# PHYSICS FOR THE OTHERWISE, REASONABLY WELL INFORMED



**Joe Evans, Ph.D**

**INTRODUCTION**

**THE SCIENTIFIC METHOD**

**MOTION & GRAVITY**

**ENERGY & WORK**

**THE PROPERTIES OF MATTER**

**VIBRATION & WAVES**

PACIFIC LIQUID & AIR SYSTEMS
PUMPS • MOTORS • CONTROLS

*761 Ahua Honolulu, HI 96819*
*Phone 808.536.7699 Fax 808.536.8761*
*www.pacificliquid.com*

## Why Physics?

After reading, riting, and rithmetic, physics is probably the most useful subject anyone could ever study. Unfortunately, it is more often thought to be too complex for the average person. If you will take the time to read this simple, basic physics presentation I can promise you that your understanding of the subject and of the world around you will be greatly enhanced. You might even find yourself gravitating towards one of the more comprehensive works to further your understanding. Unlike many subjects, physics is not complicated by conjecture and a basic understanding will allow you to enhance your decision making processes. Even local & national issues, the politicians who often initiate them, those pesky environmentalists, and the neighbor next door can be easier to confront with the help of physics.

For many years I have wanted to develop a brief introduction for you otherwise well educated adults who, for whatever reason, never studied physics in high school or college. Now, I do realize that there are many reasons why one might choose not to study physics. You may have been a language or history major and decided to avoid the sciences all together. Maybe you majored in political science or pre-law and the curriculum didn't allow courses in logic. Possibly it conflicted with a more important course such as basket weaving. These are, of course, all good reasons but usually the more honest admission is that it required that awful m-word -- math!

To be sure, a high degree of mathematical skill is required to become a theoretical physicist. Most college physics courses require calculus and even general physics courses require algebra and geometry. Fortunately though, one can gain an intuitive understanding of much of the *findings* (knowledge) of basic physics without any math at all. Certain topics do require a little math in order understand some relationship, but it is usually simple and uncomplicated.

My goal is to present this knowledge of basic physics without having to delve into the mathematics that gave rise to it. The only formulas or equations you will find here will be those that clarify something we have discussed. They are not, however, always necessary to the understanding of a point or topic. Just remember that math is really just a sort or shorthand. It allows us to illustrate a relationship or value in a very concise manner.

You will also notice that, unlike most most presentations, there are no illustrations. This is not because I do not think that they are useful. It is simply because I want you to read this as might a child. Use your imagination, draw on your own experiences and much of what you read will become visible also. What I will do is direct you to web pages that, I think, do a very good job of illustrating the various topics we discuss. Most offer animated illustrations that are far superior to anything I could provide you. You will find these links in a footnote following the topic.

There are also very good short courses and introductions to elementary physics on the web but, most use math every step of the way. It is not difficult math -- mostly simple algebra -- but, since my basic premise is that it was math that caused you to avoid physics in the first place, I will not use them to supplement this introduction. Instead I will reference them for later study, should you decide to do so.[1]

The most difficult part of this effort is deciding what and how much information to include. The intent is to provide enough information to keep you interested, but not so much that it becomes overwhelming. I would appreciate feedback concerning the topics and the depth (or lack thereof) with which I have presented them.

Who would want to read this short introduction to physics? Probably not the audience I'm after, so maybe the question should read *should want*. That answer is easy-- anyone who is curious about or mystified by this complex world around us. The beauty of physics is that it helps to explain almost everything in every day life. Everything around us -- plants, animals, computers, airplanes, cars, even the universe -- follows the basic laws of physics. An intuitive understanding of these laws can help us navigate life a little more easily.

[1] A good supplement to this introduction is a site called Physics Comics. It uses a less formal means of conveying some of the same information contained here. If you find yourself in need of a little “visual” help go to: www.geocities.com/physicscomix/

# INTRODUCTION

## What Is Physics?

### It's Greek to Me

What is physics? Physics comes from the Greek word, *physikos,* which means natural. In its most basic form, physics is the study of naturally occurring phenomena. Originally it included all areas of science but as our base of knowledge grew, it became a bit overwhelming and specialties began to emerge. Biology, chemistry, geology, and astronomy all were once all a part of physics but became separate fields early on. What separated physics from these *empirical* sciences was the use and development of mathematics as a primary tool of study.[2]

There was much to be learned from the empirical sciences simply through observation. For example, biologists could map the vascular system of an animal through dissection or categorize plants based upon their visual features. Early physicists, on the other hand, had none of the tools necessary to carry out even the simplest experiments that could prove or disprove their theories. Instead they developed and used mathematics to help them understand their observations.

### Common Sense & Intuition

You have probably noticed that those of us with a modicum of common sense have a much easier time in life. We don't often make the same mistake in logic twice (well, maybe more than twice). After the first or second failure we tend to rethink the situation and try a different approach.[3]

The knowledge to be gained from physics also tends to be intuitive and can help us succeed in every day life. We do not necessarily need to understand every detail about why an event occurs. The fact that it does occur and will continue to occur may well be the more important point. But, we do need to understand the basics behind the event if we want to use it to help explain related events.

For example, suppose you were to jump off the back steps of your house. Common sense tells us that you will fall to the ground and, if the distance is not too great, you will probably land upright. Make that same jump from a second story window and the result will probably be quite different. Again, common sense tells us that you will hit the ground much harder and probably injure yourself.

