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CONTENT
17.2

17.2 The Avogadro Number

READ

Atoms are so small that you could fit millions of them on the head of a pin. As you have learned, the masses of atoms and molecules are measured in atomic mass units. Working with atomic mass units in the laboratory is very difficult because each atomic mass unit has a mass of $^1/_{12}$ the mass of one carbon atom.

In order to make atomic mass units more useful, it would be convenient to relate the value of one atomic mass unit to one gram. One gram is an amount of matter we can actually see. For example, the mass of one paper clip is about 2.5 grams. The Avogadro number, 6.02×10^{23}, allows us to convert atomic mass units to grams.

What is a mole?

In chemistry, the term "mole" does not refer to a furry animal that lives underground. In chemistry, a mole is *quantity* of something and is used just like we use the term "dozen." One dozen is equal to 12. One mole is equal to 6.02×10^{23}, or the Avogadro number. If you have a *dozen* oranges, you have 12. If you have a *mole* of oranges, you have 6.02×10^{23}. This would be enough oranges to cover the entire surface of Earth seven feet deep in oranges!

Could you work with only a dozen atoms in the laboratory? You cannot see 12 atoms without the aid of a very powerful microscope. A mole of atoms would be much easier to work with in the laboratory because the mass of one mole of atoms can be measured in grams. Moles allow us to convert atomic mass units to grams. This relationship is illustrated below:

$$1 \text{ carbon atom} = 12.0 \text{ amu}$$

$$1 \text{ mole of carbon atoms} = 6.02 \times 10^{23} \text{atoms} = 12.0 \text{ grams}$$

To calculate the mass of one mole of any substance (the **molar mass**), you use the periodic table to find the atomic mass (not the mass number) for the element or for the elements that create the compound. You then express this value in grams.

EXAMPLE ▶

Substance	Elements in substance	Atomic mass of element (amu)	No. of atoms of each element	Formula mass (amu)	Molar mass (g)
Na	Na	22.99	1	22.99	22.99
U	U	238.03	1	238.03	238.03
H_2O	H O	1.01 16.00	2 1	18.01	18.01
$CaCO_3$	Ca C O	40.08 12.01 16.00	1 1 3	100.09	100.09
$Al(NO_3)_3$	Al N O	26.98 14.01 16.00	1 3 9	313.1	313.1

CONTENT 17.2

PRACTICE

For the following elements and compounds, complete the following table to calculate the mass of one mole of the substance:

Substance	Elements in substance	Atomic mass of element (amu)	No. of atoms of each element	Formula mass (amu)	Molar mass (g)
Sr					
Ne					
$Ca(OH)_2$					
NaCl					
O_3					
$C_6H_{12}O$					

The molar mass of a substance can be used to calculate the number of particles (atoms or molecules) present in any given mass of a substance. You can determine the number of particles present by using the Avogadro number.

READ

Using the Avogadro number

The Avogadro number states that for one mole of any substance, whether element or compound, there are 6.02×10^{23} particles present in the sample. Those particles are atoms if the substance is an element and molecules if the substance is a compound. If we look again at our previous examples we see that every substance has a different molar mass:

Substance	Elements in substance	Atomic mass of element (amu)	No. of atoms of each element	Formula mass (amu)	Molar mass (g)
Na	Na	22.99	1	22.99	22.99
U	U	238.03	1	238.03	238.03
H_2O	H	1.01	1	1.01	1.01
CaCO3	Ca	40.08	1	100.09	100.09
	C	12.01	1		
	O	16.00	3		
$Al(NO_3)_3$	Al	26.98	1	313.1	313.1
	N	14.01	3		
	O	16.00	9		

However, one mole of each of these substances contains exactly the same number of fundamental particles, 6.02×10^{23}. The difference is that each of these fundamental particles, atoms, and molecules, has a different mass based on its composition (number of protons and neutrons, numbers and types of atoms). Therefore, the number of particles in one mole of any substance is identical; however, the mass of one mole of substances varies based on the formula mass for that substance.

When a substance's mass is reported in grams and you need to find the number of particles present in the sample, you must first convert the mass in grams to the mass in moles. By using proportions and ratios, you can easily calculate the molar mass of any given amount of substance.

EXAMPLE ▶

How many molecules are in a sample of NaCl that has a mass of 38.9 grams?

First, determine the molar mass of NaCl:

Element	Atomic mass (amu)	No. of atoms	Molar mass (g)
Sodium (Na)	22.99	1	22.99
Chlorine (Cl)	35.45	1	35.45
Molar mass of NaCl			**58.44 g**

Next, determine how many particles are in 38.9 g of NaCl:

We know that 58.44 g of NaCl contains 6.02×10^{23} molecules of NaCl. Therefore, we can set up a proportion to determine the number of molecules in 38.9 g of NaCl:

$$\frac{58.44 \text{ g NaCl}}{6.02 \times 10^{23}} = \frac{38.9 \text{ g NaCl}}{x}$$

Solving for x using cross-multiplication gives us a value of 4.0×10^{23} molecules of NaCl.

CONTENT 17.2

PRACTICE

Complete the following table by determining the molar mass of each listed substance and either providing the number of particles in the given mass of sample or the mass of the sample that contains the given number of particles.

Substance	Molar Mass (g)	Mass of Sample (g)	Number of Particles Present
$MgCO_3$		12.75	
H_2O			296×10^{50}
N_2			7.1×10^{8}
Yb		0.00038	
$Al_2(SO_3)_3$		4657	
K_2CrO_4			0.23×10^{19}

Name: ______________________________ Date: __________

CONTENT 17.2

17.2 Formula Mass

READ

A chemical formula gives you useful information about a compound. First, it tells you which types of atoms and how many of each are present. Second, it lets you know which types of ions are present in a compound. Finally, it allows you to determine the mass of one molecule of a compound, relative to the mass of other compounds. We call this the formula mass. This skill sheet will show you how to calculate the formula mass of a compound.

EXAMPLE

Calculating formula mass: a step-by-step approach

A common ingredient in toothpaste is a compound called sodium phosphate. If you examine a tube of toothpaste, you will find that it is usually listed as trisodium phosphate.

- What is the formula mass of sodium phosphate?

Step 1: Determine the formulas and oxidation numbers of the ions in the compound.

Sodium phosphate is made up of the *sodium ion* and the *phosphate ion*. The oxidation number for the sodium ion can be determined from the periodic table. Since sodium, Na, is located in group 1 of the periodic table, it has an oxidation number of 1+ like all of the elements in group 1.

The chemical formula and oxidation number for sodium is: Na^+

To find the formula and oxidation number for the phosphate ion, use the ion chart in Chapter 16 of your textbook.

The chemical formula and oxidation number for the phosphate ion is: PO_4^{3-}

Step 2: Write the chemical formula of the compound.

Remember that compounds must be neutral that is, the oxidation numbers of the elements and ions must be equal to zero. Since sodium = $\mathbf{Na^+}$ and phosphate = $\mathbf{PO_4^{3-}}$ how many of each do you need to make a neutral compound? You need three sodium ions for each phosphate ion to make a neutral compound.

The chemical formula of sodium phosphate is: Na_3PO_4.

Step 3: List the type of atom, quantity, atomic mass, and total mass of each atom.

Atom	Quantity	Atomic mass (from the periodic table)	Total mass (number × atomic mass)
Na	3	22.99 amu	3 × 22.99 = 68.97 amu
P	1	30.97 amu	1 × 30.97 = 30.97 amu
O	4	16.00 amu	4 × 16.00 = 64.00 amu

Step 4: Add up the values and calculate the formula mass of the compound.

68.97 amu + 30.97 amu + 64.00 amu = 163.94 amu

The formula mass of sodium phosphate is 163.94 amu

PRACTICE

Now try one on your own:

Eggshells are made mostly of a brittle compound called calcium phosphate. What is the formula mass of this compound?

1. Write the chemical formula and oxidation number of each ion in the compound:

   First ion: Second ion:

2. Write the chemical formula of the compound:

3. List the type of atom, quantity, atomic mass, and total mass of each atom.

Atom	Quantity	Atomic mass (from the periodic table)	Total mass (number × atomic mass)

4. Add up the values to calculate the formula mass of the compound.

PRACTICE

Write the chemical formula and the formula mass for each of the compounds below. Use separate paper and show all of your work.

1. barium chloride
2. sodium hydrogen carbonate
3. magnesium hydroxide
4. ammonium nitrate
5. strontium phosphate

Name: ______________________ Date: __________

CONTENT 17.2

17.2 Chemical Equations

READ

Chemical symbols provide us with a shorthand method of writing the name of an element. Chemical formulas do the same for compounds. But what about chemical reactions? To write out, in words, the process of a chemical change would be long and tedious. Is there a shorthand method of writing a chemical reaction so that all the information is presented correctly and is understood by all scientists? Yes! This is the function of chemical equations. You will practice writing and balancing chemical equations in this skill sheet.

What are chemical equations?

Chemical equations show what is happening in a chemical reaction. They provide you with the identities of the reactants (substances entering the reaction) and the products (substances formed by the reaction). They also tell you how much of each substance is involved in the reaction. Chemical equations use symbols for elements and formulas for compounds. The reactants are written to the left of the arrow. Products go on the right side of the arrow.

$$H_2 + O_2 \rightarrow H_2O$$

The arrow should be read as "yields" or "produces." This equation, therefore, says that hydrogen gas (H_2) plus oxygen gas (O_2) yields or produces the compound water (H_2O).

