Understanding Moles as a Unit of Measurement

Overview
This activity uses tangible items (paperclips) to help students understand how scientists measure atoms (moles).

Time allotted: 1 class period

Grade level: 9-12 or undergraduate

Keystone Assessment Anchors
HEM.B.1.1 Explain how the mole is a fundamental unit of chemistry

Student Materials (per group):
- Worksheets (see below)
- Several boxes of large and small paperclips (same brand).
- Electronic balance (±0.1g (preferred) or ±0.01g),
- Plastic weighing boats (3.5" x 3.5"), 3 per group

Counting Moles Student Handout

Introduction: Now that we know that atoms exist, how do we keep track of them? One can imagine that the number of atoms in the world is an extremely large number. Is there a convenient way to count them on a measurable scale? For instance, what does one atom weigh or is it easier to count how many atoms are in one gram? As scientists, we try to design experiments that will help us find this information and the most useful way to use it on a lab scale.

We know that atoms are really small and that they are made of protons, electrons, and neutrons. In order to keep track of atoms during chemical reactions, we need a convenient way to count them. One can imagine that counting atoms one-at-a-time is an extremely difficult task. In fact, it is much easier to find the mass of a collection of atoms than it is to count them. If we are going to find the mass, then we need to keep two things in mind: 1) do all atoms have the same mass? and 2) how do we relate the laboratory scale of measuring to atomic sizes?

Most experiments in the early-to-mid 1800's regarding atoms and molecules revolved around the measurement of gases. Italian physicist, Amedo Avagadro, was one scientist working on this problem in 1811. He is credited with determining that gases at the same temperature and pressure have a constant relationship between mass and volume. For example, as the volume of the gas increases, so does the mass. In addition, he was the first to distinguish between "atoms" and "molecules." According to Dalton, fundamental particles were described, but there was not a known relationship between molecules as a compound made of different atoms. As credit for this important discovery, *Avagadro's Number (or Constant)* was named after him. Avagadro's number, symbolized by N_A, is 6.022141×10^{23}. It represents the number of atoms, molecules, ions, etc. in 1 mole. However, Avagadro never really worked on determining this value. That was done by other scientists.

In 1865, Josef Loschmidt determined that the number of particles in a given volume of gas at standard temperature and pressure should be constant. This helped lead to the idea that molecules have a given mass, much like atoms, as confirmed by Berzelius. It was determined later that the mass of the molecule is related to the proportions of atoms and their masses in the molecule. It was not until the early 1900's when Robert Milliken's experiments with electrons led to the numerical definition of Avagadro's constant.

Since carbon-12 was used as the standard relative mass for other elements, it was the standard for molar masses as well. This means that 1 mole of carbon atoms was defined as 12.01 g (12.01 amu per C atom).

Counting Moles: In this experiment, we will be using small and large paper clips to model how we count atoms and how we determine their amount in laboratory experiments.

Materials:

Several boxes of large and small paperclips (same brand).

Electronic balance (±0.1g (preferred) or ±0.01g),

Plastic weighing boats (3.5" x 3.5"), 3 per group

Words that Represent Numbers: It is common practice to use words that represent a specific number of "things." For example, a *couple* or *pair* represents 2 things. It could mean a married couple, husband and wife (2 people), or a couple of jokesters (2 clowns), or a *pair* of pears (2 pears). Below is a table of common words that represent numbers. The importance of these words is that the *units*, or things, represented by the number is interchangeable, like people, clowns and pears in the example. Each represents the different units of a couple or pair. The unit is not attached to the word couple. Another example is a dozen. One can have a dozen eggs, a dozen cookies, or a dozen cupcakes. In each case, a dozen means 12. The units of eggs, cookies, or cupcakes is not attached to the word dozen. One can express this as 12 "things" per dozen or 2 "things" per pair. "Things" can be any object and would be considered the units for that particular example.

Word	**Amount**
Couple or Pair	2
Dozen	12
Score	20
Gross	144
Mole	6.02×10^{23}

Counting Moles Procedure

Part 1: In this activity, you will determine the masses of paperclips for two trials. For each trial gather the necessary amounts of paperclips. We will also assume that the balances weigh the paperclips in atomic mass units (amu). We will convert everything to grams at the end.

Trial 1: Collect 12 large paperclips.
Trial 2: Collect 20 small paperclips.

The following instructions are given:

1. Keep large and small paperclips in separate cups.
2. Find the mass of the Lg paperclips (record in Table 1 column 1).
3. Using this value, calculate the mass of a single Lg paperclip (divide the total mass by the number of paperclips weighed). Record this value in Table 1 column 2.
4. Fill in the rest of Table 1 using conversions to relate one mass to another for the Lg paperclips.
5. Repeat Steps 1 - 4 for the Sm paperclips.

6. Weigh a single Lg paperclip to find the mass (record in Table 2 column 1).
7. Repeat Step 6 for 4 more Lg paperclips to fill in Table 2.
8. Calculate the average mass for the 5 paperclips.
9. Repeat for Sm paperclips.

10. Convert your masses from amu/mole (Table 1, column 6) to grams/mole (Table 3). The conversion factor is 1.66×10^{-24} g = 1 amu.
11. "React" 1 Lg paperclip with 1 Sm paperclip to form the compound LgSm (Lg + Sm -> LgSm). Find the mass of LgSm. Record in Table 4, column 1. Calculate the other values in Table 4.

What numbers are the same but with different units for the large paperclips? for the small paperclips? What values are different for the large paperclips compared to the small paperclips? What values are the same?

How does the mass of LgSm (amu/compound) compare to Lg (amu/clip) and Sm (amu/clip)? How does the molar mass of LgSm (g/mole) compare to the molar mass of Lg (g/mole) and the molar mass of Sm (g/mole)?