Intuitively, we know that there is some relationship between the height of the jump and the force of impact. But what is it? Is the force of impact merely due to the distance you fell? If that were the case, ski jumping and sky diving would not be very popular sports. Physics allows us to

[2] Empirical - Learned through observation or practical experience

[3] Albert Einstein once said that common sense is composed of the prejudices we acquire prior to the age of eighteen. I believe that it can be quite a bit more than that, but he did have a point. Often, what we have learned through experience can and does prejudice our view when we are confronted with something that is outside our current area of understanding.

explain these kinds of relationships in a very concise and understandable way. It helps us to predict, accurately, the outcome of an event even though we may not have experienced it in the past.

Physics is the most basic of all sciences. Unfortunately, many of our public schools have been slow to recognize this fact and still tend to offer physics only in high school and then only after biology and chemistry! Can you imagine studying chemistry before learning about the atom? In many instances physics isn't even a required course. Physics, and especially the kind of physics you will study here, should begin in elementary school. Higher math is just not needed to gain a conceptual understanding of classical physics.

**The Basics**

Over time many of the empirical sciences (biology, geology, etc) have undergone a transition and now incorporate physics in their study. Astrophysics employs techniques that were once limited only to physics in the study of astronomy. Similarly, biophysics applies these techniques to the study of biology and biochemistry. In our studies, we are going to forego these specialties and focus on the basics because, it is the basics that will help us better understand the events that surround us. Our basics, often referred to as *mechanics*, will include motion & gravity, work & energy, the properties of matter, and vibration & waves. I will leave you on your own to study the other important areas.

But, before we start our study of mechanics, I want to introduce you to the *methodology* of physics or, for that matter, that of science in general. One of the nice things about the laws of nature is that they are *invariable*, or at least as far as we know they are invariable. It is only our understanding of them that changes. Fortunately, science is one of the few areas of study where it is OK to be wrong! When we find that something is wrong, it often leads us to the correct answer or, at least, an answer that is less wrong. It is this methodology, not found in other studies, that allows the findings of physics to survive the test of time.

# THE SCIENTIFIC METHOD

There are many similarities among the diverse fields of study within that broad category known as the arts and sciences. There is, however, one characteristic that separates science from all other fields. That characteristic is the *hypothesis*. An hypothesis is simply an educated guess as to why (notice I did say educated). Why what? Why anything actually. Why something exists, why it occurs, or why it does something a certain way. It is the basis of a process we call the *scientific method*.

The scientific method describes an organized way to study some phenomenon. It is usually credited to both Galileo and Francis Bacon and takes the form of the following five steps.

1. Make an observation of some phenomenon

2. Make an educated guess (hypothesis) as to what or why

3. Use the hypothesis to make predictions

4. Perform experiments to test the predictions

5. Examine the data and draw conclusions. If the hypothesis is proven incorrect, return to step 2.

There is also an important sixth step that is not within the researcher's control. Others, who learn of his conclusions, repeat the same experiments and see if their results are the same as his. In other words, they want to see if his work is repeatable. Repeatability is a corner stone of the scientific method. It virtually guarantees that shoddy work will not survive.

What makes the scientific method so different from other methods of study is the hypothesis. And what makes the hypothesis so different than other guesses or hunches is its unique requirements. In order for a hypothesis to exist, there must be a way of *verifying its correctness*. Equally as important, there must be a *way of proving it incorrect*. This second requirement makes it unique and eliminates what would otherwise be an open ended guess. The fact that something must be susceptible to being proven wrong separates science and non science. Consider the following possible hypotheses.

1) There is an undiscovered planet somewhere between the Earth and Mars

2) Intelligent life exists somewhere else in the universe

The first example is a true hypothesis albeit an incorrect one. Today, we can verify the existence of an undiscovered planet by a number of means. We can use optical or infrared telescopes to search for it. We can look for unexplainable gravitational effects on known planets. We can also send unmanned spacecraft to those areas we cannot see very well. The fact that we have the means to search every nook and cranny between here and Mars not only allows us to verify the existence of another planet, but also allows us to disprove its existence. If we did not have a way to search the entire space in between, we might still prove the hypothesis (if we happened to find another planet) but we could never disprove it. After all that undiscovered planet could reside in the unsearchable area regardless of how small that area may be.

Our second example is not a hypothesis. We can explore a portion of the universe and could conceivably detect other life forms within that portion. But since we cannot explore all of the universe, we cannot conclusively disprove its occurrence. Therefore the possibility of the presence of other intelligent beings is simply speculation.

I cannot over emphasize the importance of the hypothesis and the scientific method. In science theories, hypotheses, and laws change based upon new findings. Change is a strength of science that is often lacking in other areas of study. Evolution of theories keeps our knowledge up to date and prevents flawed theories from supporting new ones.

Earlier scientists also realized that there needed to be some way to limit flawed theories. This was a time of great philosophical debate and little actual experimentation. Under those circumstances, it is easy to imagine how theories became more and more complex as the debates expanded. So, in the early 1300's, long before Galileo and Bacon, an Englishman named William of Ockham proposed a method for choosing the better of two competing theories. William said quite simply that "entities should not be multiplied unnecessarily". Known as Ockham's Razor, his principle states that when two different theories are supported equally by the same data, one should study the simpler one first. It is still quite valid today.[4]

Now, do not let my emphasis on the scientific method lead you to believe that it is the only way to study some phenomenon. There is nothing wrong with the fact that history, art, law, etc are not science. And, because they are not they are studied differently. On the other hand, just because something is not science doesn't mean we cannot use the methodology of science to study them. In fact, it can often be a valuable tool. But, we must always remember that the results are not *scientific* but merely *scientifically* obtained.

