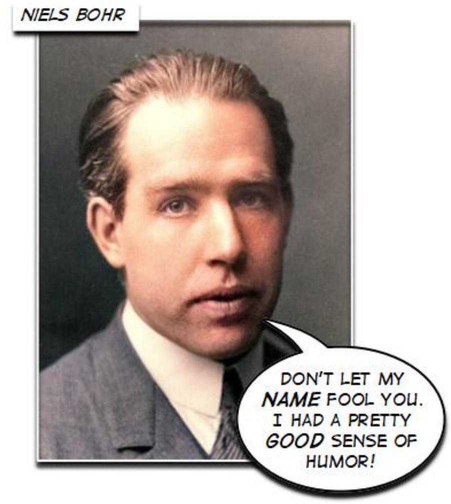
Chapter One

Intro to Chemistry



One of the most clever and poetic ways to describe how connected we are to the world around us was said by Niels Bohr, a pioneer of quantum theory, and a researcher we will be studying in future chapters, when he said,

"A physicist is just an atom's way of looking at itself."

We cannot escape the fact that everything is made of atoms – you, me, your pet, air, the planets... everything! And physicists (those who study the scientific discipline of physics) try to understand how things move, how forces work, and how energy behaves. This means that we are made of the same atoms that we study.

Humans are made of atoms, and when we study science, it's like the universe is studying itself through us.

Deep, huh?

If this is not your first book in the Classic Science series, you cannot have escaped a singular phrase that has been mentioned many times:

Everything in the universe is connected together.

This book will be no different! Science is not separate from nature—we are a part of it. By understanding both chemistry and physics, we begin to discover who we are and how everything around us works. With that being said, let's get to work...

How Chemistry and Physics Are Connected

Chemistry and physics are two major branches of science that help us understand how the world works. At first, they may seem like separate subjects—chemistry deals with substances and reactions, while physics focuses on energy and movement. But in reality, these two sciences are deeply connected. They often work together to explain how matter and energy behave in everyday life. Think of it this way...

Physics explains how the universe moves. Chemistry explains what the universe is made of. Together, they reveal why the universe behaves the way it does.

What Are Chemistry and Physics?

Chemistry is the study of matter—what things are made of, how they change, and how they react with other substances. For example, when baking soda is mixed with vinegar, bubbles form as a chemical reaction takes place. Chemists figure out why those bubbles form and what substances are created during the reaction.

Physics, on the other hand, is the study of energy and motion. Physicists would ask different questions like: How fast do the bubbles rise? What forces act on them as they move through the liquid? Physicists study how pressure, gravity, and energy affect the motion and behavior of the bubbles, rather than how the bubbles were chemically created.

How Do Chemistry and Physics Work Together?

Although chemistry and physics focus on different areas, they often overlap because both are concerned with changes in matter and energy. Here are a few ways they connect:

Changes in Matter

Chemistry explains how substances change, such as water turning into ice or steam. Physics explains why this happens by describing how temperature affects atoms in motion. Together, they explain why heating melts ice and freezing forms solid ice.

Using Energy

When a chemical reaction takes place, like burning wood or gasoline, energy is either released or absorbed. Chemistry studies the reaction itself, while physics explains how that energy moves, such as heat traveling from a campfire to your hands. Both fields help us understand and control energy use in engines, heaters, and power plants.

Creating Technology

Chemistry helps scientists design new materials, such as plastics, metals, or synthetic fabrics. Physics helps engineers use those materials to build tools and machines, like bicycles, airplanes, or cell phones. When scientists combine chemistry and physics, they create safer, stronger, and more efficient products.

Why Are They Important?

These sciences are important because they help explain the world around us. In many cases, understanding everyday problems or questions requires knowledge from both subjects. For example:

- Why does a metal spoon feel cold when placed in ice water? (Chemistry explains the spoon's metal; physics explains heat transfer.)
- Why does a balloon pop when it gets too hot? (Chemistry explains the rubber material; physics explains the pressure buildup before the explosion.)
- How does a battery make a toy car move? (Chemistry shows how energy is stored; physics shows how it powers motion.)