PRACTICE

Write chemical equations for the following reactions:

Reactants	Products	Unbalanced Chemical Equation
Hydrochloric acid **HCl** and Sodium hydroxide **NaOH**	Water **H_2O** and Sodium chloride **NaCl**	
Calcium carbonate **$CaCO_3$** and Potassium iodide **KI**	Potassium carbonate **K_2CO_3** and Calcium iodide **CaI_2**	
Aluminum fluoride **AlF_3** and Magnesium nitrate **$Mg(NO_3)_2$**	Aluminum nitrate **$Al(NO_3)_3$** and Magnesium fluoride **MgF_2**	

Conservation of atoms

READ

Take another look at the chemical equation for making water:

$$2H_2 + O_2 \rightarrow 2H_2O$$

Did you notice that something has been added?

The large number in front of H_2 tells how many molecules of H_2 are required for the reaction to proceed. The large number in front of H_2O tells how many molecules of water are formed by the reaction. These numbers are called *coefficients*. Using coefficients, we can balance chemical equations so that the equation demonstrates conservation of atoms. The law of conservation of atoms says that no atoms are lost or gained in a chemical reaction. The same types and numbers of atoms must be found in the reactants and the products of a chemical reaction.

Coefficients are placed before the chemical symbol for single elements and before the chemical formula of compounds to show how many atoms or molecules of each substance are participating in the chemical reaction. When counting atoms to balance an equation, remember that the coefficient applies to all atoms within the chemical formula for a compound. For example, $5CH_4$ means that 5 atoms of carbon and 20 atoms (5×4) of hydrogen are contributed to the chemical reaction by the compound methane.

Balancing chemical equations

EXAMPLE

To write a chemical equation correctly, first write the equation using the correct chemical symbols or formulas for the reactants and products.

The displacement reaction between sodium chloride and iodine to form sodium iodide and chlorine gas is written as:

$$NaCl + I_2 \rightarrow NaI + Cl_2$$

Next, count the number of atoms of each element present on the reactant and product side of the chemical equation:

Reactant Side of Equation	Element	Product Side of Equation
1	Na	1
1	Cl	2
2	I	1

For the chemical equation to be balanced, the numbers of atoms of each element must be the same on either side of the reaction. This is clearly not the case with the equation above. We need coefficients to balance the equation.

First, choose one element to balance. Let's start by balancing chlorine. Since there are two atoms of chlorine on the product side and only one on the reactant side, we need to place a "2" in front of the substance containing the chlorine, the NaCl.

$$2NaCl + I_2 \rightarrow NaI + Cl_2$$

This now gives us two atoms of chlorine on both the reactant and product sides of the equation. However, it also give us two atoms of sodium on the reactant side! This is fine—often balancing one element will temporarily unbalance another. By the end of the process, however, all elements will be balanced.

We now have the choice of balancing either the iodine or the sodium. Let's balance the iodine. (It doesn't matter which element we choose.)

There are two atoms of iodine on the reactant side of the equation and only one on the product side. Placing a coefficient of "2" in front of the substance containing iodine on the product side:

$$2NaCl + I_2 \rightarrow 2NaI + Cl_2$$

There are now two atoms of iodine on either side of the equation, and at the same time we balanced the number of sodium atoms!

In this chemical reaction, two molecules of sodium chloride react with one molecule of iodine to produce two molecules of sodium iodide and one molecule of chlorine. Our equation is balanced.

PRACTICE

Balance the following equations using the appropriate coefficients. Remember that balancing one element may temporarily unbalance another. You will have to correct the imbalance in the final equation. Check your work by counting the total number of atoms of each element—the numbers should be equal on the reactant and product sides of the equation. Remember, the equations **cannot** be balanced by changing subscript numbers!

1. $Al + O_2 \rightarrow Al_2O_3$
2. $CO + H_2 \rightarrow H_2O + CH_4$
3. $HgO \rightarrow Hg + O_2$
4. $CaCO_3 \rightarrow CaO + CO_2$
5. $C + Fe_2O_3 \rightarrow Fe + CO_2$
6. $N_2 + H_2 \rightarrow NH_3$
7. $K + H_2O \rightarrow KOH + H_2$
8. $P + O_2 \rightarrow P_2O_5$
9. $Ba(OH)_2 + H_2SO_4 \rightarrow H_2O + BaSO_4$
10. $CaF_2 + H_2SO_4 \rightarrow CaSO_4 + HF$
11. $KClO_3 \rightarrow KClO_4 + KCl$

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CONTENT 17.3

17.3 Classifying Reactions

READ

Chemical reactions may be classified into different groups according to the reactants and products. The five major groups of chemical reactions are summarized below.

Addition reactions - when two or more substances combine to form a new compound.

- *General equation*: $A + B \rightarrow AB$
- *Example*: When rust forms, iron reacts with oxygen to form iron oxide (rust).
  $4Fe\ (s) + 3O_2\ (g) \rightarrow 2\ Fe_2O_3\ (s)$

Decomposition reactions - when a single compound is broken down to produce two or more smaller compounds.

- *General equation*: $AB \rightarrow A + B$
- *Example*: Water can be broken down into hydrogen and oxygen gases.
  $2H_2O\ (l) \rightarrow 2H_2\ (g) + O_2\ (g)$

Single displacement reactions - when one element replaces a similar element in a compound.

- *General equation*: $A + BX \rightarrow AX + B$
- *Example*: When iron is added to a solution of copper chloride, iron replaces copper in the solution and copper falls out of the solution.
  $Fe\ (s) + CuCl_2\ (aq) \rightarrow Cu\ (s) + FeCl_2\ (aq)$

Double displacement reactions - when ions from two compounds in solution exchange places to produce two new compounds.

- *General equation*: $AX + BY \rightarrow AY + BX$
- *Example*: When carbon dioxide gas is bubbled into lime water, a precipitate of calcium carbonate is formed along with water.
  $CO_2\ (g) + CaO_2H_2\ (aq) \rightarrow CaCO_3\ (s) + H_2O\ (l)$

Combustion reactions - when a carbon compound reacts with oxygen gas to produce carbon dioxide and water vapor. Energy is released from the reaction.

- *General equation*: Carbon Compound + $O_2 \rightarrow CO_2 + H_2O$ + energy
- *Example*: The combustion of methane gas.
  $CH_4\ (g) + 2O_2 \rightarrow CO_2\ (g) + 2H_2O\ (g)$

EXAMPLE

Classify the following reaction as addition, decomposition, single displacement, double displacement, or combustion. Explain your answer.

$Mg\ (s) + CuSO_4\ (s) \rightarrow MgSO_4\ (aq) + Cu\ _{(s)}$

Answer: Displacement. Magnesium replaces copper in the compound.

PRACTICE

Classify the reactions below as either: addition, decomposition, single displacement, double displacement, or combustion. Explain your answers.

1. CO_2 (g) + H_2O (l) → H_2CO_3 (aq)
2. Cl_2 (g) + 2KI (aq) → 2KCl (aq) + I_2 (g)
3. H_2O_2 (l) → H_2O (l) + O_2 (g)
4. $MnSO_4$ (s) → MnO (s) + SO_3 (g)
5. $C_6H_{12}O_6$ (s) + $6O_2$ (g) → $6CO_2$ (g) + $6H_2O$ (g)
6. $CaCl_2$ (aq) + $2AgNO_3$ (aq) → $Ca(NO_3)_2$ (aq) + 2AgCl (s)
7. 2NaCl (aq) + $CuSO_4$ (aq) → Na_2SO_4 (aq) + $CuCl_2$ (s)
8. $CaCl_2$ (aq) + 2Na (s) → Ca (s) + 2NaCl (aq)
9. $CaCO_3$ (s) → CaO (s) + CO_2 (g)
10. C_3H_8 (g) + $5O_2$ (g) → $3CO_2$ (g) + $4H_2O$ (g)

Answer the following questions.

11. You mix two clear solutions. Instantly, you see a bright yellow precipitate form. What type of reaction did you just observe? Explain your answer.
12. What type of reaction occurs when you strike a match?
13. Solid sodium reacts violently with chlorine gas. The product formed in the reaction is sodium chloride, also known as table salt. What type of reaction is this? Explain your answer.
14. Hydrogen-powered cars burn hydrogen gas to produce water and energy. The reaction is:

    $2H_2$ (g) + O_2 (g) → $2H_2O$ (g) + Energy

    While this reaction can be classified as an addition reaction, it is sometimes referred to as combustion. What characteristics does this reaction share with other combustion reactions? How is it different?

Name: ________________________ Date: __________

CHALLENGE! 17.3

17.3 Predicting Chemical Equations

READ

Chemical reactions cause chemical changes. Elements and compounds enter into a reaction, and new substances are formed as a result. Often, we know the types of substances that entered the reaction and can tell what types of substance(s) were formed. Sometimes, though, it might be helpful if we could predict the products of the chemical reaction—know in advance what would be formed and how much of it would be produced.

For certain chemical reactions, this is possible, using our knowledge of oxidation numbers, types of chemical reactions, and how equations are balanced. In this skill sheet, you will practice writing a complete balanced equation for chemical reactions when only the identities of the reactants are known.

Review: Chemical equations

Recall that chemical equations show the process of a chemical reaction. The equation reads from left to right with the reactants separated from the products by an arrow that indicates "yields" or "produces."

In the chemical equation:

$$2Li + BaCl_2 \rightarrow 2LiCl + Ba$$

Two atoms of lithium combine with one molecule of barium chloride to yield two molecules of lithium chloride and one atom of barium. The equation fully describes the chemical change for this reaction.