In fact, any time we humans become a part of the equation, we can be pretty sure that science will take a back seat! Take economics for example. There are volumes of mathematical models covering almost every aspect of economic theory but, it is we humans who ultimately determine their outcome. We buy and sell stocks, we set the value of currency, we print the money, and we even decide who can participate in the process. As long as we are the *force* that drives a particular field of study, it can *never* be science. For the very same

[4] An interesting corollary, often used to test conspiracy theories, is known as Hanlon's Razor. It suggests "never attribute to malice that which can be explained adequately by stupidity"!

reasons law is not a science. Even medicine is only partly science. Much of it still relies on the best guesses of the physician. Fortunately for us, their individual work is watched closely by both the medical and scientific communities.[5]

There are, however, areas where science is misused. Some of the so called *pseudosciences* can be misleading while others are down right corrupt. Psychology, for example, has some of its roots in science but the bulk of its findings cannot be considered scientific. Most are purely speculation but are usually espoused as fact and often lead to flawed decisions by those who accept them as scientific.

You will find that *honest* science does not use complex terms to try to confuse the layman. Good science takes pains to explain them in every day terms. Of course there are, occasionally, terms for which there are no synonyms but, they tend to be the exception rather than the rule.

[5] Wish I could say the same for lawyers

# MOTION & GRAVITY

Everything around us is moving -- the moon, planets, people, birds, trains, ships, cars -- everything. Even things that appear to be motionless are a beehive of activity. The atoms that make up a rock are in continuous motion and even the couch potato has a beating heart and blood flowing through his veins. Motion and the forces that control it drive our world as we know it. It is the most basic component in the study of physics and is an ideal place for us to start.

In this chapter we will take a look at the different types of motion that an object can undergo. We will discuss speed, velocity, and acceleration as well as the laws that define the relationships between both moving and stationary objects and the forces that act upon them. A discussion of gravity, both on earth and in space, will allow us to investigate the motion that results from a combination of other motions. Gravity will also help us understand the difference between weight and mass. Finally we will take a look at the motion of planets and satellites and unravel the mystery of why they just keep going around and around.

## The Heavens

We all know that our moon orbits about the earth and that the earth and the other planets in our solar system orbit about the sun. Most of us also know that our solar system moves about the center of our galaxy and that all of the galaxies in the universe move about some common center. This was not always the case.

In the mid 300's BC the Greek *philosopher* (lover of wisdom), Aristotle, was convinced that the earth was the center of the universe and that the moon, planets, sun, and stars orbited the earth. About 500 years later, Ptolemy (also Greek) developed a model that attempted to explain how Aristotle's theory could possibly work. As you might expect, it had a few holes in it but it was generally accepted because it tended to agree with the early Christian scriptures.[6]

It wasn't until the early 1500's, almost two thousand years after Aristotle's pronouncement, that the Polish priest, Copernicus, presented the idea that the sun was stationary and that the planets moved in circular orbits around it.[7] Needless to say, this was not taken too seriously in many Greek circles. Almost a century later the Italian astronomer, Galileo, used the telescope, a new invention at the time, to prove that everything did not orbit around the earth. It was still unknown; however, how the planets orbited the sun and why they were visible in different places at different times. We finally got that explanation in 1687, through the labors of Sir Isaac Newton.

The paragraphs above represent much more than a brief history of the study of motion. They also make us aware of how long it took science to explain events that

[6] Go to www.nasm.edu/ceps/etp/discovery/disc_ancient.html for a brief explanation and look at Ptolemy's model.

[7] Actually some of the early Greeks suggested this but it did not agree with the teachings of the church.

we take for granted. Most of physics is like that. Theories evolve, they are modified, they change directions, and if they are wrong they are discarded. There was nothing wrong with Aristotle's theory in the beginning. In fact, it was quite useful at the time. But when it was shown to be incorrect, it was replaced with one that was even more useful.[8]

## Motion in a Single Direction

A rock, thrown into the air, falls to the ground and thus leads to the old adage "what goes up must come down". But why? Aristotle believed that all things had their own *natural place* in the universe. Since the rock was part of the earth, it was reasonable to expect that the rock would return to the earth the first chance it got. Aristotle took his natural place theory a step further. He reasoned that if one object were heavier than another, it would fall back to earth faster than the lighter one because it had a greater need to be in its natural place. Now, you have to admit that this does make sense. Maybe not the *greater need* part, but certainly intuition would lead us to the same conclusion. After all we cannot throw a heavy ball nearly as high as a lighter one. If it won't go as high, might it also fall faster? And, Aristotle's reasoning was supported by the observation that rocks fell to the earth in a much shorter time than a tree leaf (also part of the earth's realm). Unfortunately, the ancient Greeks were not the experimenters we are today. Had they been, they would have surely noticed that a flat sheet of parchment falls through the air much more slowly than a crumpled piece even though they weigh the same.