Physical Science and Mathematics

To fully understand how chemistry and physics explain the world around us, scientists rely on more than just observations and experiments—they also need a powerful tool to describe, measure, and predict what will happen - mathematics. Math is the language of science. It helps scientists express complex ideas in a clear and exact way. Whether they are calculating the speed of a moving object, the amount of energy released in a chemical reaction, or the force needed to lift an object, math is essential.

The following sections will provide you with a crash-course on two important concepts used by scientists to communicate their knowledge:

Scientific Notation and the Metric System

Scientific Notation

Many values in chemistry and physics are either extremely large or incredibly small. For example, the distance between atoms is measured in billionths of a meter, while the speed of light is nearly 300,000,000 meters per second! Writing all those zeros can be confusing and take up space. **Scientific notation** allows scientists to write these numbers in a shorter and more manageable form using powers of 10.

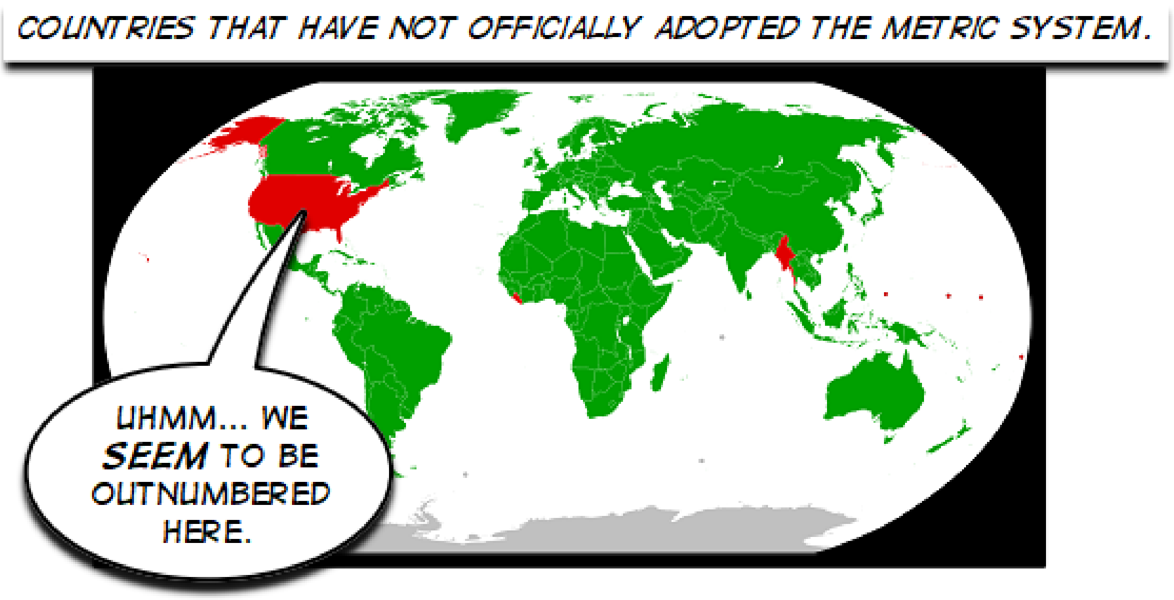
For example, the speed of light is written in scientific notation as:

$$3.0 \times 10^8 \text{ meters/second}$$

instead of 300,000,000 meters/second

Metric System

The **metric system**, which is also based on the powers of 10, makes it easy to convert between units (e.g from meters to kilometers or from grams to milligrams) by simply moving a decimal point of a number to the left or right. Since both chemistry and physics involve measuring things like length, mass, time, temperature, and volume, the metric system provides a universal and simple way for scientists around the world to understand each other's work.



We have to give algebra some credit too...