For reactions such as the one above, a single displacement reaction, we are often able to predict the products in advance and write a completely balanced equation for the chemical change. Here are the steps involved:

1. Predict the replacements for the reaction.

In single displacement reactions, one element is replaced by a similar element in a compound. The pattern for this replacement is easily predictable: if the element doing the replacing forms a positive ion, it replaces the element in the compound that forms a positive ion. If the substance doing the replacing forms a negative ion, it replaces the element in the compound that forms a negative ion.

For the reaction described above, we could predict that the lithium would replace the barium in the compound barium chloride since both lithium and barium have positive oxidation numbers. The resulting product would pair lithium (1+) and chlorine (1-): the positive/negative combination required for ionic compounds.

2. Determine the chemical formula for the products.

Once you have determined which elements will be swapped to form the products, you can use oxidation numbers and the fact that the sum of the oxidation numbers for an ionic compound must equal zero in order to determine the chemical formula for the reaction products.

3. Balance the chemical equation

Once you have determined the nature and formulas of the products for a chemical reaction, the final step is to write a balanced equation for the reaction.

EXAMPLE

- If beryllium (Be) combines with potassium iodide (KI) in a chemical reaction, what are the products?

  Solution:

  First, we decide which element of KI will be replaced by the beryllium. Since beryllium has an oxidation number of 2+, it replaces the element in KI that also has a positive oxidation number—the potassium (K^{1+}). It will therefore combine with the iodine to form a new compound.

  Because beryllium has an oxidation number of 2+ and iodine's oxidation number is 1–, it is necessary for two atoms of iodine to combine with one atom of beryllium to form an electrically neutral compound. The resulting chemical formula for beryllium iodide is BeI_2.

  In single-displacement reactions, the component of the compound that has been replaced by the uncombined reactant now stands alone and uncombined. The resulting products of this chemical reaction, therefore, are BeI_2 and K. Balancing the equation give us:

$$Be + 2KI \rightarrow BeI_2 + 2K$$

PRACTICE

Predict replacements

1. If Na^{1+} were to combine with $CaCl_2$, what component of $CaCl_2$ would be replaced by the Na^{1+}?
2. If Fe^{2+} were to combine with K_2Br, what component of K_2Br would be replaced by the Fe^{2+}?
3. If Mg^{2+} were to combine with $AlCl_3$, what component of $AlCl_3$ would be replaced by the Mg^{2+}?

Predict product formulas

For the following combinations of reactants, predict the formulas of the products:

4. $Li + AlCl_3$
5. $K + CaO$
6. $F_2 + KI$

Predicting chemical equations for displacement reactions

Write complete balanced equations for the following combinations of reactants.

7. Ca and K_2S
8. Mg and Fe_2O_3
9. Li and NaCl

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CONTENT 18.2

18.2 Percent Yield

READ

You can predict the amount of product to expect from a reaction if you know how much reactant you started with. For example, if you start out with one mole of limiting reactant, you can expect to produce one mole of product.

In real-world chemical reactions, the actual amount of product is usually less than the predicted amount. This is due to experimental error and other factors (such as the fact that some product is difficult to collect and measure).

The amount of product you expect to produce is called the *predicted yield*. The amount of product that you are able to measure after the reaction is called the *actual yield*. The *percent yield* is the *actual yield* divided by the *predicted yield* and then multiplied by 100.

$$\text{Percent yield} = \frac{\text{Actual yield}}{\text{Predicted yield}} \times 100$$

The percent yield can provide information about how carefully the experiment was performed. If a percent yield is low, chemical engineers look for sources of error. Manufacturers of chemical products try to maximize their percent yield so that they can get the maximum amount of product to sell from the reactants that they purchased.

EXAMPLE

- In the reaction below, potassium and water are combined in a chemical reaction that produces potassium hydroxide and hydrogen gas. If two moles of potassium (the limiting reactant) are used, what is the predicted yield of potassium hydroxide (KOH) in grams?

  $2K + 2H_2O \rightarrow 2KOH + H_2$

1. Looking for:	Predicted yield of KOH in grams
2. Given:	Two moles of the limiting reactant (K) are used
3. Relationships:	Two moles of limiting reactant should produce two moles of product. Two moles of the product will have a mass twice its molar mass.
4. Solution:	Molar mass of KOH = atomic mass of K + atomic mass of O + atomic mass of H From periodic table, molar mass of KOH = 39.10 + 16.00 + 1.01 = 56.11 grams Because we started with two moles of limiting reactant, we should end up with two moles, or 112.22 grams, of KOH.

- If the actual yield of KOH was 102.5 grams, what was the percent yield for this reaction?

1. Looking for:	Percent yield of KOH
2. Given:	Actual yield = 102.5 g; predicted yield = 122.22 g
3. Relationships:	Percent yield = actual yield ÷ predicted yield × 100
4. Solution:	Percent yield = 102.5 g ÷ 112.22 g × 100 = 91.3%

PRACTICE

1. In the balanced reaction below, hydrochloric acid reacts with calcium carbonate to produce calcium chloride, carbon dioxide, and water.

   $2HCL + CaCO_3 \rightarrow CaCl_2 + CO_2 + H_2O$

   If one mole of calcium carbonate (the limiting reactant) is used, how much calcium chloride should the reaction produce? Give your answer in grams. (Hint: use your periodic table to find the atomic masses of calcium and chlorine).

2. If the actual yield of calcium chloride in the reaction is 97.6 grams, what is the percent yield?

3. In order to get a 94% actual yield for this reaction, how many grams of calcium chloride would the reaction need to produce?

4. If you put an iron nail into a beaker of copper (II) chloride, you will begin to see a reddish precipitate forming on the nail. In this reaction, iron replaces copper in the solution and copper falls out of the solution as a metal. Here is the balanced reaction:

   $Fe + CuCl_2 \rightarrow FeCl_2 + Cu$

   If you start out with one mole of your limiting reactant (Fe), how many grams of copper can you expect to produce through this reaction?

5. If the actual yield of copper in the reaction is 55.9 grams, what is the percent yield?

6. How much copper would the reaction need to produce to achieve a 96% yield?

7. When sodium hydroxide and sulfuric acid react, sodium sulfate and water are produced. Here is the balanced reaction:

   $2NaOH + H_2SO_4 \rightarrow NaSO_4 + 2H_2O$

   If two moles of sodium hydroxide (the limiting reactant) are used, one mole of $NaSO_4$ should be produced. How many grams of $NaSO_4$ should be produced?

8. If 100.0 grams of $NaSO_4$ are actually produced, what is the percent yield?

9. How much $NaSO_4$ would have to be produced to achieve a 90% yield?

10. Name two reasons why the actual yield in a reaction is usually lower than the predicted yield.

Name: ______________________________ Date: __________

BIOGRAPHY 18.3

18.3 Lise Meitner

Lise Meitner identified and explained nuclear fission, proving it was possible to split an atom.

Prepared to learn

Lise Meitner was born in Vienna on November 7, 1878, one of eight children; her father was among the first Jews to practice law in Austria. At 13, she completed the schooling provided to girls. Her father hired a tutor to help her prepare for a university education, although women were not yet allowed to attend.

The preparation was worthwhile. When the University of Vienna opened its doors to women in 1901, Meitner was ready. She found a mentor there in physics professor Ludwig Boltzmann, who encouraged her to pursue a doctoral degree. Physicist Otto Robert Frisch, Meitner's nephew, wrote that "Boltzmann gave her the vision of physics as a battle for ultimate truth, a vision she never lost."

Pioneer in radioactivity

In 1906 Meitner went to Berlin after earning her doctorate, only the second in physics awarded to a woman by the university. There was great interest in theoretical physics in Berlin. There she began a 30-year collaboration with chemist Otto Hahn. Together, they studied radioactive substances. One of their first successes was the development of a new technique for purifying radioactive material.

During World War I, Meitner volunteered as an X-ray nurse-technician with the Austrian army. She pioneered cautious handling techniques for radioactive substances, and when she was off duty, continued her work with Hahn.

Elemental discoveries

In 1917, they discovered the element protactinium. Afterward, Meitner was appointed head of the physics department at the Kaiser Wilhelm Institute for Chemistry in Berlin, where Hahn was head of the chemistry department. The two continued their study of radioactivity, and Meitner became the first to explain how conversion electrons were produced when gamma rays were used to remove orbital electrons.

Atomic-age puzzles

In 1934, when Enrico Fermi produced radioactive isotopes of uranium by neutron bombardment, he was puzzled by the products. Meitner, Hahn, and German chemist Fritz Strassmann began looking for answers.

Their research was interrupted when Nazi Germany annexed Austria in 1938 and restrictions on "non-Aryan" academics tightened. Meitner, though she had been baptized and raised a Protestant, went into exile in Sweden. She continued to correspond with her collaborators and suggested that they perform further tests on a product of the uranium bombardment.

When tests showed it was barium, the group was puzzled. Barium was so much smaller than uranium. Hahn wrote to Meitner that uranium "can't really break into barium … try to think of some other possible explanation."

Meitner and Frisch (who was also in Sweden) worked on the problem and proved that splitting the uranium atom was energetically possible. Using Neils Bohr's model of the nucleus, they explained how the neutron bombardment could cause the nucleus to elongate into a dumbbell shape. Occasionally, they explained, the narrow center of the dumbbell could separate, leaving two nuclei. Meitner and Frisch called this process *nuclear fission*.

Meitnerium honors achievement

In 1944, Hahn received the Nobel Prize in chemistry for the discovery of nuclear fission. Meitner's role was overlooked or obscured.

