The Mole

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CONCEPT 1 The Mole

Lesson Objectives

The student will:

- express the value of Avogadro's number and explain its relevance to moles.
- use Avogadro's number to convert to moles given the number of particles of a substance, and vice versa.
- use the molar mass to convert to grams given the number of moles of a substance, and vice versa.

Vocabulary

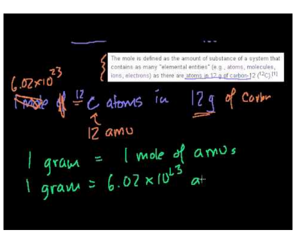
- Avogadro's number
- molar mass
- mole

Introduction

When objects are very small, it is often inconvenient, inefficient, or even impossible to deal with one object at a time. For these reasons, we often deal with groups of small objects and even have names for these groups. The most common of these is dozen, which refers to 12 objects. We frequently buy objects in groups of twelve, like doughnuts or pencils. Even smaller objects, such as straight pins or staples, are usually sold in boxes of 144, or a dozen dozen. A group of 144 objects is called a gross.

The problem of trying to deal with very small things individually also occurs in chemistry. Atoms and molecules are too small to see, let alone to count or measure. Chemists needed to select a group of atoms or molecules that would be convenient to operate with.

This video introduces the concept of the mole **(3b, 3c)**: http://www.youtube.com/watch?v=AsqEkF7hcII (9:44).



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Avogadro's Number

In chemistry, it is nearly impossible to deal with a single atom or molecule. Instead, chemists have defined a group of particles that is convenient to work with. Since molecules are extremely small, you might suspect that the number of particles in this group is going to be very large. In fact, the number of particles in this group is 6.02×10^{23} particles, and the name of this group is the **mole** (abbreviated as mol). The number 6.02×10^{23} is called Avogadro's number and is symbolized as the capital letter N. Although Italian scientist Amedeo Avogadro did not determine this number, but the number was named in honor of him. One mole of any object contains an Avogadro's number, or 6.02×10^{23}, of those objects.

The number of objects in a mole was not chosen arbitrarily. Instead, there is a very particular reason that the number 6.02×10^{23} was chosen. When chemists carry out chemical reactions, it is important to understand the relationship between the numbers of particles of each element involved in the reaction. Chemists realized that they obtained equal numbers of particles when they used one atomic or molecular mass in grams of the substances. By looking at the atomic masses on the periodic table, chemists knew that the mass ratio of one carbon atom to one sulfur atom was 12 amu to 32 amu. If they measured out one atomic mass in grams of both substances (in other words, 12 grams of carbon and 32 grams of sulfur), they would have the same number of atoms of each element. They didn't know how many atoms were in each pile, but they knew the number in each pile had to be the same. This logic is the same as knowing that if a basketball has twice the mass of a soccer ball, then 100 lbs of basketballs and 50 lbs of soccer balls both contain the same number of balls.

This amount of substance (its molecular mass in grams) became known as a gram-molecular mass. One gram-molecular mass of any substance had the same number of particles in it. Years later, when it became possible to count particles using electrochemical reactions, the number of particles in a gram-molecular mass was counted. That number turned out to be 6.02×10^{23} particles. This number of particles continued to be called a gram-molecular mass for many years, but eventually the name was changed to the mole.

The mole is defined so that 1.00 mole of carbon-12 atoms has a mass of 12.0 grams and contains 6.02×10^{23} atoms. Likewise, 1.00 mole of water has a mass of 18.0 grams and contains 6.02×10^{23} molecules. One mole of any element or compound has a mass equal to its molecular mass in grams and contains 6.02×10^{23} particles. The mass in grams of 6.02×10^{23} particles of a substance is now called the **molar mass** (mass of 1.00 mole).

Converting Molecules to Moles and Vice Versa

We now know that because the mass of a single molecule of H_2SO_4 is 98 daltons, the mass of an Avogadro's number of H_2SO_4 molecules is 98 grams. We can use this information to find the mass in grams of a single H_2SO_4 molecule because we know that 98 grams contains 6.02×10^{23} molecules. If we divide 6.02×10^{23} molecules into 98 grams, we will get the mass of a single H_2SO_4 molecule in grams. After performing this calculation, we would obtain an answer of 1.6×10^{-22} grams/molecule – tiny, indeed. If we are given a number of molecules of a substance, we can convert it into moles by dividing by Avogadro's number, and vice versa.