Algebra plays a major role in solving science problems. In physics, for example, there is a very famous equation that is used to describe motion...

$$F = ma$$

Force (F) equals Mass (m) times Acceleration (a)

For example, if you know the force and mass acting on a specific object, but not its acceleration, you can rearrange the equation to solve for the missing value. This type of math is common in science because it helps students and scientists figure out unknown values using formulas. It's a basic skill that becomes more and more important as scientific problems become more complex. If this sounds foreign to you - don't' worry! You will have plenty of time to practice this necessary skill in this chapter. Let's get started...

Scientific Notation 101

You just learned that the speed of light can be written in scientific notation as the following number:

$$3.0 \times 10^8$$

Scientific notation breaks a number like this into two parts:

- A number between 1 and 9.999, called the **coefficient**. With the speed of light, the coefficient would be 3.0
- Attached to the coefficient is the **exponent**, which tells you how many times to multiply by 10. In this case, we will be multiplying 3.0 by ten a total of 8 times (10^8).

Below are a couple of examples of how to convert very large and very small numbers into scientific notation:

Scientific Notation Practice Problem #1: Converting a Large Number

Problem: Convert 45,000,000 into scientific notation.

Find where to place the decimal point:
To write 45,000,000 in scientific notation, we need to move the decimal point so that it's after the first non-zero digit. The decimal for any whole number like this is at its end (45,000,000.) So, we move the decimal point <u>7 places to the left</u> to get 4.5. Remember, the coefficient must be between 1.0 and 9.999.

Count how many places you moved the decimal point:
Since we moved the decimal <u>7 places to the left</u>, the exponent will be "10^7".

Write it in scientific notation:
$45{,}000{,}000 = 4.5 \times 10^7$

Answer: 45,000,000 in scientific notation is 4.5×10^7

Scientific Notation Practice Problem #2: Converting a Small Number

Problem: Convert 0.000032 into scientific notation.

Find where to place the decimal point:

To write 0.000032 in scientific notation, move the decimal point so that it is placed after the first non-zero digit (which is 3). In this case, we would move the decimal 5 places to the right to get 3.2.

Count how many places you moved the decimal point:

Since we moved the decimal 5 places to the right, the exponent will be "10^{-5}". The negative sign in the exponent means that we need to divide the coefficient by 10 a total of five times.

Write it in scientific notation:

$0.000032 = 3.2 \times 10^{-5}$

Answer: 0.000032 in scientific notation is 3.2×10^{-5}

Scientific Notation Summary

When converting a large number into a smaller coefficient (e.g. 25,000 to 2.5), move the decimal to the left and the exponent will be positive. (2.5×10^{4})

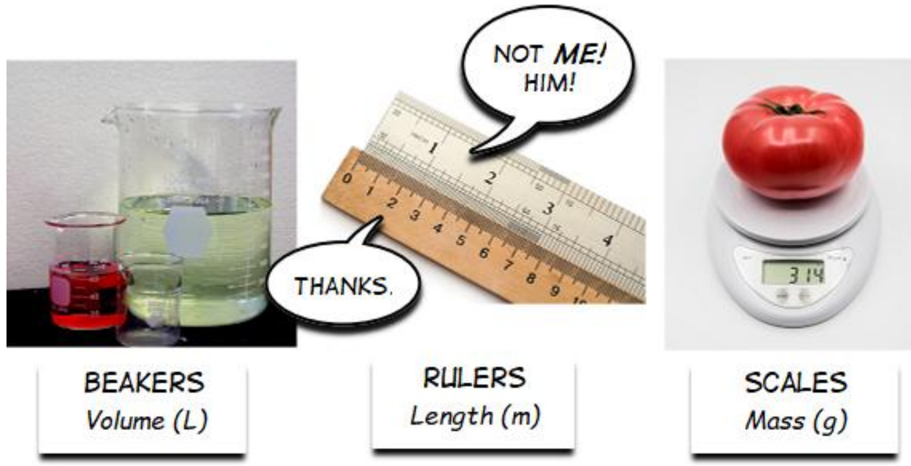
When converting a smaller number into a larger coefficient (e.g. 0.003 to 3.0), move the decimal to the right and the exponent will be negative. (3.0×10^{-3})

Metric system 101

The **metric system** is a system of measurement used all around the world. It's based on powers of 10, which makes it very easy to use and convert between units. Instead of using different words like "inches," "feet," and "yards," the metric system uses a specific list of prefixes as shown on the next page along with three different **base units**:

Length, Mass, and Volume

Of these three base units, **meters** are used to measure length, **grams** are used to measure mass (how much stuff is in something), and **liters** is used to measure volume (how much space something takes up).