In 1966, she, Hahn, and Strassman shared the Enrico Fermi Award, given by President Lyndon B. Johnson and the Department of Energy. Meitner died two years later, just days before her 90th birthday. In 1992, element 109 was named *meitnerium* to honor her work.

Reading reflection

1. **Research:** Ludwig Boltzmann was an important mentor to Lise Meitner. Who was Boltzmann? Research and list one of his contributions to science.

2. What element did Meitner and Otto Hahn discover? Using the periodic table, list the atomic number and mass number of this element. Does this element have stable isotopes?

3. What is nuclear fission? Explain this event in your own words and draw a diagram showing how fission occurs in a uranium nucleus.

4. **Research** and describe at least two ways nuclear fission was used in the twentieth century.

5. Meitner did not receive the Nobel Prize for her work on nuclear fission, though she was honored in other ways. List how she was honored for her work in physics.

6. On a separate sheet of paper, compose a letter to the Nobel Prize Committee explaining why Meitner deserved this prize for her work. Be sure to explain your reasoning clearly and be sure to use formal language and correct grammar in your letter.

Name: ________________________ Date: __________

BIOGRAPHY 18.3

18.3 Marie and Pierre Curie

Marie and Pierre Curie's pioneering studies of radioactivity had a dramatic impact on the development of twentieth-century science. Marie Curie's bold view that uranium rays seemed to be an intrinsic part of uranium atoms encouraged physicists to explore the possibility that atoms might have an internal structure. Out of this idea the field of nuclear physics was born. Together the Curies discovered two radioactive elements, polonium and radium. Through Pierre Curie's study of how living tissue responds to radiation, a new era in cancer treatment was born.

The allure of learning

Marya Sklodowska was born on November 7, 1867, in Russian-occupied Warsaw, Poland. She was the youngest of five children of two teachers, her father a teacher of physics and mathematics, her mother also a singer and pianist.

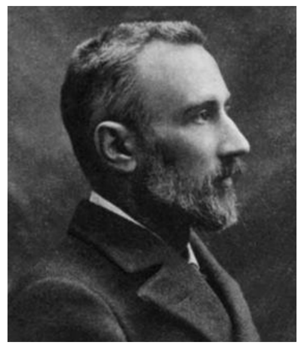
Marya loved school, and especially liked math and science. However, in Poland, as in much of the rest of the world, opportunities for higher education were limited for women. At 17, she and one of her sisters enrolled in an illegal, underground "floating university" in Warsaw.

After these studies, she worked for three years as a governess. Her employer allowed her to teach reading to the children of peasant workers at his beet-sugar factory. This was forbidden under Russian rule. At the same time, she took chemistry lessons from the factory's chemist, mathematics lessons from her father by mail, and studied on her own.

By fall 1891, Sklodowska had saved enough money to enroll at the University of Paris (also called the Sorbonne). She earned two master's degrees, in physics and mathematics.

A Polish friend introduced Marie, as she was called in French, to Pierre Curie, the laboratory chief at the Sorbonne's Physics and Industrial Chemistry Schools.

The piezoelectric effect



Pierre Curie's early research centered on properties of crystals. He and his brother Jacques discovered the piezoelectric effect, which describes how a crystal will oscillate when electric current is applied. The oscillation of crystals is now used to precisely control timing in computers and watches and many other devices.

Pierre Curie and Marie Sklodowska found that despite their different nationalities and background, they had the same passion for scientific research and shared the desire to use their discoveries to promote humanitarian causes. They married in 1895.

Crystals and uranium rays

Pierre continued his pioneering research in crystal structures, while Marie pursued a physics doctorate. She chose uranium rays as her research topic. Uranium rays had been discovered only recently by French physicist Henri Becquerel.

Becquerel's report explained that uranium compounds emitted some sort of ray that fogged photographic plates. Marie Curie decided to research the effect these rays had on the air's ability to conduct electricity. To measure this effect, she adapted a device that Pierre and Jacques Curie had invented 15 years earlier.

Marie Curie confirmed that the electrical effects of uranium rays were similar to the photographic effects that Becquerel reported—both were present whether the uranium was solid or powdered, pure or in compound, wet or dry, exposed to heat or to light.

She concluded that the emission of rays by uranium was not the product of a chemical reaction, but could be something built into the very structure of uranium atoms.

Allies behind a revolutionary idea

Marie Curie's idea was revolutionary because atoms were still believed to be tiny, featureless particles. She decided to test every known element to see if any others would, like uranium, improve the air's ability to conduct electricity. She found that the element thorium had this property.

Pierre Curie decided to join Marie after she found that two different uranium ores (raw materials gathered from uranium mines) caused the air to conduct electricity much better than even pure uranium or thorium. They wondered if an undiscovered element might be mixed into each ore.

They worked to separate the chemicals in the ores and found two substances that were responsible for the increased conductivity. They called these elements polonium, in honor of Marie's native country, and radium, from the Greek word for ray.

A new field of medicine

While Marie Curie searched for ways to extract these pure elements from the ores, Pierre turned his attention to the properties of the rays themselves. He tested the radiation on his own skin and found that it damaged living tissue.

As Pierre published his findings, a whole new field of medicine developed, using targeted rays to destroy cancerous tumors and cure skin diseases. Unfortunately, both Curies became ill from overexposure to radiation.

Curies share the Nobel Prize

In June 1903, Madame Curie became the first woman in Europe to receive a doctorate in science. In December of that year, the Curies and Becquerel shared the Nobel Prize in physics.

The Curies were honored for their work on the spontaneous radiation that Becquerel had discovered. Marie Curie called spontaneous radiation "radioactivity." She was the first woman to win the Nobel in physics. And in 1904, her second daughter, Eve, was born. The elder daughter, Irene, was seven.

Tragedy intrudes

In April 1906, Pierre was killed by a horse-drawn wagon in a Paris street accident. A month later, the Sorbonne asked Madame Curie to take over her husband's position there. She agreed, in hopes of creating a state-of-the art research center in her husband's memory.

Marie Curie threw herself into the busy academic schedule of teaching and conducting research (she was the first woman to lecture, the first to be named professor, and the first to head a laboratory at the Sorbonne), and found time to work on raising money for the new center. The Radium Institute of the University of Paris opened in 1914 and Madame Curie was named director of its Curie Laboratory.

The scientist-humanitarian

In 1911, Curie received a second Nobel Prize (the first person so honored), this time in chemistry for her work in finding elements and determining the atomic weight of radium.

With the start of World War I in 1914, she turned her attention to the use of radiation to help wounded soldiers. Assisted by her daughter Irene, she created a fleet of 20 mobile x-ray units to help medics quickly determine and then treat injuries in the field. Next, she set up nearly 200 x-ray labs in hospitals and trained 150 women to operate the equipment.

Legacy continues

After the war, Curie went back to direct the Radium Institute, which grew to two centers, one devoted to research and the other to treatment of cancer. In July 1934, she died at 66 of radiation-induced leukemia. The next year, Irene Joliot-Curie and her husband, Frederic Joliot-Curie, were awarded the Nobel Prize in chemistry for their discovery of artificial radiation.

Reading reflection

1. Why might Marie Curie have been motivated to teach the children of beet workers? Recall that this was forbidden by Russian rule.
2. What fundamental change in our understanding of the atom was brought about by the work of Marie Curie?
3. Describe how Marie and Pierre Curie discovered two elements.
4. Name at least three new fields of science that stem from the work of Marie and/or Pierre Curie.
5. **Research:** In your own words, describe Marie Curie as a role model for women in science. Use your library or the Internet to research how she worked to balance a scientific career and motherhood.

Name: ______________________________ Date: __________

BIOGRAPHY 18.3

18.3 Rosalyn Sussman Yalow

Rosalyn Sussman Yalow and her research partner, Solomon Berson, developed radioimmunoassay, or RIA. This important medical diagnostic tool uses radioactive isotopes to trace hormones, enzymes, and medicines that exist in such low concentrations in blood that they were previously impossible to detect using other laboratory methods.

Encouraged and inspired

Rosalyn Sussman was born in 1921 in New York City. Neither of her parents attended school beyond eighth grade, but they encouraged Rosalyn and her older brother to value education. In the early grades, Rosalyn enjoyed math, but in high school her chemistry teacher encouraged her interest in science.

She stayed in New York after high school, studying physics and chemistry at Hunter College. After her graduation in 1941, she took a job as a secretary at Columbia University. There were few opportunities for women to attend graduate school, and Sussman hoped that by working at Columbia, she might be able to sit in on some courses.

A wartime opportunity

However, as the United States began drafting large numbers of men in preparation for war, universities began to accept women rather than close down. In fall 1941, Sussman arrived at the University of Illinois with a teaching assistantship in the School of Engineering, where she was the only woman.

There, she specialized in the construction and use of devices for measuring radioactive substances. By January 1945 she had earned her doctorate, with honors, in nuclear physics, and married Aaron Yalow, a fellow student.

From medical physics to 'radioimmunoassay'

From 1946-50, Yalow taught physics at Hunter College, which had only introduced it as a major her senior year and which now admitted men. In 1947, she also began working part time at the Veterans Administration Hospital in the Bronx, which was researching medical uses of radioactive substances.

In 1950 she joined the hospital full time and began a research partnership with Solomon A. Berson, an internist. Together they developed the basic science, instruments, and mathematical analysis necessary to use radioactive isotopes to measure tiny concentrations of biological substances and certain drugs in blood and other body fluids. They called their technique radioimmunoassay, or RIA. (Yalow also had two children by 1954.)

RIA helps diabetes research

One early application of RIA was in diabetes research, which was especially significant to Yalow because her husband was diabetic. Diabetes is a condition in which the body is unable to regulate blood sugar levels. This is normally accomplished through the release of a hormone called insulin from the pancreas.