[8] Unfortunately, the church did protract this delay

But again, this was an early theory and it was useful at the time. Aristotle and his contemporaries were true theorists and relied on the power of reasoning as opposed to experimentation. There was a good reason for this. After all, even the simple tools needed to test many of these events did not exist.

### Enter the Italian

Although the early Greeks *slowly* advanced the field of physics for almost two thousand years the Italian scientist, Galileo Galilei (1564-1642), gave us spectacular advances in a mere sixty years. This was due, in part, to his ardent belief in and use of *experimentation* to prove or disprove a theory.

Galileo disagreed with Aristotle's theory, that heavier objects must fall faster than lighter ones, but he still shared one problem with those before him--the inability to measure time accurately. In Galileo's time, clocks were quite rudimentary and could not be used to time the falls of various objects of different sizes and weights. After all, relatively heavy objects dropped from short distances strike the ground very quickly. Supposedly, he recognized this when he dropped objects of differing weight from the Tower of Pizza.[9] Based upon his observations, they appeared to hit the ground in the same or very similar times

[9] One wonders if dropping heavy weights near the tower's base could have, over time, contributed to its less than perfect vertical alignment.

but he could not be sure. If only he could find a way to slow their descent he might then devise ways to accurately time their fall.

Ever the experimenter, he came upon the idea to try an *inclined plane*.[10] Galileo built a long, straight track with a groove along its surface. He could tilt the track, place a ball in the groove and it would roll down the track without rolling off either side. He found that the tilt or angle of the plane would determine the time it took the ball to roll from one end of the track to the other. From these initial experiments, he predicted that the roll time of the ball would be *proportional* to the plane's angle. In other words, if the plane was set at an angle of 90 degrees (vertical) the ball would essentially fall freely to the ground (shortest roll time). If the angle was 0 degrees (horizontal) the ball would remain motionless. Any angle from 1 and 89 degrees would generate proportionally shorter roll times. For example, if the plane was adjusted to 45 degrees (exactly half of vertical) it would take twice as long for the ball to roll down the track than it would if it were in the vertical position.

He now had a way of reliably and predictably slowing objects enough to measure their descent. He observed that relatively heavy balls of different weights reached the end of the track in just about the same amount of time. But when very light balls, similar in size to the heavy balls, were used they moved much more slowly. He predicted that this had nothing to do with the ball's weight per se, but to its size relative to its weight and the *air resistance* it encountered during its trip down the track. His prediction was correct because all moving objects, be they rolling balls, autos, or airplanes must move air out of their path. When going down hill heavier objects can do this more easily than lighter ones of similar size. Were air resistance not a major factor, sky divers would be limited to a single jump!

Galileo thought that if his experiments could be performed in a *vacuum* all objects, regardless of their size and weight, would fall at the same rate.[11] Much later when vacuums were achievable, there were dramatic experiments showing a feather and a lead weight that appeared to fall at the same rate. Actually they fell at the same rate based on visual observation. The only way they could fall at exactly the same rate would be in a perfect vacuum (not even one molecule of air) which is, so far, beyond our capability.

So through simple experimentation, Galileo was able to demonstrate that Aristotile's prediction, that heavier objects fell more quickly than lighter ones, was incorrect. He also noted something else that was equally as important. As a ball rolled down the inclined plane, its *velocity* (speed) increased the further it rolled. For example when the ball was first released it moved very slowly. After a few feet it was moving faster. A few more feet and it was going even faster. This increase in velocity continued until the ball came to rest at the bottom of the track.

[10] An example of an inclined plane is the typical playground slide. If you would like to see a reproduction of Galileo's original inclined plane go to www.imss.florence.it/museo/4/evi13.html

[11] A vacuum is an environment where no air exists

## Velocity vs Speed

Now is probably a good time to discuss velocity and speed. In everyday life we tend to use the terms interchangeably but, in physics, they have very different meanings. Speed is the *distance covered over a period of time*. If, for example, you drive a distance of 100 miles over a period of two hours -- your average speed for the trip is 50 miles per hour. The equation used to determine speed is:

$$\text{speed (s)} = \text{distance (d)} \; / \; \text{time (t)}$$

$$s = d / t$$

$$50 \text{ miles} \; / \; \text{hour} = 100 \text{ miles} \; / \; 2 \text{ hours}$$

Although your instantaneous speed may have changed many times during the drive (your speedometer displays your instantaneous speed) your average speed is still 50 mph.

Velocity is different because, in addition to time and distance, it takes into account the *direction* of travel. If you drive 50 miles north, turn around, and drive 50 miles south you will cover a distance of 100 miles. If it takes two hours for the entire drive, your average speed is 50 mph. Your average velocity , however, is 0! Why? Because velocity considers, not the total distance traveled, but your final location relative to where you started. Since you ended up where you started there was no change in location.

The equation for velocity, seen at the top of the right hand column, is a little different than the one above.

$$\text{velocity(v)} = \text{position change}(\Delta p) / \text{time(t)}$$

$$v = \Delta p \; / \; t$$

The Δ symbol always indicates change. In this case it means a change in position. Since you traveled 50 miles in one direction and then 50 miles in the exact opposite direction, Δp is 50 minus 50 or zero. Your average velocity is:

$$v = \Delta p \; / \; t$$

$$0 \text{ miles/hour} = 0 \text{ miles} \; / \; 2 \text{ hours}$$

Another example is driving in a circle. If that same 100 mile trip were a circle and you completed it in two hours, your average speed would still be 50 mph. Your velocity, however, will change constantly because, when driving in a circle, your direction is changing constantly. Your average velocity, however, will again be 0 because, once again you ended up where you started. Speed and velocity become equal only when the distance traveled and the change in position (Δp) are equal.