What makes the metric system so simple is that it uses prefixes in front of these base units to change the size of a unit; and, these <u>prefixes</u> always relate to multiples of 10.

Another way to look at it is this…

A metric prefix tells you how big or small the unit is; and, the base unit tells you what is being measured (e.g. length, mass, volume).

Prefixes? Base units? What is going on here?

The chart on the right will show you the metric prefixes we will be using frequently throughout this book. It wouldn't hurt to have this written down somewhere in your notes – hint, hint…

Metric Prefix	Symbol
kilo-	k
hecto-	h
deka-	da
Base Unit (Meters, Liters, Grams)	—
deci-	d
centi-	c
milli-	m
N/A	
N/A	
micro-	μ
N/A	
N/A	
nano-	n

Here are a couple of examples:

An object that has a mass of five kilograms would be written as 5kg.

- *The "k" represents the metric prefix, while the "g" identifies we are dealing with grams (mass).*

If an object's length is five kilometers, we would write this as 5km.

- *Once again, the "k" represents the metric prefix "kilo", and the "m" identifies we are studying meters (length).*

FYI -The cells marked with "N/A" on this chart show empty steps between milli- and micro-, and again between micro- and nano-. There are no prefixes that exist for these steps. It was learned that most measurements in science and engineering don't need separate names for every power of ten. This is because using scientific notation or decimals works just fine.

In many cases throughout this book, you will be asked to make conversions between two different metric units. To accomplish this, we will use the metric prefixes chart to make our job a little easier...

Metric Conversions

It may help if the metric steps are listed horizontally like below:

$$\text{kilo} \rightarrow \text{hecto} \rightarrow \text{deka} \rightarrow \text{BASE UNIT} \rightarrow \text{deci} \rightarrow \text{centi} \rightarrow \text{milli} \xrightarrow{X3} \text{micro} \xrightarrow{X3} \text{nano}$$

This will make your conversions a little easier, especially since we only need to move decimal places to the left or to the right. Let's look at a couple of sample problems:

Metric Conversions Sample Problem #1

Problem: Convert 5 kilometers (5km) to meters (m).

Since the base unit of meters is three steps to the right of kilometers on the metric chart, we move the decimal point three places to the right to convert from kilometers to meters.

5.000 = 5000.

Answer: 5km = 5,000 meters

Metric Conversions Sample Problem #2

Problem: Convert 250 microliters (250μL) to milliliters (mL)

Since milliliters are three steps to the left of micrometers on the metric chart, we move the decimal point three places to the left to convert from micrometers to milliliters.

250. = 0.25

Answer: 250μL = 0.25 mL

So, where does the "powers of 10" come into all of this?

The "powers of 10" is the math behind all of these moving decimals! Let's go back to the sample problems. When we converted 5 kilometers to meters, we moved three steps to the right on the metric chart. If you multiply 5 by 10 three times (10 × 10 × 10), you get 5,000. That's the same as moving the decimal three places to the right.

$$5 \times 10 \times 10 \times 10 = 5000 \text{ is the same as } 5.000 = 5000.$$

In the second example, we went from 250 milliliters to liters, which is three steps to the left. That's the same as dividing by 10 three times, or dividing by 1,000. So, 250 becomes 0.25 liters.

$$250 \div 10 \div 10 \div 10 = 0.25 \text{ is the same as } 250. = 0.25$$

Here's an easy way to remember it:

If the decimal moves to the right on the horizontal metric chart, multiply by 10 for each step. If it moves to the left, divide by 10 for each step.