Using RIA, they showed that adult diabetics did not always lack insulin in their blood, and that, therefore, something must be blocking their insulin's normal action. They also studied the body's immune system response to insulin injected into the bloodstream.

Commercial applications, not commerce

RIA's current uses include screening donated blood, determining effective doses of medicines, detecting foreign substances in the blood, testing hormone levels in infertile couples, and treating certain children with growth hormones.

Yalow and Berson changed theoretical immunology and could have made their fortunes had they chosen to patent RIA, but instead, Yalow explained, "Patents are about keeping things away from people for the purpose of making money. We wanted others to be able to use RIA." Berson died unexpectedly in 1972; Yalow had their VA research laboratory named after him, and lamented later that his death had excluded him from sharing the team's greatest recognition.

A rare Nobel winner

Yalow was awarded the Nobel Prize in Physiology or Medicine in 1977. She was only the second woman to win in that category, for her work on radioimmunoassay of peptide hormones.

Reading reflection

1. Rosalyn Yalow has said that Eve Curie's biography of her mother, Marie Curie, helped spark her interest in science. Compare the lives of these two scientists.

2. Describe radioimmunoassay in your own words.

3. What information about adult diabetes was discovered using RIA?

4. Find out more about the role of patents in medical research. Do you agree or disagree with Yalow's statement? Why?

Name: ______________________ Date: __________

BIOGRAPHY 18.3

18.3 Chien-Shiung Wu

During World War II, Chinese-American physicist Chien-Shiung Wu played an important role in the Manhattan Project, the Army's secret work to develop the atomic bomb. In 1957, she overthrew what was considered an indisputable law of physics, changing the way we understand the weak nuclear force.

Determined to learn

Chien-Shiung Wu was born on May 31, 1912, in a small town outside Shanghai, China. Her father had opened the region's first school for young girls, which Chien-Shiung finished at age 10.

She then attended a girls boarding school in Suzhou that had two sections—a teacher training school and an academic school with a standard Western curriculum. Chien-Shiung enrolled in teacher training, because tuition was free and graduates were guaranteed jobs.

Students from both sections lived in the dormitory, and as Chien-Shiung became friends with girls in the academic school, she learned that their science and math curriculum was more rigorous than hers. She asked to borrow their books and stayed up late teaching herself the material.

Chien-Shiung Wu graduated first in her class and was invited to attend prestigious National Central University in Nanjing. There, she earned a bachelor's degree in physics and did research for two years. In 1936 Wu emigrated from China to the United States. She earned her doctorate from the University of California at Berkeley in 1940.

A key scientist in the Manhattan Project

Wu taught at Smith College and Princeton University until 1944, when she went to Columbia University as a senior scientist and researcher and was asked to join the Manhattan Project. There she helped develop the process to enrich uranium ore.

In the course of the project, her renowned colleague Enrico Fermi turned to Wu for help with a fission experiment. A rare gas which she had studied in graduate school was causing the problem. With Wu's assistance, Fermi was able to solve the problem and continue his work.

Right and left in nature?

After the war, Wu continued her research in nuclear physics at Columbia. In 1956, she and two colleagues, Tsung-Dao Lee of Columbia and Chen Ning Yang of Princeton, reconsidered the *law of conservation of parity*. This law stated that nature does not distinguish between left and right in nuclear reactions. They wondered if the law might not be valid for interactions of subatomic particles involving the **weak nuclear force**.

Wu was a leading specialist in **beta decay**. She figured out a means of testing their theory. She cooled cobalt-60, a radioactive **isotope**, to 0.01 degree above absolute zero. Next, she placed the cobalt-60 in a strong magnetic field so that the cobalt nuclei lined up and spun along the same axis. She observed what happened as the cobalt-60 broke down and gave off electrons.

According to the law of conservation of parity, equal numbers of electrons should have been given off in each direction. However, Wu found that many more electrons flew off in the direction opposite the spin of the cobalt-60 nuclei. She proved that in beta decay, nature does in fact distinguish between left and right.

Always a landmark achiever

Unfortunately, when Lee and Yang were awarded the Nobel Prize in physics in 1957, Wu's contribution to the project was overlooked. However, among her many honors and awards, she later received the National Medal of Science, the nation's highest award for science achievement.

In 1973, she became the first female president of the American Physical Society. Wu died at 84 in 1997, leaving a husband and son who were both physicists.

Reading reflection

1. Use a dictionary to look up the meaning of each boldface word. Write a definition for each word. Be sure to credit your source.
2. How did Chien-Shiung Wu's work in graduate school help her with her work on the Manhattan Project?
3. From the reading, define *the law of conservation of parity* in your own words.
4. How many protons and neutrons does cobalt-60 have? List the nonradioactive isotopes of cobalt.
5. Briefly describe Wu's elegant experiment that proved that nature distinguishes between right and left.
6. **Research:** Wu was the first woman recipient of the National Medal of Science in physical science. Two other women have since received this award. Who were they and what did they do?
7. What are three questions that you have about Wu and her work?
8. Suggest some possible reasons why Wu did not receive the Nobel Prize for her work.

Name: ______________________ Date: __________

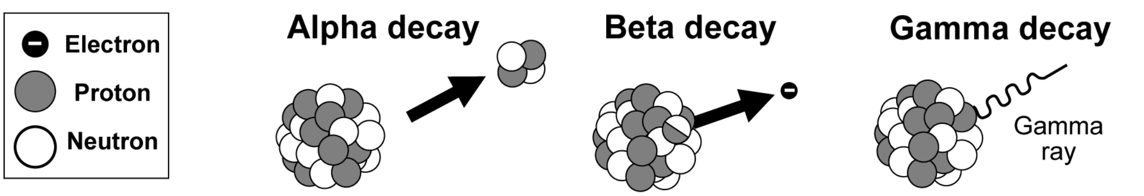
CHALLENGE!
18.3

18.3 Radioactivity

READ

There are three main types of radiation that involve the decay of the nucleus of an atom:

- **alpha radiation** (α): release of a helium-4 nucleus (two protons and two neutrons). We can represent helium-4 using isotope notation: ${}^{4}_{2}He$. The top number, 4, represents the mass number, and the bottom number represents the atomic number for helium, 2.
- **beta radiation** (β): release of an electron.
- **gamma radiation** (γ): release of an electromagnetic wave.



Protons	Decrease by 2	Increase by 1	Unchanged
Neutrons	Decrease by 2	Decrease by 1	Unchanged

EXAMPLE

Half-life

The time it takes for half of the atoms in a sample to decay is called the half-life. Four kilograms of a certain substance undergo radioactive decay. Let's calculate the amount of substance left over after 1, 2, and 3 half-lives.

- After one half-life, the substance will be reduced by half, to 2 kilograms.
- After two half-lives, the substance will be reduced by another half, to 1 kilogram.
- After three half-lives, the substance will be reduced by another half, to 0.5 kilogram.

So, if we start with a sample of mass *m* that decays, after a few half-lives, the mass of the sample will be:

Number of half-lives	Mass left	
1	$\frac{1}{2^1}m =$	$\frac{1}{2}m$
2	$\frac{1}{2^2}m =$	$\frac{1}{4}m$
3	$\frac{1}{2^3}m =$	$\frac{1}{8}m$
4	$\frac{1}{2^4}m =$	$\frac{1}{16}m$

CHALLENGE!

18.3

PRACTICE

1. The decay series for uranium-238 and plutonium-240 are listed below. Above each arrow, write "a" for alpha decay or "b" for beta decay to indicate which type of decay took place at each step.

   a. $^{238}_{92}U \rightarrow {}^{234}_{90}Th \rightarrow {}^{234}_{91}Pa \rightarrow {}^{234}_{92}U \rightarrow {}^{230}_{90}Th \rightarrow$

   $^{226}_{88}Ra \rightarrow {}^{222}_{86}Rn \rightarrow {}^{218}_{84}Po \rightarrow {}^{214}_{82}Pb \rightarrow {}^{214}_{83}Bi \rightarrow$

   $^{214}_{84}Po \rightarrow {}^{210}_{82}Pb \rightarrow {}^{210}_{83}Bi \rightarrow {}^{210}_{84}Po \rightarrow {}^{206}_{82}Pb$

   b. $^{240}_{94}Pu \rightarrow {}^{240}_{95}Am \rightarrow {}^{236}_{93}Np \rightarrow {}^{232}_{91}Pa \rightarrow {}^{232}_{92}U \rightarrow$

   $^{228}_{90}Bi \rightarrow {}^{224}_{88}Ra \rightarrow {}^{224}_{89}Ac \rightarrow {}^{220}_{87}Fr \rightarrow {}^{216}_{85}At \rightarrow$

   $^{212}_{83}Bi \rightarrow {}^{212}_{84}Po \rightarrow {}^{208}_{82}Pb \rightarrow {}^{208}_{83}Bi$

2. Fluorine-18 ($^{18}_{9}F$) has a half-life of 110 seconds. This material is used extensively in medicine. The hospital laboratory starts the day at 9 a.m. with 10 grams of $^{18}_{9}F$.

   a. How many half-lives for fluorine-18 occur in 11 minutes (660 seconds)?

   b. How much of the 10-gram sample of fluorine-18 would be left after 11 minutes?

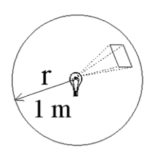
3. The isotope $^{14}_{6}C$ has a half-life of 5,730 years. What is the fraction of $^{14}_{6}C$ in a sample with mass, *m*, after 28,650 years?

