

Relative Mass and the Mole

How can atoms be counted using a balance?

Why?

Consider the following equation for a chemical reaction: $2\text{H}_2 + \text{O}_2 \rightarrow 2\text{H}_2\text{O}$

This can be interpreted as two molecules of hydrogen and one molecule of oxygen combining to form two water molecules. But how often do chemists limit their reactions to one or two molecules? Usually a reaction is done with an unimaginable number of molecules. How then do chemists know they have the right mix? The molecules need to be quickly counted! How do we count molecules? The answer is the unit called the **mole**. This activity will start by considering two egg farmers (a chicken farmer and a quail farmer). They produce such large numbers of eggs that they can't count them all individually, so they count in dozens of eggs in some cases, while in other cases they use mass. Weighing is often easier than counting!

Model 1 – Eggs

Chicken		Quail		Ratio of numbers of eggs	Ratio of masses of eggs
Number of eggs in the sample	Mass of the sample	Number of eggs in the sample	Mass of the sample		
1	37.44 g	1	2.34 g	1 : 1	16 : 1
10		10			
438		438			
1 dozen		1 dozen			
1 million		1 million			

1. Consider the data in Model 1.
 - a. What is the mass of a standard chicken egg?
 - b. What is the mass of a standard quail egg?
 - c. Show mathematically how the 16:1 ratio of masses was calculated in the last column of Model 1.
2. Use a calculator to complete the table in Model 1. Divide the work among group members. Reduce all ratios to the lowest whole numbers possible.

3. Imagine you have two baskets—one filled with quail eggs and one filled with the same number of chicken eggs.
 - a. Which basket would be heavier?

 - b. How many times heavier would that basket be?

 - c. Explain mathematically how it is possible for you to answer part *b* with confidence, even though you don't know the actual number of eggs.

4. A farmer weighs out 32.0 kg of chicken eggs.
 - a. What mass of quail eggs would he need to weigh out to have the same number of eggs in both samples?

 - b. If the farmer had weighed out 32.0 pounds of chicken eggs (rather than kilograms), what mass of quail eggs would he need to weigh out to have the same number of eggs in both samples?

5. A farmer makes up a new counting unit called a “cluckster.”
 - a. If the farmer had 3 clucksters of chicken eggs and 3 clucksters of quail eggs, what could you say about the ratio of their masses?

 - b. Does it matter in this problem how many eggs are in a “cluckster”? Explain.



Read This!

Let's take what we learned in the egg model and apply it to atoms. Like eggs, atoms of the same element may have slightly different masses (remember isotopes). The periodic table lists an average atomic mass for the atoms in a sample of each element. These masses are recorded in “atomic mass units” where 1 amu is approximately equal to the mass of a proton (or neutron).

Model 2 – Atoms

Oxygen		Sulfur		Ratio of numbers of atoms	Ratio of masses of atoms
Number of atoms in the sample	Mass of the sample	Number of atoms in the sample	Mass of the sample		
1	16.00 amu	1	32.00 amu		
10		10			
1 dozen		1 dozen			
1 million		1 million			
1 mole	16.00 grams	1 mole	32.00 grams		

Note: The masses shown for oxygen and sulfur have been rounded to make the arithmetic a bit easier.

6. What is the ratio of the mass of an oxygen atom to the mass of a sulfur atom?
7. Fill in the table in Model 2 in a similar fashion to the eggs table in Model 1. Divide the work evenly among group members. Reduce all ratios to the lowest whole numbers possible.
8. Circle the phrase below that completes the sentence.

When two samples contain the same number of atoms _____.

the masses of the samples will be equal.

the ratio of the sample masses will be equal to the ratio of the atom's masses.

the masses are unrelated.

9. Explain why it is not necessary to know how many atoms are in “1 mole” to finish the last row of the table in Model 2.



10. How would the number of oxygen atoms in a 16.00 lbs sample compare to the number of sulfur atoms in a 32.00 lbs sample?

11. In the front of the room, there is a bottle that contains a 32.00 g sample of sulfur. This is 1 mole of sulfur. Estimate how many atoms are in the bottle. Your group must reach consensus.



Read This!

A long time ago chemists discovered what you have just discovered: *The relative masses of the elements can be used to “count” atoms.* If you measure out a sample equal to an atom's atomic mass in grams, you always end up with the same number of atoms. Chemists call that quantity the **mole**—a quantity of any sample whose mass is equal to its atomic mass in grams.

Model 3 – Molar Mass

Average Mass of a Single Particle	
1 atom of hydrogen (H)	1.01 amu
1 atom of copper (Cu)	63.55 amu
1 molecule of oxygen (O ₂)	32.01 amu
1 molecule of water (H ₂ O)	18.02 amu
1 formula unit of sodium chloride (NaCl)	58.44 amu

Average Mass of One Mole of Particles (Molar Mass)	
1 mole of hydrogen atoms (H)	1.01 g
1 mole of copper atoms (Cu)	63.55 g
1 mole of oxygen molecules (O ₂)	32.01 g
1 mole of water molecules (H ₂ O)	18.02 g
1 mole of sodium chloride formula units (NaCl)	58.44 g

12. Look at a periodic table. What number in each element box would a chemist use to find the values in the “Average Mass of a Single Particle” column in Model 3?
13. How is the mass of a single particle changed to get the mass of one mole of particles?
14. Which sample contains more atoms, 18.016 amu of water or 18.016 g of water? Explain.



15. If the formula mass of iron(II) sulfate (FeSO₄) is 151.9 amu, what is the molar mass of iron(II) sulfate?
16. Use a periodic table to calculate the molar mass of ammonia (NH₃).
17. How would the number of atoms in a 1.01 g sample of hydrogen compare to the number of atoms in a 63.55 g sample of copper?

Read This!

So how many “things” are in a mole? By estimating the size of atoms and taking volume measurements of 1 mole samples scientists can estimate that

$$1 \text{ mole} = 6.022 \rightarrow 10^{23} \text{ particles or } 602 \text{ 200 000 000 000 000 000 000 particles}$$

(More than you could count in a lifetime!)

This number is called Avogadro’s number, named after Amedeo Avogadro.



18. Fill in the blanks below using a periodic table. Be sure to include units of g or amu on all masses.

1 atom of helium has a mass of _____.

1 mole of helium contains _____ atoms, and has a mass of _____.

1 formula unit of calcium chloride (CaCl_2) has a mass of _____.

1 mole of CaCl_2 contains _____ formula units, and has a mass of _____.



Extension Questions

19. Use a periodic table to answer the following questions.

- a. Fluorine gas consists of diatomic molecules of fluorine (F_2). How many molecules of fluorine are in one mole of fluorine?

- b. What is the mass of 1 mole of fluorine gas?

- c. How many *atoms* of fluorine are in this sample? Show your work.

20. The mass of one mole of lead (Pb) atoms is 207.2 g. Use a proportion to calculate the number of lead atoms in a 15.00 g sample of lead.

21. What is the mathematical relationship between atomic mass units (amu) and grams (g)?

1 gram = _____ amu