Since we are on the topic of math, I believe I can speak for most people that learning algebra for the first time can feel really frustrating—like suddenly being dropped into a puzzle where all the numbers have been replaced with letters. It's confusing at first because you're used to working with actual values, and now you're told that x, y, a, b, and m can all "stand for something." You might ask yourself, "*Why not just give me the number?!*"

At first, it can seem like math is making things harder on purpose. It takes time and practice to get used to the idea that variables are just symbols that hold a place for numbers we don't know yet. But here's the good news...

In science, the use of variables actually makes things easier.

That's because in science, the variables always represent the same thing. For example, "F" always means force, "a" means acceleration, and "m" means mass in any physics class, in any textbook, anywhere in the world. This should take away some of the confusion. Once you learn a formula like F = ma, you don't have to relearn it or wonder what the letters mean - they always represent the same thing. That makes solving problems in science more straightforward, because the math is built on a clear and consistent language.

Let's look at a few sample problems using this same formula (F = ma). Don't worry about the units behind the numbers – we'll explore these in much greater detail later in this book! For now, just focus on the mechanics of setting up the formula to give you the answer you need to solve the problem.

Algebra Practice Sample Problem #1

Problem: What is the force acting on an object whose mass is 40kg and is accelerating at a rate of $4m/s^2$? *(Again, don't worry about the letters and symbols that are behind the numbers. You'll learn about these very soon!)*

The first thing you always want to do with these problems is to write out what you are given within the problem. This will help organize what you have and what you will need to solve the problem.

What you are given:

- Mass (m) = 40kg
- Acceleration (a) = $4m/s^2$
- Force (F) = ??? (It is important to write this out as well!)

Since you have identified the variables m, a, and F within your given information, and we have an equation that contains all of these variables, we know what our next step must be...

Use F = ma to solve for the missing variable of force (F):

F = ma

Now, substitute in the values for what has been given to you and do the math:

F = (40kg)($4m/s^2$) = 160N (Focus on the numbers here!)

Answer: The force acting on a 40kg mass that is accelerating at $4m/s^2$ is 160N.

This last problem used basic algebra to solve a rather simple problem. However, what would happen if the problem asked for something different?

Algebra Practice Sample Problem #2

Problem: A force of 30N is applied to an object, and it accelerates at $6m/s^2$. What is the mass of the object?

Let's write out what we are given so we can identify the correct formula to use.

Givens:

- Force (F) = 30N
- Acceleration = $6m/s^2$
- Mass = ???

In this situation, we can use F = ma to solve for our missing variable (mass); however, we are going to have to rearrange this formula to isolate mass (m) from both Force (F) and acceleration (a). In other words, we need to move acceleration to the other side of the equals sign so that we can isolate mass (m) by itself. To do that we can use a method called **cross multiplication** which looks at these formulas as fractions.

**** If you are already good at solving problems like these, and you have a different method of solving them correctly – that is perfect! There is no need for you to learn how to do cross multiplication. However, if this is new to you, or if you would like to learn a new way to solve these types of problems, let's go through a few examples to help you along!*

Let's take our equation (F=ma) and set it up as a fraction. Since we need to isolate mass (m) on the right side of the equals sign, we will need to remove the acceleration (a) variable. To do this, we simply divide the "ma" by acceleration:

$$F = \frac{ma}{a}$$

That is a good start! However, there is an <u>equals</u> sign in this equation, which means that whatever we do on the right side of the equation must <u>equal</u> what is done on the left side as well. Therefore...

$$\frac{F}{a} = \frac{ma}{a}$$

Now, we can use basic algebra to cancel out any single variables that are identical on the top and bottom. In this case, the acceleration (a) variables on the right side of the equation can be removed:

$$\frac{F}{a} = \frac{m\cancel{a}}{\cancel{a}} \quad \text{which leaves behind: } \frac{F}{a} = m$$

Our unknown variable (mass) is now isolated from the other two variables so we can start plugging in our given values to solve the problem:

$$m = \frac{F}{a} = \frac{30N}{6m/s^2} = 5kg$$

Answer: The mass of a 30N object accelerating at $6m/s^2$ is 5kg.