Part 2:

1. Collect a handful of large paperclips.
2. Find the mass of the paperclips. Record the mass of the large paperclips in Table 5.
3. Calculate the values in Table 5 using the values determined in Table 1.
4. Repeat Steps 1-3 for the small paperclips.

Student Data Tables for Modeling Atoms using Paperclips Activity

Table 1: Masses of Sets

	1	2	3	4	5	6
Trial	Mass of Total (amu)	Mass of Individual (amu/clip)	Mass per Dozen (amu/dozen)	Mass per Score (amu/score)	Mass per Gross (amu/gross)	Mass per Mole (amu/mole)
Lg						
Sm						

Table 2: Mass of Individual Paperclips

	1	2	3	4	5	6
Trial	Mass 1 (amu)	Mass 2 (amu)	Mass 3 (amu)	Mass 4 (amu)	Mass 5 (amu)	Average Mass (amu/clip)
Lg						
Sm						

Table 3: Converting AMUs to Grams

Trial // Mass	per mole (amu)	per mole (g)
Lg		
Sm		

Table 4: Molar Masses of Compounds

	1	2	3	4	5	6
Trial	Mass of LgSm (amu/compound)	Mass of Lg (amu/clip)	Mass of Sm (amu/clip)	Mass per Dozen (amu/dozen LgSm)	Mass per Mole (amu/mole LgSm)	Mass per Mole (g/mole LgSm)
LgSm						

Table 5: Using Mass Conversions to Count

	1	2	3	4	5
Trial	Mass of Clips (amu)	Number of Dozens	Number of Scores	Number of Grosses	Number of Moles
Lg					
Sm					

Student Directions to Help Analyze Paperclip Data

Analysis of Data

Table 1: Masses of Sets

Column 2: Total mass of paperclips (column 1) divided by the number of paperclips.

Column 3: Mass per paperclip (column 2) times 12 or Total mass (column 1) times 12/20 for small paperclips.

Column 4: Mass per paperclip (column 2) times 20 or Total mass (column 1) times 20/12 for large paperclips

Column 5: Mass per paperclip (column 2) times 144 or Mass per dozen (column 3) times 12

Column 6: Mass per paperclip (column 2) times Avagadro's number (6.02×10^{23})

Table 5: Using Mass Conversions to Count

Column 2: Total mass of paperclips (column 1) divided by Table 1, column 3.

Column 3: Total mass of paperclips (column 1) divided by Table 1, column 4.

Column 4: Total mass of paperclips (column 1) divided by Table 1, column 5.

Column 5: Total mass of paperclips (column 1) divided by Table 1, column 6.

Name __________________________________

Student Handout: Counting Moles

Part 1:

1. Does the mass increase or decrease across the row in Table 1? Explain.

2. How does the mass per clip of the Lg compare to the mass per clip of Sm? How do the masses per mole compare?

3. How many clips are in a gross of Lg? What is the mass of 1 gross of Lg? How many clips are in a gross of Sm? What is the mass of 1 gross of Sm?

4. How many clips are in a mole of Lg? How many clips are in a mole of Sm? What is the molar mass of Lg? What is the molar mass of Sm?

5. Compare the value of the mass of one clip of Lg in Table 1 to the average value from Table 2.

6. Are all of the individual masses for a Lg (or Sm) clip in Table 2 the same? What would the analogy be for atoms of a specific element?

7. What does the mass of a specific element on the periodic table represent based on your answer to #6?

8. Is it more accurate to measure the mass of a single atom or a large number of atoms when determining the molar mass?

Part 2:

1. How many LgSm compounds could be formed from the piles of Lg and Sm that you collected for Table 5?

2. What would be the mass of the LgSm compounds calculated in #2?

Name __*Sample Student Response*

Student Handout: Counting Moles
Answer Key for the Instructor (Notes in Blue.)

Part 1:

1. Does the mass increase or decrease across the row in Table 1? Explain.

   Increase. With more paper clips (increase in the denominator units), the mass should increase

2. How does the mass per clip of the Lg compare to the mass per clip of Sm? How do the masses per mole compare?

   It is larger. The mass per mole of Lg is larger than the mass per mole of Sm.

3. How many clips are in a gross of Lg? What is the mass of 1 gross of Lg? How many clips are in a gross of Sm? What is the mass of 1 gross of Sm?

   144. the value of mass/gross calculated for Lg. 144. The value of mass/gross of Sm.

   Lg value should be bigger, but the number of clips of each is equal, 144.

4. How many clips are in a mole of Lg? How many clips are in a mole of Sm? What is the molar mass of Lg? What is the molar mass of Sm?

   6.02×10^{23}. Same. Value from Table 3, Column 2 for each size.

5. Compare the value of the mass of one clip of Lg in Table 1 to the average value from Table 2.

   They are similar (same). Slight variation based on average of 5 clips.

6. Are all of the individual masses for a Lg (or Sm) clip in Table 2 the same? What would the analogy be for atoms of a specific element?

   No. These would be representative of isotopes.

7. What does the mass of a specific element on the periodic table represent based on your answer to #6?

The average value based on isotopes and their abundance.

8. Is it more accurate to measure the mass of a single atom or a large number of atoms when determining the molar mass?

Large number because it would account for differences in isotopes.

In fact, it should account for the abundance of isotopes as well, making the average of a large number near the weighted average based on isotope abundance.

Part 2:

1. How many LgSm compounds could be formed from the piles of Lg and Sm that you collected for Table 5?

Depends on which set is the limiting reactant.

2. What would be the mass of the LgSm compounds calculated in #1?

The number from question 1 times the “molar mass” of LgSm (sum of Lg mass and Sm mass)