Speed is known as a *scalar* quantity (from the Latin word for ladder) and possesses *magnitude* only. Velocity is known as a *vector* quantity (from the Latin word for convey) and possesses both *magnitude and direction*. You will recognize the importance of this difference when we discuss motion in more than one direction.[12]

[12] Go to www.glenbrook.k12.il.us/gbssci/phys/class/idkin/u1l1d.htms for a good demonstration of speed versus velocity.

## Acceleration

Now back to Galileo's observation. What caused the ball to roll faster and faster the further it traveled down the inclined plane? This increase in velocity was caused by *acceleration* which, in this case, is due to the gravitational pull of the earth on the ball.[13] It is acceleration that causes you to press back into your seat as an airplane speeds down the runway. It also causes that funny feeling you get in your stomach when an elevator begins its descent. Acceleration is defined as the *rate of change in velocity*. Since velocity already takes time into account, the rate of change in velocity implies that yet another time component must be involved.

Suppose we are in a car at a traffic light, the light turns green, and we press down on the accelerator. At the end of one second our speedometer shows that we are traveling at 5 mph. At the end of two seconds it shows 10 mph and at the end of three seconds we are traveling at 15 mph. You have probably noticed that our velocity has increased by 5 mph during each of those three seconds. This increase in velocity over time is acceleration. In this example, our acceleration is 5 mph per second. In other words, if our acceleration remains constant, our velocity will increase by 5 mph each and every second that we travel.

$$\text{acceleration}(a)=\text{velocity}(v) / \text{time}(t)$$
$$a = v / t$$

[13] We will discuss gravity in detail a little later

If velocity and speed are equal, velocity becomes distance divided by time and the equation above can also be written as:

$$a = d / t / t$$

Now you can easily see the two time components involved.

Let's take a look at a different example. Suppose that 10 seconds after leaving the light we are traveling at 50 mph. Our acceleration during this period may be stated as 50 mph / 10 seconds or 5 mph per second, which is the same value we obtained earlier.

In the first example acceleration could be considered *constant* because our velocity, measured in one second intervals, increased by 5 mph each second we traveled. In the second example we cannot say this because we noted only one velocity (50 mph) and only one measurement interval (10 seconds). All that we can say is that our *average* acceleration over the ten second period was 5 mph per second. After all, we could have floorboarded it and accelerated rapidly for the first few seconds and then let up a bit and accelerated more slowly for the remainder of the run.

This concept of changing versus constant acceleration is an important one in nature. If the acceleration of a falling object were to change randomly, it would be impossible to predict its velocity at any time during its fall. Galileo's experiments, however, demonstrated that the rolling balls not only continued to accelerate as they rolled down the plane, but did so at a constant rate.[14] Another important point to remember about acceleration is that it occurs only when a force is present. When we press down on the accelerator, the engine provides the force that causes the car to accelerate. When we let up, the force goes away and our velocity ceases to increase.

## The Laws of Motion

In the late 1600's the English scientist, Isaac Newton, refined the work done by Galileo. From these earlier experiments and those of his own, Newton was able to define three basic rules of motion. He did this in a quite phenomenal way. Newton too, suffered from the lack of equipment necessary to perform certain experiments with a high degree of accuracy. Furthermore the mathematics available to him at the time (algebra, geometry, and trigonometry) were not sufficient to explain many of his ideas and findings. This did not, however, deter Newton. He simply invented the branch of mathematics we call *calculus* so that he could continue his work!

Today these rules are known as the laws of motion or Newton's laws. Newton's laws clearly and concisely define the relationships between moving or stationary objects and the forces that act upon them. They apply not only to objects on the earth's surface but also to those in space. Understand Newton's laws and you will understand basic motion.[15]

### The First Law

Newton's first law states that *a body that is motionless will remain motionless unless it is acted upon by some outside force.* Likewise, *a body already in motion will remain in motion and travel in a straight line at a constant velocity unless it is acted upon by some outside force.* This first law is also known as the law of *inertia*.[16] When you think about it, this law seems pretty straight forward and it is, but up to this point in time no one had stated these principles so concisely.

It is intuitively obvious that a car, parked on a level surface, will remain there unless we push it, tow it, or drive it away. On the other hand some of us may question the second part of this law. After all, we know from experience that if, while driving, we place the gear shift in neutral or turn off the ignition the car will eventually come to a halt. This seems to conflict with the first law but, actually, it follows it exactly. The car slows and eventually comes to a stop due to outside forces. Wind resistance (moving air out of its path) acts against motion. If you don't believe it, try running into a brisk head wind for a few minutes. Another outside force is friction.[17] Friction is a force that arises when objects come in contact with

[14] To view Galileo's inclined plane in action go to www.imss.firenze.it/museo/a/epianoi.html and click on the AVI camera icon. There you will see the acceleration of a rolling ball in AVI or Quicktime format.

[15] In the early 1900's Einstein's theory of relativity redefined Newton's laws. They were found to be slightly inaccurate under normal conditions and downright wrong as velocity approaches the speed of light. They are still, however, extremely useful in our every day world.