You will be using this method quite a lot in this book. Let's go through another sample problem:

Algebra Practice Sample Problem #3

Problem: A student pushes a 3kg sled across snow with a force of 12 newtons. What is its acceleration?

Givens:

- Force (F) = 12N
- Mass = 3kg
- Acceleration = ???

Start with the proper equation:

F = ma

Rearrange the equation to solve for the missing variable:

$$\frac{F}{m} = \frac{\cancel{m}a}{\cancel{m}} \longrightarrow \frac{F}{m} = a$$

Plug in the given values and solve the problem:

$$a = \frac{12N}{3kg} = 4m/s^2$$

Answer: The sled is accelerating at $4m/s^2$

Now that you've practiced the math skills used throughout physical science, you're ready to apply them to real-world scientific ideas. In the next chapter, we'll begin exploring chemistry, the study of matter and how it changes. You'll learn what substances are made of, how they interact, and why chemical reactions happen. These chemistry topics will build a strong foundation for understanding the physical world around you. Later in the book, we'll shift our focus to physics, where you'll see how motion, energy, and forces connect to the same math you've just practiced. By learning both chemistry and physics, you'll gain a complete picture of how science explains everything from atoms to acceleration.

Match the following vocabulary terms with their correct definition:

Base Unit	Exponent
Coefficient	Chemistry
Physics	Scientific Notation

1)	________________	A shorthand way of writing very large or very small numbers using powers of 10.
2)	________________	The study of energy and motion.
3)	________________	The standard units used to measure basic quantities like length (meter), mass (gram), and volume (liter), without any prefixes attached.
4)	________________	A number that describes how many times to multiply or divide by 10 in scientific notation.
5)	________________	The study of what things are made of, how they change, and how they react with other substances.
6)	________________	A number between 1 and 9.999 that is multiplied by a power of ten to represent a very large or small number.

Convert the following metric values.

1) 5 kilometers = _______ meters

2) 1,200 milliliters = _______ liters

3) 0.25 meters = _______ centimeters

4) 75 grams = _______ kilograms

5) 3,000 milligrams = _______ grams

6) 4.7 liters = _______ milliliters

7) 0.9 kilometers = _______ meters

8) 63 centimeters = _______ meters

9) 8,500 grams = _______ kilograms

10) 0.045 liters = _______ milliliters

11) 1.2 kilograms = _______ grams

12) 0.005 meters = _______ millimeters

13) 820 milliliters = _______ liters

14) 0.6 meters = _______ centimeters

15) 0.002 kilograms = _______ grams

Write the following numbers in scientific notation ($2000 = 2x10^3$) or convert the scientific notation into its normal form ($3x10^2 = 300$).

16) 5,000,000 = ______________________

17) 0.00036 = ______________________

18) 2.4×10^3 = ______________________

19) 9.1×10^{-4} = ______________________

20) 0.000001 = ______________________

21) 3.2×10^6 = ______________________

22) 4.5×10^{-2} = ______________________

23) 0.0051 = ______________________

24) 1,250 = ______________________

25) 0.00000075 = ____________________

26) 6.7×10^5 = ______________________

27) 9.99×10^{-3} = ______________________

28) 0.082 = ______________________

29) 5.75×10^2 = ______________________

30) 0.0000000086 = __________________

Rearrange the following equations:

31) Rearrange the equation $v = \frac{d}{t}$ (velocity = $\frac{\text{distance}}{\text{time}}$) to solve for time:

32) Rearrange the equation $a = \frac{v}{t}$ (acceleration = $\frac{\text{velocity}}{\text{time}}$) to solve for velocity:

33) Rearrange the equation $d = \frac{m}{v}$ (density = $\frac{\text{mass}}{\text{volume}}$) to solve for mass:

34) Rearrange the equation V = IR (voltage = current × resistance) to solve for current: