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 Calculations (1)

- What is the maximum mass of P_4O_{10} that can be formed from 1.09×10^4 kg P?
- Beginning of unit analysis setup.

$$? \text{ kg } P_4O_{10} = 1.09 \times 10^4 \cancel{\text{kg}} \text{ P} \left(\frac{\quad}{1 \cancel{\text{kg}}} \right)$$

- The formula for P_4O_{10} provides us with a conversion factor that converts from units of P to units of P_4O_{10}.

$$\frac{1 \text{ molecule } P_4O_{10}}{4 \text{ atoms P}}$$

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

$$? \text{ kg } P_4O_{10} = 1.09 \times 10^4 \cancel{\text{kg}} \text{ P} \left(\frac{\quad}{1 \cancel{\text{kg}}} \right)$$

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

Counting by Weighing for Nails

- **Step 1:** Choose an easily measurable property.
  - Mass for nails
- **Step 2:** Choose a convenient unit for measurement.
  - Pounds for nails

Counting by Weighing for Nails (cont)

- **Step 3:** If the measurable property is mass, determine the mass of the individual objects being measured.
  - Weigh 100 nails: 82 are 3.80 g, 14 are 3.70 g, and 4 are 3.60 g
- **Step 4:** If the objects do not all have the same mass, determine the weighted average mass of the objects.

$$0.82(3.80\ g) + 0.14(3.70\ g) + 0.04(3.60\ g) = 3.78\ g$$

Counting by Weighing for Nails (cont)

- **Step 5:** Use the conversion factor from the weighted average to make conversions between mass and number of objects.

$$? \text{ nails} = 218 \text{ lb nails} \left(\frac{453.6 \text{ g}}{1 \text{ lb}}\right)\left(\frac{1 \text{ nail}}{3.78 \text{ g nails}}\right) = 2.62 \times 10^4 \text{ nails}$$

Counting by Weighing for Nails (cont)

- **Step 6**: Describe the number of objects in terms of a collective unit, such as a dozen, a gross, or a ream.

$$\frac{?\ \text{g nails}}{1\ \text{gross nails}} = \left(\frac{3.78\ \text{g nails}}{1\ \cancel{\text{nail}}}\right)\left(\frac{144\ \cancel{\text{nails}}}{1\ \text{gross nails}}\right) = \frac{544\ \text{g nails}}{1\ \text{gross nails}}$$

$$?\ \text{gross nails} = 218\ \cancel{\text{lb nails}}\left(\frac{453.6\ \cancel{\text{g}}}{1\ \cancel{\text{lb}}}\right)\left(\frac{1\ \text{gross nails}}{544\ \cancel{\text{g nails}}}\right) = 182\ \text{gross nails}$$

Counting by Weighing for Carbon Atoms

- **Step 1:** Choose an easily measurable property.
  - Mass for carbon atoms
- **Step 2:** Choose a convenient unit for measurement.
  - Atomic mass units (u) for carbon atoms
  - Atomic mass unit (u) = 1/12 the mass of a carbon-12 atom (with 6 p, 6 n, and 6 e^-)

Counting by Weighing for Carbon Atoms (cont.)

- **Step 3:** If the measurable property is mass, determine the mass of the individual objects being measured.
  - For carbon: 98.90% are 12 u and 1.10% are 13.003355 u.
- **Step 4:** If the objects do not all have the same mass, determine the weighted average mass of the objects.

$$0.9890(12\ \text{u}) + 0.0110(13.003355\ \text{u}) = 12.011\ \text{u}$$

Counting by Weighing for Carbon Atoms (cont.)

- For two reasons, we will skip step 5 where we would have used the weighted average mass, 12.011 u per atom, as a conversion factor.
  - The first reason is that we don't measure mass in unified mass units.
  - The second reason is that if we used 12.011 u per atom as a conversion factor, we would get the actual number of atoms, which for any sample of carbon would be a huge and inconvenient number.

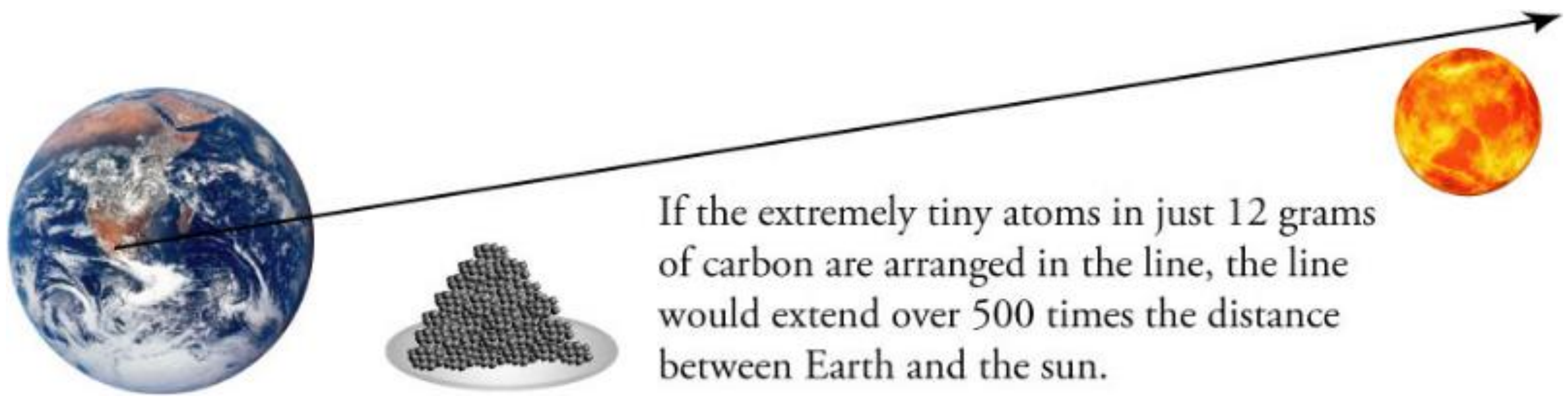
Counting by Weighing for Carbon Atoms (cont.)