Example:

How many moles are present in $1,000,000,000$ (1 billion or 1×10^9) molecules of water?

Solution:

$$\text{moles} = (1,000,000,000 \text{ molecules}) \cdot \left(\frac{1 \text{ mole}}{6.02 \times 10^{23} \text{ molecules}}\right) = 1.7 \times 10^{-15} \text{ moles}$$

You should note that this amount of water is too small for even our most delicate balances to determine the mass. A *very* large number of molecules must be present before the mass is large enough to be detected with our balances.

Example:

How many molecules are present in 0.00100 mole?

Solution:

$$\text{molecules} = (0.00100 \text{ mole}) \cdot \left(\frac{6.02 \times 10^{23} \text{ molecules}}{1 \text{ mole}}\right) = 6.02 \times 10^{20} \text{ molecules}$$

Unlike the previous example, the mass of $602,000,000,000,000,000,000$ can be measured with a balance.

Converting Grams to Moles and Vice Versa

We can also convert back and forth between grams of substance and moles. The conversion factor for this is the molar mass of the substance. To convert the grams of a substance into moles, we divide by the molar mass. To convert the moles of a substance into grams, we multiply by the molar mass.

Example:

How many moles are present in 108 grams of water?

Solution:

$$\text{moles} = \frac{\text{grams}}{\text{molar mass}} = \frac{108 \text{ grams}}{18.0 \text{ grams/mole}} = 6.00 \text{ moles}$$

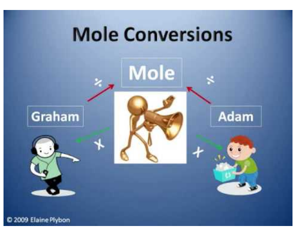
Example:

What is the mass of 7.50 moles of CaO?

Solution:

$$\text{grams} = (\text{moles}) \cdot (\text{molar mass}) = (7.50 \text{ moles}) \cdot (56.0 \text{ grams/mole}) = 420. \text{ grams}$$

This video tells a story to help students remember the easy way to perform mole conversions **(3d)**: http://www.youtube.com/watch?v=Kg-zaG0ckVg (2:52).



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Lesson Summary

- There are 6.02×10^{23} particles in 1.00 mole. The number 6.02×10^{23} is called Avogadro's number.
- The number of moles in a given number of molecules of a substance can be found by dividing the number of molecules by Avogadro's number.
- The number of moles in a given mass of substance can be found by dividing the mass by the formula mass expressed in grams/mole.

Further Reading / Supplemental Links

The *learner.org* website allows users to view streaming videos of the Annenberg series of chemistry videos. You are required to register before you can watch the videos, but there is no charge to register. The website has a video that apply to this lesson called "The Mole."

- http://learner.org/resources/series61.html

The website below reviews how to calculate the molar mass of chemical compounds.

- http://misterguch.brinkster.net/molarmass.html

Review Questions

1. Convert the following to moles.
   a. 60.0 grams of $NaOH$
   b. 2.73 grams of NH_4Cl
   c. 5.70 grams of ZrF_4
   d. 10.0 grams of PbO_2
2. Convert the following to grams.
   a. 0.100 moles of CO_2
   b. 0.437 moles of $NaOH$
   c. 0.500 moles of $(NH_4)_2CO_3$
   d. 3.00 moles of $ZnCl_2$
3. How many molecules (formula units for ionic compounds) are present in the following quantities?
   a. 0.250 mole of H_2O
   b. 6.00 moles of H_2SO_4
   c. 0.00450 mole of $Al_2(CO_3)_3$
4. How many moles are present in the following quantities?
   a. 1.00×10^{20} molecules of H_2O
   b. 1.00×10^{25} molecules of H_2
   c. $5,000,000,000,000$ atoms of carbon
5. How many molecules, atoms, or formula units are present in the following masses?
   a. 1.00 gram of Na_2CO_3
   b. 8.00 grams of helium
   c. 1000. grams of H_2O
6. Convert the following to grams.
   a. 1.00×10^{23} molecules of H_2
   b. 1.00×10^{24} formula units of $AlPO_4$
   c. 1.00×10^{22} formula units of $NaOH$
7. What is the mass of a single atom of silver, Ag, in grams?
8. If you determined that the volume of a silver bar is 100. mL, how many atoms of silver would be in the bar? The density of silver is 10.5 g/mL.