3.1.1.1: Motion and Force

The location of an object is called the ***position*** and is generally measured in *meters* (or centimeters or inches or feet, etc.) starting from an agreed upon starting point (called the origin). Sometimes it is convenient to set up a coordinate system with and x-axis, y-axis and z-axis in order to locate something precisely in three dimensional space. We may want to also know how far something is from where it started or from its normal, at rest position. This is the displacement or ***displacement from equilibrium*** and is also measured in meters. For example, when a violin string is plucked or bowed, different points on the string are displaced from their equilibrium positions by different amounts initially.

Speed, v, is the rate of change of position and is measured in *meters per second*, m/s (or ft/sec or miles per hour, mph, etc.). If there is no acceleration, speed is related to distance traveled as rate times time equal distance; $vt = d$. ***Velocity*** is speed with additional information about which direction something is moving. So if you are traveling at 50 mph (no direction given) you have a speed but if you are traveling 50 mph and headed north-east we call that a velocity.

Acceleration is a word that has a specific definition in science but gets confused with speed and velocity in everyday use. Acceleration is a change in velocity over a given time and is measured in *meters per second squared*, m/s^2 (or ft/s^2, etc.). A car going down the road in the same direction might have a constant speed of 50 mph. If neither the speed or direction changes then the acceleration is zero. If the car speeds up, slows down or changes direction then the velocity has changed and there is acceleration. The gas pedal in your car is both an acceleration pedal (if you push it to the floor or ease off the pedal you change your speed and get faster or slower) and also a speed pedal (if you hold it constant you keep a constant speed with no acceleration). Your brake pedal is also an acceleration pedal; it slows you down. Your steering wheel is also an accelerator control because it changes your direction.

For objects near the surface of the earth there is a special acceleration, called the ***acceleration of gravity***. For something falling in the case where air resistance doesn't slow it down too much, the speed changes by 9.8 m/s every second so we say it has an acceleration of 9.8 m/s per 1s or 9.8 m/s^2 (or 32 ft/s^2 in the English system). So if a pot gets pushed off an upper story window ledge it starts from rest (zero speed) and will be falling at a speed of 9.8 m/s after one second, $9.8\text{ m/s} + 9.8\text{ m/s} = 19.6\text{ m/s}$ after two seconds, $9.8\text{ m/s} + 9.8\text{ m/s} + 9.8\text{ m/s} = 29.4\text{ m/s}$ after three seconds, etc. This acceleration of gravity works the same for any object, regardless of size or weight, as long as air resistance is small and you are near the earth's surface. This is what Galileo figured out by dropping different sized objects off the leaning tower of Pisa; objects accelerate (get faster) at the same rate no matter what their size (again, if you can ignore air resistance).

The amount of 'stuff' an object has regardless of where it is (in space, on earth, on the moon), its 'heft' you might say, is called ***mass*** and is measured in *kilograms*, kg (or sometimes grams where $1000\text{ g} = 1\text{ kg}$). The English units of mass are the slug and the stone but we seldom use them.

A ***force*** is a push or shove and is measured in *newtons* , N, which is a kilogram-meter per second squared, kg m/s^2. The tension in a guitar string is the force pulling at either end of the string (the force pulling each end is the same and balances out so the string doesn't go anywhere). The English unit of force is the pound which is also the unit used to measure weight. This can lead to some confusion because the pound is also sometimes incorrectly used for mass.

Weight is the force that gravity causes an object to exert on the earth. Weight is measured in *newtons* in the metric system or pounds in the English system. This is how mass and weight get confused; in everyday use we use weight and mass interchangeably which, strictly speaking is incorrect. For example in the grocery store you may see a bag of sugar that says 5 lbs or 2.3 kg which is really comparing different things; lbs measures weight but kg measures mass which is different. What the label should say is "this item weights 5 lbs or 22.3 newtons" (because 2.3 kg times 9.8 m/s^2 is 22.3 newtons which is a unit of weight). Or it could say "this item has a mass of 2.3 kg or 0.16 slug" (5 lbs divided by 32 ft/s^2 is 0.16 slugs and slugs and kg measure mass). So if you see something that claims to have a weight of 2.3 kg (or 5 lbs) remember what that really means is its mass is 2.3 kg.

Questions on Motion:

1. Why are units (such as meters or seconds or miles) important in science?
2. What is different about numbers in a science course as compared to numbers in a math course?
3. What is the difference between speed and velocity?
4. What is the difference between velocity and acceleration?
5. Does a car speedometer measure speed or velocity? Explain.

6. If you go around a curve at constant speed, do you have an acceleration? Explain.
7. Can a rapidly moving object have the same acceleration as a slowly moving one? Explain.
8. Can an object have an instantaneous velocity of zero and have a non-zero acceleration? Give an example.
9. At the end of its arc, the velocity of a pendulum is zero. Is its acceleration also zero at this point? Why or why not?
10. Assuming air resistance can be ignored, which gets to the ground first, a bowling ball or a tennis ball if they are dropped from the same height at the same time? Explain.
11. What is the difference in saying something is moving at a constant velocity and saying it is moving with zero acceleration?
12. Explain the difference between mass and weight.
13. Consult a table for the speed of sound in various substances (found in chapter six). If you have one ear in the water and one ear out while swimming in a pool and a bell is rung that is half way in the water, which ear hears the sound first?
14. At $20^{\circ}\ \mathrm{C}$ the speed of sound is $344\ \mathrm{m/s}$. How far does sound travel in 1 s? How far does sound travel in 60 s?
15. Compare the last two answers with the distance traveled by light which has a speed of $3.0 \times 10^{8}\ \mathrm{m/s}$. Why do you see something happen before you hear it?
16. The speed of sound in water is $1482\ \mathrm{m/s}$. How far does sound travel under water in 1 s? How far does sound travel under water in 60 s?
17. What would an orchestra sound like to someone in the audience if different instruments produced sounds that traveled at different speeds?
18. For the previous question, would it make a difference if you sat further away from the orchestra?