[16] Inertia - a body's resistance to a change in motion

[17] We will discuss friction in detail in Chapter 2

one another. Tires create friction as they roll along the road's surface. Internal parts such as bearings and gears create friction as they rotate. Even wind resistance creates a form or friction. Any of these outside forces is enough to eventually stop the car.

The amount of wind resistance a body experiences depends upon its size and shape. The bigger it is the more air it must displace as it moves forward. How quickly a moving object slows due to friction, on the other hand, depends upon the amount it encounters. For example, a hockey puck will travel much further on the ice than it will on the street because the surface of the ice is much slicker and therefore creates less friction. Rub your hands together briskly with them just barely touching. Try it again but this time press them together tightly. The *heat* you felt the second time is the result of friction. In order to generate heat you must consume energy and, it is the heat created by friction that steals the energy that kept the car in motion.

Unlike acceleration, a force is not required to maintain the *velocity* of a body in motion. But, even today, we cannot truly explain why a body in motion and not under the influence of some outside force actually remains in motion. All we know is that it does!

### The Second Law

Newton's second law takes the first law a step further and explains how an outside force acts upon a stationary body or one that is already in motion. It may not seem as intuitive as the first but a few examples will clear up any concerns.

The second law states that *the acceleration a body, at rest or in motion, undergoes due to some outside force is directly proportional to the size of the force and inversely proportional to the mass of the body*.[18]

When we say that one thing is *directly proportional* to another we mean that if one changes, the other changes in exactly the same way. Suppose an object's weight is directly proportional to its size. If we double its size its weight will double also. If we reduce its size by one half, its weight will also be halved.

An *inverse* relationship is the exact opposite. Have you ever noticed that the closer you move a magnet to a metal object the harder it pulls? This is an example of an inverse relationship. The smaller the distance, the greater the attraction. The greater the distance, the smaller the attraction. Lets take a look at a few examples of the second law in action.

When you kick a soccer ball, the distance it travels depends upon how hard you kick it. Kick it lightly and the ball leaves your foot slowly and rolls only a short distance. Kick it as hard as you can and it leaves your foot more quickly and rolls much further. Your kick accelerates the ball and it is *acceleration* that causes the ball to roll. How far the ball rolls depends upon the force of your kick. According to the second law, the distance the ball rolls is directly proportional to the force of your kick.

[18] For the time being think of mass and weight as being the same. When we discuss gravity, I will explain the difference between the two.

Once the ball is rolling, if someone else kicks it several things can happen. It can be reaccelerated in the same direction, veer off to one side or the other, or it can reverse direction and head back to you. Regardless of which direction the ball goes its acceleration, and the distance it travels, will still be directly proportional to the force of the kick.

Now lets take a look at the second part of this law. Suppose we were to replace the soccer ball with a bowling ball. If you kick it with the same force as before, you will probably feel an intense pain in your foot and may eventually notice that the bowling ball did not roll nearly as far as the soccer ball. Why? After all you kicked it just as hard. The answer is obvious, of course. The bowling ball is many times heavier and a swift kick just cannot accelerate it as quickly as it will the lighter ball. Assuming the same force is used to kick balls of different weights, the ball's acceleration will decrease as its weight increases. Double its weight and its acceleration will be halved. This is an example of the inverse relationship of the second law.

Mathematically the direct and inverse relationships of the second law are:

$$\text{acceleration}(a) = \text{force}(f) \ / \ \text{mass}(m)$$

$$a = f \ / \ m$$

If we keep mass (weight) constant and increase force, acceleration will increase in direct proportion to the increase in force. On the other hand, if we keep force constant and increase mass (weight) acceleration will decrease in inverse proportion to the increase in weight. [19]

As a final example consider the following. You decide to purchase a new car and it offers the option of two engines. One is the gas conscious model and is rated at 150 horsepower and the other is the macho 300 horsepower model. If the overall weight of the car is about the same regardless of the engine chosen we would expect that the car's ability to accelerate will increase in direct proportion to an increase in engine horsepower. And, to a close degree it does. Now suppose, on the other hand, a compact car and a full size van use the same engine. Since the weight of these two cars varies significantly, we would expect acceleration to be inversely proportional to the weight of the two cars. In other words, the heavier van will accelerate more slowly than the lighter compact. Again, to a close degree it does.
The reason the results do not follow Newton's law exactly is because the force developed by an internal combustion engine is not always directly proportional to its horsepower. This is a good example of a common sense application of the law, one where the law applies but the outcome appears to differ slightly because the familiar unit of comparison ( in this case horsepower) is not a true unit of force.[20]

[19] If we rearrange this simple relationship, we find that a force created by a moving object is equal to the mass of the object times its acceleration (f=ma).

[20] We will discuss units of force in Chapter 2

## The Third Law

Newton's third law describes the results we observe when when an outside force acts upon an object. It states that *for every action there is an equal and opposite reaction*.

I hit you, you hit me back -- right? Not exactly what I had in mind. Push a cue ball with a cue stick and the ball rolls forward. When it impacts another ball, the energy of the rolling cue ball is transferred to the other ball and that ball rolls and the cue stops or slows. Hit the other ball at an angle and both balls veer off at opposite angles. These are simple examples of action and reaction. One ball hitting the other is the action and the resulting change in motion of both is the reaction.