- We would rather have a conversion factor that has a more common mass unit, such as grams, and we would rather describe the number of atoms in terms of a collective unit, such as a dozen, a gross, or a ream.
- That collective unit is a mole.

Mole

- A ***mole*** (mol) is an amount of substance that contains the same number of particles as there are atoms in 12 g of carbon-12.
- To four significant figures, there are 6.022×10^{23} atoms in 12 g of carbon-12.
- Thus a mole of natural carbon is the amount of carbon that contains 6.022×10^{23} carbon atoms.
- The number 6.022×10^{23} is often called ***Avogadro's number***.

Avogadro's Number



Molar Mass Development

From the definition of mole $\frac{12 \text{ g C-12}}{1 \text{ mol C-12}}$

From relative atomic masses

$$\frac{12.011 \text{ g C}}{1 \text{ mol C}} \qquad \frac{24.3050 \text{ g Mg}}{1 \text{ mol Mg}}$$

$$\frac{15.9994 \text{ g O}}{1 \text{ mol O}} \qquad \frac{1.00794 \text{ g H}}{1 \text{ mol H}}$$

Molar Mass of Elements

- The atomic masses found on the periodic table can be used to get molar masses, which can be used to convert between grams and moles of any element.

$$\left(\frac{(\text{atomic mass})\ \text{g element}}{1\ \text{mol element}} \right)$$

Example Calculations

- The masses of diamonds and other gemstones are measured in carats. There are exactly 5 carats per gram. How many moles of carbon atoms are in a 0.55 carat diamond? (Assume that the diamond is pure carbon.)

$$? \text{ mol C} = 0.55 \cancel{\text{carat C}} \left(\frac{1 \cancel{\text{g}}}{5 \cancel{\text{carat}}}\right)\left(\frac{1 \text{ mol C}}{12.011 \cancel{\text{g C}}}\right)$$

$$= 9.2\times10^{-3} \text{ mol C} \left(\frac{6.022\times10^{23} \text{ C atoms}}{1 \text{ mol C}}\right)$$

$$= 5.5\times10^{21} \text{ C atoms}$$

Our Calculation

- What is the maximum mass of P_4O_{10} that can be formed from 1.09×10^4 kg P?

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

Our Calculation

- What is the maximum mass of P_4O_{10} that can be formed from 1.09×10^4 kg P?
- Here are the general steps for our calculation. We'll see how to do the first two steps in this lesson, and I'll tell you how to do the last step in another lesson.

Mass P $\longrightarrow$ moles P $\longrightarrow$ moles P_4O_{10} $\rightarrow$ mass P_4O_{10}

Our Calculation – Step 1

- What is the maximum mass of P_4O_{10} that can be formed from 1.09×10^4 kg P?

Mass P → moles P → moles P_4O_{10} → mass P_4O_{10}

- We can convert grams of P to moles of P using the molar mass of P, which comes from its atomic mass that is found on the periodic table.

$$\frac{30.9738 \text{ g P}}{1 \text{ mol P}} \quad \text{or} \quad \frac{1 \text{ mol P}}{30.9738 \text{ g P}}$$

Our Calculation – Step 1

- What is the maximum mass of P_4O_{10} that can be formed from 1.09×10^4 kg P?

  Mass P $\longrightarrow$ moles P $\longrightarrow$ moles P_4O_{10} $\rightarrow$ mass P_4O_{10}

- Before we can convert grams P to moles P, we need to convert kg to g.

Converts given mass unit into grams.

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

Converts grams of element into moles.

Our Calculation

- The chemical formula provides a conversion factor for converting from moles of phosphorus atoms to moles of tetraphosphorus decoxide molecules in the second step of our calculation.

If $\frac{1 \text{ molecule } P_4O_{10}}{4 \text{ atoms P}}$ then $\frac{1 \text{ mol } P_4O_{10}}{4 \text{ mol P}}$

Our Calculation – Steps 1 and 2

- What is the maximum mass of P_4O_{10} that can be formed from 1.09×10^4 kg P?
- Here are the first two steps in our calculation.
- We'll see how to do the last step in another section.

Converts given mass unit into grams.

Converts moles of element into moles of compound.

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

Converts grams of element into moles.