edited by:
RON DELORENZO
Middle Georgia College
Cochran, Georgia 31014

Moles, Pennies, and Nickels

R. Thomas Myers
Kent State University
Kent, OH 44242

Students frequently have difficulty with the mole concept initially because atoms and molecules are involved and these are invisible. It takes a great deal of imagination to see those N_2 and O_2 molecules in air. "Chemistry requires more imagination than art, more faith than religion." Therefore I start with a demonstration and calculation with visible entities: pennies and nickels.

The Demonstration

Pennies and nickels (relatively new, of course) are placed on opposite pans of an ordinary double-pan lab balance. You need the old-fashioned kind, with a pointer in the middle to indicate the pans are balanced. (None of your fancy digital balances or beam balances, please.) You find quickly that balance occurs with eight pennies on one pan, five nickels on the other.

The students are asked "What is the mass in grams of one penny? Of a nickel?" They answer (sometimes after prodding) "We don't know."

All that is known, of course, is that the mass of eight pennies is the same as the mass of five nickels. Now introduce a unit of mass, the "pennyweight". One penny has a mass of 1 pwt. Therefore a nickel has a mass of 8/5 = 1.6 pwt.

The Thought Experiment

Now you say "In our imagination we are going to count pennies and nickels by weighing. Specifically, we are going to count out *equal numbers* of pennies and nickels by weighing. Here is a little chart of the results." An example of this chart appears at the right.

The first task is to weigh out one of each coin. This requires 1 pwt of pennies, and 1.6 pwt of nickels. Next we increase to two of each, five of each, 10 of each, and 100 of each. Now, at the right we indicate the ratio of mass of pennies to mass of nickels. This is always 1:1.6. When the ratio of masses is equal to 1:1.6, then there will be the *same number* of pennies and nickels.

Next the question is asked "Suppose we weigh out 1 lb of pennies and 1.6 lb of nickels. What can we now say?" They will answer (sometimes with a little bit of prodding) "There are the same number of pennies and nickels." Further: "How many pennies and nickels?" "We don't know, all we know is that there is the same number of each, x." Now increase to 1 ton of pennies and 1.6 tons of nickels. They soon see that the numbers are the same for each, and is now $2000x$.

The Moral

The students are now reminded that the atomic masses are *relative* numbers, and that early chemists knew the *relative* masses of atoms, but not the exact mass of any atom (in grams). So they invented the idea of moles. They weighed out 1 g of hydrogen (1.008 g if you wish to be exact) and 16 (16.00) g of oxygen and knew that the number of atoms of each was equal. The numbers of atoms were equal, but unknown. If on the other hand they weighted out 2 g of hydrogen and 16 g of oxygen, then there were twice as many atoms of hydrogen than of oxygen. These amounts will react exactly to form H_2O, with no atoms left over. This can then be extended to 19 g of fluorine, 32 g of sulfur, 34.5 g of chlorine, etc.

Finally, the historical note can be added that chemists used this scheme—not knowing actual numbers of atoms—from about 1865 to 1910, when Avogadro's number was first measured by the French physicist, Perrin. (His value was 6.8×10^{23}.) However, the idea of moles is so handy and powerful that we still use it today.

mass of pennies	no. of pennies	mass of nickels	no. of nickels	ratio of masses
1 pwt	1	1.6 pwt	1	1:1.6
2 pwt	2	3.2 pwt	2	1:1.6
5 pwt	5	8.0 pwt	5	1:1.6
10 pwt	10	16 pwt	10	1:1.6
100 pwt	100	160 pwt	100	1:1.6
1 lb	x	1.6 lb	x	1:1.6
1 ton	$2000x$	1.6 ton	$2000x$	1:1.6