaction of dichloroethane, chlorine gas, and oxygen gas. What is the maximum mass of perchloroethylene, C_2Cl_4, that can be formed from 23.75 kilograms of dichloroethane, $C_2H_4Cl_2$? The equation for the net reaction is:

$$8C_2H_4Cl_2(l) + 6Cl_2(g) + 7O_2(g) \rightarrow 4C_2HCl_3(l) + 4C_2Cl_4(l) + 14H_2O(l)$$

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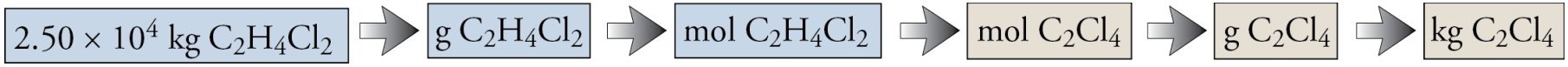
- Usual unit analysis steps

$$? \text{ kg } C_2Cl_4 = 23.75 \cancel{\text{kg}}\ C_2H_4Cl_2 \left(\frac{}{\cancel{\text{kg}}} \right)$$

- Tip-off: The calculation calls for you to convert from amount of one substance to amount of another, both of which are involved in a chemical reaction.



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What is the maximum mass of perchloroethylene, C_2Cl_4, that can be formed from 23.75 kilograms of dichloroethane, $C_2H_4Cl_2$? The equation for the net reaction is:

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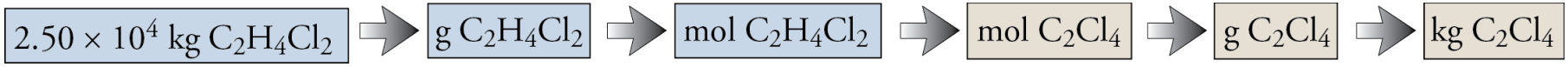
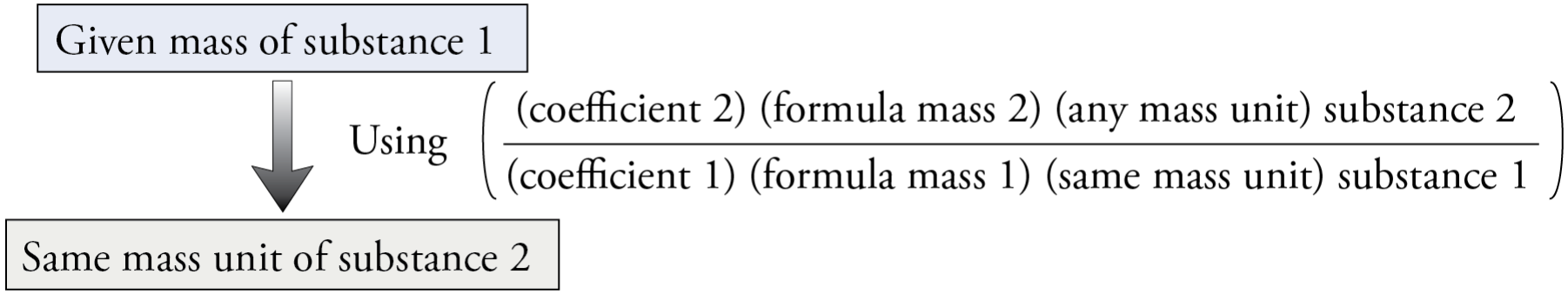
$$= \mathbf{19.90 \text{ kg } C_2Cl_4}$$



Equation Stoichiometry Shortcut for Mass-Mass Problems



? (unit) 2 = (given) (unit) 1 $\left(\frac{\text{(coefficient 2) (formula mass 2) (any mass unit) substance 2}}{\text{(coefficient 1) (formula mass 1) (same mass unit) substance 1}} \right)$

What is the maximum mass of perchloroethylene, C_2Cl_4, that can be formed from 23.75 kilograms of dichloroethane, $C_2H_4Cl_2$? The equation for the net reaction is:

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- Usual unit analysis steps

$$? \text{ kg } C_2Cl_4 = 23.75 \cancel{\text{kg}}\ C_2H_4Cl_2 \left(\frac{}{\cancel{\text{kg}}} \right)$$

- Tip-off: The calculation calls for you to convert from mass of one substance to mass of another, both of which are involved in a chemical reaction.
- We can use the shortcut.

$$? \text{ kg } C_2Cl_4 = 23.75 \cancel{\text{kg}}\ \cancel{C_2H_4Cl_2} \left(\frac{4 \times 165.833 \text{ kg } C_2Cl_4}{8 \times 98.959 \cancel{\text{kg } C_2H_4Cl_2}} \right)$$

$$= \mathbf{19.90 \text{ kg } C_2Cl_4}$$