4. What is the half-life of this radioactive isotope that decreases to one-fourth its original amount in 18 months?

5. This diagram illustrates a formula that is used to calculate the intensity of radiation from a radioactive source. Radiation "radiates" from a source into a spherical area. Therefore, you can calculate intensity using the area of a sphere ($4\pi r^2$). Use the formula and the diagram to help you answer the questions below.

Intensity

Intensity (W/m²) $I = \dfrac{P}{A}$ Power (W) / Area (m²)



Area, $A = 4\pi r^2 = 12.6\ m^2$

Intensity, $I = \dfrac{100\ W}{12.6\ m^2} = 7.96\ W/m^2$

   a. A radiation source with a power of 1,000. watts is located at a point in space. What is the intensity of radiation at a distance of 10. meters from the source?

   b. The fusion reaction $^{2}_{1}H + {}^{3}_{1}H \rightarrow {}^{4}_{2}He + n + \text{energy}$ releases 2.8×10^{-12} joules of energy. How many such reactions must occur every second in order to light a 100-watt light bulb? Note that one watt equals one joule per second.

Name: ______________________ Date: __________

LAB SKILLS

19.1 Measuring Volume

How do you find the volume of an irregular object?

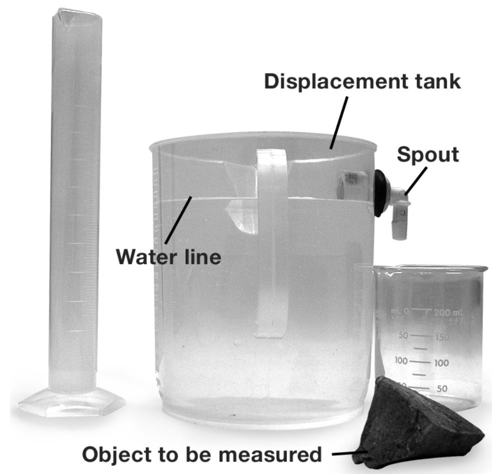
It's easy to find the volume of a shoebox or a basketball. You just take a few measurements, plug the numbers into a math formula, and you have figured it out. But what if you want to find the volume of a bumpy rock, or an acorn, or a house key? There aren't any simple math formulas to help you out. However, there's an easy way to find the volume of an irregular object, as long the object is waterproof!

Materials

- Displacement tank
- Water source
- Disposable cup
- Beaker
- Graduated cylinder
- Sponges or paper towel
- Object to be measured

Setting up the displacement tank

Set the displacement tank on a level surface. Place a disposable cup under the tank's spout. Carefully fill the tank until the water begins to drip out of the spout. When the water stops flowing, discard the water collected in the disposable cup. Set the cup aside and place a beaker under the spout.



Stop and think

a. What do you think will happen when you place an object into the tank?

____

____

____

____

b. Which object would cause more water to come out of the spout, an acorn or a fist-sized rock?

____

____

____

____

c. Why are we interested in how much water comes out of the spout?

d. Explain how the displacement tank measures volume.

Measuring volume with the displacement tank

1. Gently place a waterproof object into the displacement tank. It is important to avoid splashing the water or creating a wave that causes extra water to flow out of the spout. It may take a little practice to master this step.
2. When the water stops flowing out of the spout, it can be poured from the beaker into a graduated cylinder for precise measurement. The volume of the water displaced is equal to the object's volume.
   Note: Occasionally, when a small object is placed in the tank, no water will flow out. This happens because an air bubble has formed in the spout. Simply tap the spout with a pencil to release the air bubble.
3. If you wish to measure the volume of another object, don't forget to refill the tank with water first!

Name: ______________________ Date: __________

CONTENT 19.2

19.2 Calculating Concentration of Solutions

READ

What's the difference between regular and extra-strength cough syrup? Is the rubbing alcohol in your parents' medicine cabinet 70% isopropyl alcohol, or is it 90% isopropyl alcohol? The differences in these and many other pharmaceuticals is dependent upon the concentration of the solution. Chemists, pharmacists, and consumers often find it useful to distinguish between different concentrations of solutions. Concentration is commonly expressed in moles of solute per liter of solution, called *molarity*; or mass of solute per mass of solution, known as *mass percent*.

$$\text{Molarity (M)} = \frac{\text{Moles of solute}}{\text{Liters of solution}}$$

$$\text{Mass percent} = \frac{\text{Mass of solute}}{\text{Total mass of solution}} \times 100$$

EXAMPLES

Molarity:

- What is the molarity of two liters of a sodium nitrate ($NaNO_3$) solution that contains 138 grams of $NaNO_3$? The formula mass for $NaNO_3$ is 69.0 g/mol.

  Solution:

  First, find the number of moles of $NaNO_3$ in the solution. Then divide by the number of liters of solution.

$$\text{Molarity} = \frac{\text{Moles of solute}}{\text{Liters of solution}} = \frac{138\text{ g} \div 69.0\text{ g/mol}}{2.0\text{ L}} = \frac{2.00\text{ mol}}{2.0\text{ L}} = 1.0\text{ M}$$

Mass Percent:

- What is the mass percent concentration of a solution made up of 12 grams of sugar and 300. grams of water?

  Solution:

  In this case, the solute is sugar (12 g), and the total mass of the solution is the mass of the sugar plus the mass of the water, (12 g + 300. g).
  Substituting into the formula, where *c* = the percent concentration, we have:

$$c = \frac{12\text{ g}}{12\text{ g} + 300\text{ g}} \times 100 = \frac{12\text{ g}}{312\text{ g}} \times 100 = 3.8\%$$

The concentration of a solution of 12 grams of sugar and 300. grams of water is 3.8%.

- How many grams of salt and water are needed to make 150 grams of a solution with a concentration of 15% salt?

Solution:

Here, we are given the concentration (15%) and the total mass of the solution (150 g). We are trying to find the mass of the solute (salt). Substituting into the same formula, where m is the mass of the salt, we have:

$$15\% = \frac{m}{150\text{ g}} \times 100, \text{ so } 0.15 = \frac{m}{150\text{ g}}, \text{ and } 0.15 \times (150\text{ g}) = m = 22.5\text{ g}$$

Since the total mass of the solution is 150 grams, and we now know that 22.5 grams are salt, that leaves:

150 grams solution - 22.5 grams salt = 127.5 grams of water

To make 150 grams of a solution with a concentration of 15% salt, you would need 22.5 grams of salt and 127.5 grams of water.

PRACTICE

Find the molarity of each solution.

1. 3 moles of NaCl in 12 liters of water
2. 222 grams of $CaCl_2$ in 2.0 liters of water (formula mass of $CaCl_2$ is 110.99 g/mol)
3. 125 grams of $NaNO_3$ in 1.5 liters of water (formula mass for $NaNO_3$ is 69.00 g/mol)

Find the mass percent concentration of each solution.

4. 5 grams of salt in 75 grams of water
5. 40 grams of cinnamon in 2,000 grams of flour
6. 1.5 grams of chocolate milk mix in 250 grams of 1% milk

Find the mass of the solute in each situation.

7. 1,000 grams of a 40% salt water solution
8. 30 grams of a 12.5% sugar water solution
9. 555 grams of a 25% sand and soil solution

Carefully read and answer each of the following questions.

10. Dawn is mixing 450 grams of dishwashing liquid with 600 grams of water to make a solution for her little brother to blow bubbles. What is the concentration of the dishwashing liquid?
11. How many grams of glucose are needed to prepare 250 grams of a 5% glucose solution?
12. Jill mixes 4 grams of vanilla extract into the 800 grams of cake batter she has prepared. What is the concentration of vanilla in her "solution" of cake batter?
13. **Challenge**: Find the amount of red food coloring (in grams) necessary to add to 50 grams of water to prepare a 15% solution of red food coloring in water.

Name: ________________________ Date: __________

CONTENT 19.2

19.2 Solubility

READ

In this skill sheet you will practice solving problems about solubility. You will use solubility values to identify solutions that are saturated, unsaturated, or supersaturated. Finally, you will practice your skills in interpreting temperature-solubility graphs.

What is solubility?

A solution is made by dissolving a substance in another substance. The substance in the smaller amount is called the *solute* and the substance in the larger amount is called the *solvent*. The degree to which a solute dissolved is described by its *solubility value*. This value is the mass in grams of the solute that can dissolve in a given volume of solvent under certain conditions.

For example, the solubility of table salt (NaCl) is 1 gram per 2.7 milliliters of water at 25 °C. Another way to state this solubility value is to say that 0.38 grams of salt will dissolve in one milliliter of water at 25 °C. Do you see that these values mean the same thing?

$$\frac{1 \text{ gram NaCl}}{2.7 \text{ mL } H_2O \cdot 25°C} = \frac{0.38 \text{ grams NaCl}}{1 \text{ mL } H_2O \cdot 25°C}$$

Information about the solubility of table salt and other substances is presented in the table below. Use these values to complete the questions that follow.

Substance	Solubility Value (grams/100 mL water 25°C)
Table salt (NaCl)	38
Sugar ($C_{12}H_{22}O_{11}$)	200
Baking soda ($NaHCO_3$)	10
Chalk ($CaCO_3$)	insoluble
Talc (Mg silicates)	insoluble

PRACTICE

1. Chalk and talc are listed as "insoluble" in the table. What do you think this term means? In your response, come up with a reason to explain why chalk and talc cannot dissolve in water.
2. Come up with a reason to explain why table salt, sugar, and baking soda dissolve in different amount for the same set of conditions (same volume and temperature).
3. How much table salt would dissolve in 540 mL of water if the water was 25 °C?
4. What volume of water would you need to dissolve 72 grams of salt at 25 °C?
5. What volume of water at 25 °C would you need to dissolve 50 grams of sugar?
6. How much baking soda will dissolve in 10 milliliters of water at 25 °C?