Another straightforward example of the third law in action can be seen in our space program. When the solid or liquid fuel in a rocket engine ignites, the hot gases expand rapidly and create tremendous pressure inside the engine. Since these gases are contained by the walls of the engine there is no place for them to go except through a relatively narrow nozzle at the rear of the engine. The exit of these gases is the action. The reaction is the movement of the rocket in the opposite direction. A similar example occurs when we release an air filled rubber balloon. Air rushing out the mouthpiece is the action, while the flying balloon is the reaction.

Unfortunately, not all examples of action and reaction are as readily apparent as these. Try this one on for size. Stand behind a small car, push hard and it will move forward. The action was your push and the reaction was the car moving forward right? Wrong -- the action was your push but the equal and opposite reaction was the car *pushing* you. Try this again on a slippery surface. You may still be able to move the car forward but you too will move and your movement will be in the opposite direction!

In the first example the friction between your feet and the pavement gave the appearance that you remained in the same place, but you didn't. You actually moved backwards by an extremely minute amount. While you were applying force to the car, it was applying the same force on you. Its force was transmitted to the earth's surface through your feet and the pavement. What actually happened was that the force of the car actually moved the earth (and hence you) backwards! Hard to believe? Remember the inverse relationship of the second law? The force of your push was so small compared to the mass (weight) of the earth that the earth's acceleration backward was completely unnoticeable, but it happened. So the next time you see a truck pulling a trailer, remember that the trailer is also pulling the truck!

## Translational vs Rotary Motion

So far, our discussion of motion has been limited to the kind of motion that occurs when something moves from point A to point B. For example, if we drive an automobile a distance of one mile the entire auto makes that trip. Its motion is not limited to its hood or trunk but includes all of its parts. When something moves from one place to another in its entirety, its motion is called *translational* (from the Latin word to carry across). It is the most common form of motion and accounts for all of our examples so far.

It is not uncommon; however, for an object to be in motion yet remain in one place. A simple example, at least for those of us old enough to remember, is a phonograph. Although its platter spins about its axis the phonograph, as a whole, does not change its position. This type of motion is know as *rotational* (from the Latin word for wheel).

Although rotational and translational motion are similar, the way we describe their velocities is quite different. When an auto is traveling at 60 mph, *all* of its parts are traveling at 60 mph. This is not the case; however, with rotational motion. When a phonograph platter is rotating, a point near its outer edge moves at a greater velocity than one nearer its center. If you have trouble visualizing this, think about the circles in which the two points travel. The circle near the outer edge is larger than the one nearer the center. Although it takes the same amount of time for both points to complete one rotation, the point near the outer edge travels the greater distance and therefore must do so at a greater velocity.

The difficultly with rotational motion is that no two points along the radius of a rotating object travel at the same velocity. Therefore, it is impossible to assign some overall velocity unless we specify an exact point on that object. Instead, we use the generic quantity RPM or rotations per minute to describe its motion.[21] After all, every point along the axis of a rotating object makes the same number of rotations in a minute's time even though they are traveling at very different velocities.

In physics you will often see rotational velocity expressed in RPS (radians per second). A radian is an arc on the circumference of a circle that is equal in length to its radius. Since the circumference of a circle is equal to $2\pi r$ (where r is the radius and $\pi$ is equal to 3.14), the radian becomes a very useful quantity in describing rotational velocity. This is true because there will always be $2\pi$, or 6.28 radians (57.3° each) in a circle regardless of its size.

You will find that many bodies in the universe exhibit rotational motion. Here on earth it is the stuff of rotating machinery, wheels, gears, and even clocks (the analog ones anyway). They all follow Newton's laws although the forces that they generate and those that affect them look a little different than translational forces. *Torque*, the force of rotational motion will be a topic of discussion in Chapter 2.

Even though we have reviewed both translational and rotary motion, we have limited our discussion to that which

[21] Many think that RPM is an abbreviation for revolutions per minute. It can be but, when something moves about its own axis, it rotates. When it moves about another body, as in the earth's movement about the sun, it revolves. Therefore the earth makes one rotation per day and one revolution per year.

occurs in a single direction. All of our examples be they billiard balls, hockey pucks, or phonographs moved in one direction only. Some of the examples may have changed directions, but at any point in time they were traveling in a single direction only.

An object, however, can undergo motion in several directions simultaneously. A familiar example is the earth and its orbit about the sun. The earth makes one complete revolution about the sun in a little more than 365 days. This orbital motion is the result of two totally different motions, one forward and the other toward the sun. Motion in *more than one direction* is an extremely important and useful concept. But, before we can understand its place in nature we need to take a look at the most important natural force that we, personally, will ever encounter.

## Gravity

Have you ever heard someone speak of the "gravity of the situation". It sounds pretty heavy doesn't it? Well it is, because gravity comes from the Greek word meaning heavy or weighty.

Gravity is the *force* that causes an object to fall to the ground. It's the force that causes objects to have weight. It is the force, but not the reason, that causes your bathroom scale to show five extra pounds after the Christmas holidays. It is also the force that caused Galileo's balls (a little physical humor) to accelerate down his inclined plane at a greater and greater velocity.

