Chapter 1

Introduction, Numbers, and Units

In physics we study the interactions and motion of matter. For our introduction in this class, we will mostly study what I like to call "Physics at the human scale" because it is the physics of daily life that we observe and directly interact with. It describes an apple falling from a tree, a car slamming its brakes, a pendulum swinging, the collision of 2 billiard balls, and more.

1.1 Units

Physicists will try to describe the world around us quantitatively, meaning with numbers. In order to ascribe meaning to those numbers we need to use physical **units**. For example, think about if you were baking a loaf of bread and the recipe called for "4 flour". Would you know how much flour was required? The recipe should say "4 *cups* of flour" so that you know the amount required for the bread.

In physics, like most sciences, we use **SI units**. In the USA, you likely encounter the Imperial system of units in daily life. Common Imperial units you might have seen include the inch for length and gallon for volume. These units are not the standard for scientific disciplines, and as such we will focus on using SI units. There are 3 base units that we will use frequently:

- **kilogram** - the SI base unit of mass. Mass is a measure of how much matter there is. It is related to but not the same as weight. We will discuss weight further in a later chapter, but for now think of mass as how much "stuff" there is.

- **meter** - the SI base unit of length. If you don't have a good mental picture of a meter, it is a little longer than 3 feet.
- **second** - the SI base unit of time. We will continue to see minutes and hours used throughout, but for doing quantitative work we will want to use seconds for everything.

1.2 SI Prefixes

With these SI base units we use **prefixes** to scale the units relative to our problem. Table 1.1 contains several of the most common prefixes, with the bolded ones being most important for this class.

One thing you should see is that SI prefixes allow us to scale our units by powers of 10. This is much simpler than the Imperial system. For lengths we have 12 inches to a foot, 3 feet to a yard, and 1760 yards to a mile. Compare this to just multiplying or dividing by powers of 10 and see how much simpler SI units are to work with!

The main purpose to having the prefixes is it allows us to scale the units to our problem. If we were to talk about the distance between San Diego and Los Angeles, it would make sense to use kilometers because that distance is about 194 kilometers. In meters, it would be $194 \cdot 10^3 = 194,000$ meters. Prefixes allow us to use numbers that are closer to 1, which are easier to read and for our brains to process.

There are other prefixes and units that are used within different branches of physics and other fields of science. We will see some of this in CHAPTER HERE when we discuss the solar system. Again, the goal is always to make the numbers we work with closer to 1.

In addition to the base units, we will also have **derived units**, which are a combination of SI base units. On a car speedometer you may have seen

Table 1.1: SI Prefixes

Prefix	Abbreviation	Numerical value
nano-	n	10^{-9}
micro-	μ (Greek letter *mu*)	10^{-6}
milli-	m	10^{-3}
centi-	c	10^{-2}
kilo-	k	10^{3}
mega-	M	10^{6}
giga-	G	10^{9}

the unit km/hr, which means "kilometers per hour". This is a derived unit because it combines the units of length and time.

1.3 Converting units

Now that we have SI prefixes, it is important that we learn how to convert between different units. This process is called **dimensional analysis** because the units are the "dimensions" that we are looking at.

To convert units, we will write unit factors that are fractions equal to 1. For example,

$$\frac{1\,mm}{10^{-3}\,m} = 1 \tag{1.1}$$

is a unit factor that equals 1 because the prefix milli- means 10^{-3}, so 1 millimeter is equal to 10^{-3} meter. Now lets use that to convert 3.25 meters to millimeters. We can use the unit fraction to cancel the meters from the original value, and have a unit of millimeters left in the numerator.

$$3.25\,\cancel{m} \cdot \frac{1\,mm}{10^{-3}\,\cancel{m}} = 3,250\,mm \tag{1.2}$$

The reason this works is that our unit fraction is equal to 1, so multiplying our original quantity by that unit fraction doesn't change the value! It only changes what unit that value is given in.

You could also think of the unit fraction as 1,000 millimeters in a meter.

$$3.25\,\cancel{m} \cdot \frac{1000\,mm}{1\,\cancel{m}} = 3,250\,mm \tag{1.3}$$

Both $\frac{1000\,mm}{1\,m}$ and $\frac{1\,mm}{10^{-3}\,m}$ are valid unit fractions for converting from meters to millieters. They are equally correct, so use whichever you prefer!