READ

Saturated, unsaturated, and supersaturated solutions

The solubility value for a substance indicates how much solute is present in a *saturated* solution. When the amount of solute is less than the solubility value for a certain volume of water, we say the solution is *unsaturated*. When the amount of solute is more than the solubility value for a certain volume of water, we say the solution is *supersaturated*.

PRACTICE

Use the table on the previous page to help you fill in the table below. In each situation, is the solution saturated, unsaturated, or supersaturated?

Substance	Amount of substance in 200 mL of water at 25°C	Saturated, unsaturated, or supersaturated?
Table salt (NaCl)	38 grams	
Sugar ($C_{12}H_{22}O_{11}$)	500 grams	
Baking soda ($NaHCO_3$)	20 grams	
Table salt (NaCl)	100 grams	
Sugar ($C_{12}H_{22}O_{11}$)	210 grams	
Baking soda ($NaHCO_3$)	25 grams	

READ

The influence of temperature on solubility

Have you noticed that sugar dissolves much easier in hot tea than in iced tea? The solubility of some substances increases greatly as the temperature of the solvent increases. For other substances, the dissolving rate changes very little. A solubility graph (sometimes called a solubility curve) can be used to show how temperature affects solubility.

Below is a table of some imaginary substances dissolved in water at different temperatures. Study the table and then answer the questions.

Substance dissolved in 100 mL of water	Solubility values (grams per 100 mL of water) at different temperatures				
	10 °C	30 °C	50 °C	70 °C	90 °C
gas A	0.2	0.2	0.1	0.08	0.05
gas B	0.1	0.05	0.02	0.01	0.005
solid A	30	32	40	55	74
solid B	40	43	39	41	45

1. Use graph paper to make two solubility graphs of the data in the table. On one graph, plot the data for gases A and B. On the other graph, plot the data for solids A and B. Use two different colors to plot the data for A and for B. Label the *x*-axis, "Temperature (°C)." Label the *y*-axis, "Solubility value (grams/100 mL H_2O."
2. How does the solubility of gases A and B differ from the solubility of solids A and B in water? Explain your response.
3. For which substance does temperature seem to have the greatest influence on solubility?
4. For which substance does temperature seem to have the least influence?
5. If you had 500 mL of water at 70 °C and you made a saturated solution by adding 205 grams of a substance, which of the substances above would you be adding?
6. Organisms that live in ponds and lakes depend on dissolved oxygen to survive. Explain how the amount of dissolved oxygen in a pond or lake might vary with the seasons (winter, spring, summer, and fall). Justify your ideas.

Name: ______________________________ Date: __________

CONTENT 19.2

19.2 Salinity and Concentration Problems

READ

Bodies of water like ponds, lakes, and oceans contain solutions of dissolved substances. Often these substances are in small quantities, measured in parts per thousand (ppt), parts per million (ppm), and parts per billion (ppb). This skill sheet will provide you with practice in using these quantities and in doing calculations with them.

Unit conversions

Table 1 below provides unit conversions that will be helpful to you as you complete this skill sheet.

Table 1: Unit Conversions

Milligrams	= Grams	= Kilograms	= Liters of water
1	0.001	0.000 001	0.000 001
10	0.01	0.000 01	0.000 01
1,000	1	0.001	0.001
1,000,000	1,000	1	1
1,000,000,000	1,000,000	1,000	1,000

Review: working with small concentrations

When working with small concentrations, remember that the units of the numerator and denominator must match, as shown in the examples below.

A. Parts per thousand (ppt)

Example: 0.009 grams of phosphate in about 1000 grams of oxygenated water makes a solution that has an phosphate concentration of 0.009 ppt.

$$\frac{0.009 \text{ grams}}{1{,}000 \text{ grams}} = 0.009 \text{ ppt}$$

B. Parts per million (ppm)

Example: A good level of oxygen in a pond is 9 ppm. This means that there are 9 milligrams of oxygen for every one liter (1000 grams) of oxygenated water.

$$\frac{9 \text{ milligrams}}{1 \text{ liter}} = \frac{9 \text{ milligrams}}{1{,}000 \text{ grams}} = \frac{9 \text{ milligrams}}{1{,}000{,}000 \text{ milligrams}} = 9 \text{ ppm}$$

C. Parts per billion (ppb)

Example: The concentration of trace elements in seawater is very low. For example, the concentration of iron in seawater is 0.06 ppb. This means that there are 0.06 mg of iron in 1,000 liters of water. One thousand liters is equal to 1,000 times 1,000 grams of seawater.

$$\frac{0.06 \text{ milligrams}}{1{,}000 \text{ liters}} = \frac{0.06 \text{ milligrams}}{1{,}000 \times 1{,}000 \text{ grams}} = \frac{0.06 \text{ milligrams}}{1{,}000{,}000 \text{ grams}} = \frac{0.06 \text{ milligrams}}{1{,}000{,}000{,}000 \text{ milligrams}} = 0.06 \text{ ppb}$$

EXAMPLES

Work through these example problems and check your answers. Then you will be ready to try the practice problems on your own.

- There are 16 grams of salt in 984 grams of water. What is the salinity of this solution?

  Solution:

$$\text{salinity} = \frac{16 \text{ grams salt}}{984 \text{ grams water} + 16 \text{ grams salt}} = \frac{16 \text{ grams salt}}{1{,}000 \text{ grams solution}} = 16 \text{ ppt}$$

- A liter of solution has a salinity of 40 ppt. How many grams of salt are in the solution? How many grams of pure water are in the solution?

  Solution:

$$40 \text{ ppt} = \frac{40 \text{ grams salt}}{1{,}000 \text{ grams solution}} = \frac{40 \text{ grams salt}}{40 \text{ grams salt} + x \text{ grams water}}$$

$$1{,}000 \text{ grams solution} = 40 \text{ grams salt} + x \text{ grams water}$$

$$1{,}000 \text{ grams solution} - 40 \text{ grams salt} = 960 \text{ grams water}$$

- You measure the salinity of a seawater sample to be 34 ppt. How many grams of salt are in this sample if the mass is 2 kilograms?

  Solution: First, remember that there are 1,000 grams per kilogram. If a solution is given in parts per thousand, you can think of it as “grams per 1,000 grams” or “grams per kilogram.” Therefore, you can set up a proportion like this:

$$\frac{34 \text{ grams salt}}{1 \text{ kilogram solution}} = \frac{x \text{ grams salt}}{2 \text{ kilograms solution}}$$

  Next, solve for *x*.

$$x = \frac{34 \text{ grams salt} \times 2 \text{ kilograms solution}}{1 \text{ kilogram solution}}$$

$$x = 68 \text{ grams salt}$$

PRACTICE

For each problem, show your work.

1. Complete Table 2 below:

Table 2: Salinity of Famous Places

Place	Salinity (ppt)	Amount of salt in 1 liter (grams)	Amount of pure water in 1 liter (grams)
Salton Sea California	44		
Great Salt Lake Utah	280		
Mono Lake California	210		
Pacific Ocean	87		

2. How many grams of salt are in 2 liters of seawater that has a salinity of 36 ppt?

3. A one-liter sample of seawater contains 10 grams of salt. What is the salinity of this sample?

4. You want to make a salty solution that has the same salinity as the Dead Sea. The salinity of the Dead Sea is 210 ppt. Write a recipe for how you would make 2 liters of this solution.

5. Five kilograms of seawater contains 30 grams of salt. What is the salinity of the volume of seawater?

6. You measure the salinity of a seawater sample to be 30 ppt. How many grams of salt are in this sample if the mass is 1.5 kilograms?

7. A solution has 2 grams of a substance in 1,000,000 grams of solution. Would you describe the concentration of the substance in solution as 2 parts per million or parts per billion?

8. A solution has 5 grams of a substance in 1,000,000,000 grams of solution. Would you describe the concentration of the substance as 5 ppb or 5 ppm?

9. Menthol is a substance that tastes sweet and minty and causes a cooling effect on your tongue. The taste threshold for menthol is 400 ppb. Could you taste menthol if there were 400 milligrams in 1,000,000 grams of menthol solution? Could you taste menthol if there were 400 milligrams in 1000 liters of menthol solution?

10. Above-ground pipelines are used to transport natural gas, an important energy source. Gas leaks are potential problems with the pipelines. German Shepherd dogs can be trained to detect the gas leaks. The dogs sniff along the pipeline and then indicate a leak by perking up their ears or pawing the ground. The most sensitive electronic devices can detect gas leaks as low as 50 ppm. A German Shepherd can detect a gas leak as low as 1 ppb. How many times more sensitive is the dog as compared to the electronic device?

Name: ________________________ Date: ________

CHALLENGE! 19.2

19.2 Making Solutions

READ

Chemists are required to make many of the solutions that they use in experiments. They may be provided with a material in solid form and need to dissolve it in a suitable solvent, or they may be provided with a solution and need to dilute it to make a new solution of a certain concentration. Chemists use basic techniques to calculate the necessary amounts of the solute and solvent. You will practice these techniques in the following exercises.

What is molarity?

Making solutions is something you already know how to do! In a science lab, the ingredients for solutions often include water and a chemical compound. These solutions are described according to their *molarity*. *Molarity* is a scientific measure of concentration. The formula for molarity is:

$$\text{Molarity} = \frac{\text{Moles of solute}}{\text{Liter of solution}}$$

Remember that a *mole* is equivalent to the mass of Avogadro's number of atoms or molecules. If I had a mole of carbon atoms, I would have 6.022×10^{23} atoms. A carbon atom has a mass of 12.01 atomic mass units (amu). A mole of carbon has a mass of 12.01 grams. Remember you can derive the mass of one mole of an element by finding the atomic mass on a periodic table.

Likewise, if I had a mole of sodium chloride, I would have 6.022×10^{23} molecules of NaCl. What would be the mass of a mole of NaCl molecules?

Making solutions from a solid solute

EXAMPLE ▶

A scientist needs to prepare one liter of a solution of potassium chloride (KCl) for an experiment. The concentration of the required solution is 3.2 M. How will the scientist prepare this solution from the solid KCl she has in a jar on her lab shelf?

To answer this question, let's first break it down.

The scientist needs 1 liter of a solution. She wants the final concentration to be 3.2 M.

After reading the introduction, you know how to figure out how much KCl you would need to make a 1 M solution. The mass of a potassium atom is 39 amu and the mass of a chlorine atom is 35 amu. This means that KCl has a mass of 74 amu and one mole of KCl is 74 grams.

To make a 1 M solution of KCl you would dissolve 74.0 grams in one liter of water.

For 1 liter of a 3.20 M solution, we need 3.20 moles of solute. To find out how many grams of KCl we need to make this solution, use the following calculation.

$$3.20 \text{ moles} \times 74.0 \text{ g/mole} = 237 \text{ g KCl}$$

The scientist would make the solution by dissolving 237 grams of KCl in 1 liter of water.

PRACTICE

Practice your skills in making solutions by solving the following problems.

1. Two liters of a 0.8 M solution of KNO_3 was prepared from solid KNO_3 and water. How many grams of KNO_3 were used in the preparation of this solution?
2. A chemist needs 500 ml of a 2.1 M NaOH solution. How many grams of NaOH are required to make this solution?
3. A scientist uses 68 grams of $CaCO_3$ to prepare 1.5 liters of solution. What is the molarity of this solution?
4. An experiment requires 3 liters of a 0.75 M $Mg(OH)_2$ solution. How many grams of $Mg(OH)_2$ are required to prepare this reagent?
5. The density of two solutions—NaCl and $MgCl_2$— was measured. If the concentrations and volumes of the solutions were identical, which solution do you think would be more dense? Explain your answer.

READ

Preparing less concentrated solutions from a "stock" solution (dilution)

Have you ever bought a can of concentrated orange juice? Most of the water is taken out of the orange juice so that it can be shipped at a lesser cost. When you get home, you mix the thick concentrate with water to make orange juice. Chemists do something similar in the lab. They often buy very concentrated solutions (called "stock solutions") from a chemical supply store. The stock solutions can be diluted to make a less concentrated solution to use in an experiment. The formula below will help you do this easily.

$$V_iC_i = V_fC_f$$

where V_i and C_i represent the volume and concentration of the stock solution (the initial solution) and V_f and C_f represent the volume and concentration of the final solution. Using this formula, scientists can create any less concentrated solution from a more concentrated stock solution. The concentration of a solution can be represented as molarity or as a mass percent.

EXAMPLES

- A scientist needs to prepare 2.5 liters of 0.30 M NaCl solution. Her stock solution is 4.5 M. How will the woman prepare the final solution?

  First, we need to use the formula to calculate the volume of stock solution necessary to prepare the final solution. We know that the molarity of the stock solution (C_i) is 4.5 M, the desired molarity of the final solution is 0.3 M, and the final volume required is 2.5 liters. Inserting this information into the formula:

$$V_iC_i = V_fC_f$$

$$(V_i) \times 4.5 \text{ M NaCl} = 2.5 \text{ liters NaCl} \times 0.30 \text{ M NaCl}$$

$$V_i = 0.17 \text{ liters, or } 170 \text{ ml of } 4.5 \text{ M NaCl}$$

To prepare the final solution, the scientist would add 170 milliliters of her stock solution and add sufficient solvent to get a final volume of 2.5 liters.

CHALLENGE! 19.2

- In science laboratories, it is often important to work in a sterile environment. As you might know, isopropyl alcohol (also known as “rubbing alcohol” or isopropanol) kills bacteria. The least concentrated isopropanol solution you need to kill bacteria is 70%. How would you make 500 milliliters of a 70% isopropanol solution if you had a 95% isopropanol stock solution?

$$V_i C_i = V_f C_f$$
$$(V_i) \times 0.95 = 0.5 \times 0.70$$
$$V_i = 0.37 \text{ liters concentrated isopropanol}$$

To prepare the final solution, you would mix 370 milliliters of stock solution with 130 milliliters of water to get a final volume of 0.5 liters.

PRACTICE

1. A chemist purchases a 2.0 M stock solution of KNO_3. He would like to prepare 100 milliliters of 0.5 M KNO_3. Describe how he would prepare this solution. Show your work.
2. How many liters of 3.5 M HCl are required to make 0.75 liters of 1.5 M HCl?
3. A scientist uses 1.3 liters of 0.65 M $Ca(NO_3)_2$ solution in an experiment. The stock solution from which she prepared this solution was 2.0 M. What volume of the stock solution did she use in the preparation of the solution for the experiment? What volume of solvent was used?
4. 135 ml of a 6.0 M $NaHCO_3$ solution was used in the preparation of 1.5 liters of diluted $NaHCO_3$. What is the molarity of the diluted solution?
5. How many grams of $NaHCO_3$ went into the preparation of one liter of the 6.0 M stock solution in the previous problem?
6. You have a 80% solution of household vinegar. This means that there are 80 milliliters of vinegar in every 100 milliliters of solution. How could you use this stock solution to make up 1 liter of a 20% vinegar solution?
7. If you take 40 milliliters of a 60% solution and add it to 100 milliliters of water. What is the concentration and volume of the final solution?

Name: ______________________ Date: __________

CHALLENGE! 19.3

19.3 Calculating pH

READ

The pH of a solution is a measure of the concentration of hydrogen ions (H+) in the solution. The pH scale, which ranges from 0 to 14, provides a tool to assess the degree to which a solution is acidic or basic. As you may remember, solutions with low pH values are very acidic and contain high concentrations of hydrogen ions. Why does a low pH value mean a high concentration of H+? The answer has to do with what pH means mathematically. In this skill sheet, we will examine how pH values are calculated.

How do you calculate pH?

The pH value for any solution is equal to the negative logarithm of the hydrogen ion (H+) concentration in that solution. The formula is written this way:

$$pH = -\log[H^+]$$

Concentration of hydrogen ions is implied by placing brackets (“[ ]”) around H+.

A term used by scientists to describe the concentration of a substance in a solution is *molarity*. Molarity (M) means how many moles of a substance are present in a given volume of solution.

For hydrogen ions in solutions, the concentration generally ranges from 10 to 10^{-14} M. The larger the molarity, the greater the concentration of H+ in the solution. If a solution had a H^+ concentration of 10^{-3} M, the corresponding pH value would be:

$$pH = -\log[10^{-3}]$$

$$10^{pH} = -[10^{-3}]$$

$$pH = -[-3]$$

$$pH = 3$$

For a solution with an H^+ concentration of 10^{-5} M, the corresponding pH value would be:

$$pH = -\log[10^{-5}]$$

$$10^{pH} = -[10^{-5}]$$

$$pH = -[-5]$$

$$pH = 5$$

The first solution has a higher H^+ concentration than the second solution (10^{-3} M versus 10^{-5} M); however, its pH value is a smaller number. Strong acids have small pH values. Larger pH values (like 14) have lower concentrations of H^+, and the solutions represent weaker acids.

CHALLENGE!

19.3

PRACTICE

1. Practice working with numbers that have exponents. In the blank provided, write greater than, less than, or equals.

   a. 10^{-2} ____________________ 10^{-3}

   b. 10^{-14} ____________________ 10^{1}

   c. 10^{-7} ____________________ 0.0000001

   d. 10^{0} ____________________ 10^{1}

2. Solutions that range in pH from 0 to 7 are acidic. Solutions that range in pH from 7 to 14 are basic. Solutions that have pH of 7 are neutral. The hydrogen ion concentrations for some solutions are given below. Use the pH formula to determine which is an acid, which is a base, and which is neutral.

   a. Solution A: The hydrogen ion concentration is equal to 10^{1} M.

   b. Solution B: The hydrogen ion concentration is equal to 0.0000001 M.

   c. Solution C: The hydrogen ion concentration is equal to 10^{-13}M.

3. Orange juice has a hydrogen ion concentration of approximately 10^{-4} M. What is the pH of orange juice?

4. Black coffee has a hydrogen ion concentration of roughly 10^{-5} M. Is black coffee a stronger or weaker acid than orange juice? Justify your answer and provide all relevant calculations for supporting evidence.

5. Pure water has a hydrogen ion concentration of 10^{-7} M. What is the pH of water? Would you say water is an acid or a base? Explain your answer.

6. A solution has a pH of 11. What is the H^+ concentration of the solution? Is this solution an acid or a base?

7. A solution has a pH of 8.4. What is the H^+ concentration of this solution?

8. Acids are very good at removing hard water deposits from bathtubs, sinks, and glassware. Your father goes to the store to buy a cleaner to remove such deposits from your bathtub. He has a choice between a product containing lemon juice ($H^+ = 10^{-2.5}$ M) and one containing vinegar ($H^+ = 10^{-3.3}$ M). Which product would you recommend he purchase? Explain your answer.