Example 1.1

Convert 500 nanometers to centimeters.

We can convert 500 nanometers to meters first, then convert from meters to centimeters.

$$500\,\cancel{nm} \cdot = \frac{10^{-9}\,m}{1\,\cancel{nm}} = 5 \cdot 10^{-7}\,m \tag{1.4}$$

$$5 \cdot 10^{-7}\,\cancel{m} = \frac{100\,cm}{1\,\cancel{m}} = 5 \cdot 10^{-5}\,cm \tag{1.5}$$

Sometimes it is useful to convert to an intermediary unit to help you get to the requested final unit.

Example 1.2

Convert 1 meter to feet. Use the following information:

- 1 foot = 12 inches
- 1 inch = 2.54 cm

The given unit conversions tell us how to solve this problem. First we convert the meter to centimeters, then use the given conversion from centimeters to inches. Finally, we can use the given conversion from inches to feet.

$$1\,\cancel{m} \cdot \frac{100\,\cancel{cm}}{1\,\cancel{m}} \cdot \frac{1\,\cancel{in}}{2.54\,\cancel{cm}} \cdot \frac{1\,foot}{12\,\cancel{in}} = 3.28\,feet \tag{1.6}$$

Example 1.3

Convert the speed 45 kilometers per hour $\frac{km}{hr}$ to meters per second $\frac{m}{s}$

First let's write out the unit to help us see how to convert this.

$$45\,\frac{km}{hr} \tag{1.7}$$

We have kilometers in the numerator and hours in the denominator, so e have to make sure we write our unit fractions correctly to cancel them. First, let's convert the kilometers to meters.

$$45\,\frac{\cancel{km}}{hr} \cdot \frac{10^3\,m}{1\,\cancel{km}} = 45,000\,\frac{m}{hr} \tag{1.8}$$

Now we can convert the hour to seconds. It may be helpful to convert to minutes first, then to seconds.

$$45,000\,\frac{m}{\cancel{hr}} \cdot \frac{1\,\cancel{hr}}{60\,\cancel{min}} \cdot \frac{1\,\cancel{min}}{60\,s} = 12.5\,\frac{m}{s} \tag{1.9}$$

Chapter 2

Quantities of motion and kinematics

The first thing we must do to describe the motion of objects is define specific terms that we will use. These terms will have clear, specific definitions that may differ from how they are used in everyday language.

The first quantity to talk about is **position**. This is a measurement of where something is along an axis (or multiple axes). This is a length, so the SI unit for position is the meter. Position will be denoted with the variable x in equations.

When we study motion, we often look at an object moving from one position to the other. The first position is the **initial** position, and the second position is the **final** position. In equations we will use subscript i and f for initial final respectively, so that the initial position is x_i and the final position is x_f. To indicate the change in a quantity we will use Δ, which is the Greek letter Delta. The change in position between the initial state and final state can be written as

$$\Delta x = x_f - x_i \tag{2.1}$$

which is a measure of how the position changed moving from the initial state x_i to the final state x_f.

The second quantity we will talk about is **velocity**. This is a measurement of the rate of change in position of a moving object. Velocity will be denoted with the variable v in equations. Velocity has a direction, so it is a vector quantity. The direction can be denoted with a positive or negative sign to indicate the direction along a position axis.

Average velocity is the average rate of change in position as an object moves from its initial position x_i to its final position x_f over a time interval Δt. For average velocity we will use a subscript "avg", so it is written as v_{avg}.

$$v_{avg} = \frac{\Delta x}{\Delta t} \tag{2.2}$$

Average velocity does not give us any information about the moment-to-moment velocity throughout the motion, only the average throughout the time interval.

The third quantity we will talk about is **acceleration**. This is a measurement of the rate of change of velocity of a moving object. Acceleration will be denoted with the variable a in equations. Acceleration has a direction, so it is a vector quantity.

Average acceleration is the average rate of change in velocity as an object moves from its initial position x_i to its final position x_f over a time interval Δt. Similar to position, the initial velocity is v_i, the final velocity is v_f, and the change in velocity is $\Delta v = v_f - v_i$.

$$a_{avg} = \frac{\Delta v}{\Delta t} \tag{2.3}$$