Well, exactly what is gravity? Gravity is the attractive force that is created by an object's mass. It is not magnetic or electrical in nature nor is it nuclear. The greater an object's mass, the greater its attractive force. Since all objects possess mass, all objects will attract each other. The earth attracts you and holds you to the ground, but you also attract the earth (because you too possess mass). The earth also exerts its gravitational force on all other bodies in the universe just as all other bodies in the universe exert their gravitational forces upon the earth. It is the earth's attraction of the moon, and the moon's attraction of the earth, that keeps the moon in orbit about the earth. The same relationship between the sun and earth keeps the earth from flying off into space.

I didn't quite answer the question I posed, did I? If I could, you probably would not be reading this because I would be lying on some beach enjoying the fruits of my Nobel Prize. If you look up the definition of gravity in the dictionary, you will find some very general descriptions but not a true definition. The reason for this is that we really don't know the answer. You will find this often in physics -- we can quantify things, explain their relationship to other things, and even predict the outcome of events they influence. But, many times we just don't know enough to truly define them. We are learning a lot about the other two attractive forces in nature (nuclear and electromagnetic) and they exhibit both similarities and differences when compared to gravity.

Perhaps we may find the real answer in the not too distant future.

So, how did we learn about this force called gravity? As I mentioned in the beginning of this section, the early Greeks had a very different view of the Universe than those who followed later. For hundreds of years they thought the sun and the other planets revolved about the earth. After Copernicus concluded that maybe it was the other way around, great philosophical discussions followed. Since a theory of this magnitude is quite difficult to prove or disprove without a huge amount of supporting data, scientists of the time did the next best thing -- they discussed it ad nausium! And, you probably thought that our politicians invented this delaying tactic!

Fortunately the Danish astronomer, Tycho Brahe (1546-1601), took a different approach. He decided that the only way to prove such a theory was to actually gather the necessary data. Using this novel approach, he spent almost his entire life charting the movement of the planets. Even though the telescope had not yet been invented, his measurements were extremely accurate and are still in use today.

Upon Brahe's death his German assistant, Johannes Kepler (1571-1630), used these volumes of data to describe several important facts about planetary motion. His first finding was that the planets do not orbit the sun in *circles* as was originally suggested. He found that they traveled in *ellipses* which are a type of foreshortened circle with one diameter slightly shorter than the other. He also discovered that they do not travel at a *constant* speed. They travel faster when their orbits bring them closer to the sun and more slowly when they are further away. His final discovery, some years later, was that a planet's period, or the time it takes to complete its orbit, is proportional to the length of its major axis (the longer diameter of the ellipse). He used these findings to pen three laws, known today as Kepler's laws of planetary motion.[22]

About the same time, Galileo was using the telescope to study the motion of the planets. One of his major interests was what kept the planets moving in what he thought were circular orbits. Earlier, he had discovered the principle of inertia and figured that it must have something to do with their continued movement. But, he still could not explain why they appeared to move faster during certain parts of their orbits. Had Galileo and Kepler worked together, they may have been able to apply the principle of inertia to Kepler's laws and come up with a fascinating discovery. But alas, it would be left to Sir Isaac to put the whole thing in one tidy package.

Newton was also very interested in planetary motion and, like Galileo, believed that inertia must somehow be involved. His second law refined the principle of inertia by proposing that the only way the motion (speed or direction) of a body could change is through some outside force. While Galileo was primarily interested in the force that kept

[22] If you would like to see Kepler's laws in animation go to www.cvc.org/science/kepler.htm

the planets moving, Newton wondered what it was that kept them from flying off into space. After all, if you swing a yo-yo in a circle about your head, it will fly away if you let it go. The only thing keeping it in its circular orbit is your *pull* on the string.[23]

From this line of thinking, Newton deduced that no outside force was required to keep a planet in motion because its own inertia, in the vacuum of space, could satisfy that need. But some force, *acting at a right angle* to that motion, was necessary to keep it in orbit. Were there no outside force pulling it toward the sun, it would continue in a straight line and disappear into space. In other words, that force had to be toward the sun rather than around the sun. A little later this force would be called gravity . By analyzing Kepler's laws, Newton was able to show that the further away a planet is from the sun the weaker this attractive force might be while, in closer orbits the force might increase. This accounted for the higher velocity when a planet was nearer the sun and the lower velocity when it was further away. This discovery led Newton to his best work ever.

**The Universal Law of Gravity**

As if calculus and the laws of motion were not enough, Newton's crowning (actually knighting, as in Sir Isaac) achievement was his universal law of gravitation. He proposed that any two bodies in the universe attract each other with a force that is *proportional to their masses* and *inversely proportional to the distance* between them. More precisely, he said that any two bodies (objects) in the universe attract each other with a force that is *directly proportional to the product of their masses* and *inversely proportional to the square of the distance* between their centers. Simply stated, the more massive a body is, the greater its attractive force will be. But as the distance to a body increases its attractive force will diminish. Mathematically it looks like this:

$$f = \frac{m1 \times m2}{d^2}$$

Where: f is the attractive force, m1 & m2 the masses of the bodies, and d the distance between them.[24]

This is one of several, so called, *inverse square laws* that describe the attractive force between two objects. When you study electricity and magnetism you will find that their attractive forces abide by similar laws.

Now, if you have been paying attention, you may be thinking that the Universal Law seems to conflict with Galelio's observation -- that all bodies fall to earth at the same rate regardless of their mass or weight. How can his observation be correct if the force of gravity depends upon both the mass of the earth *and* that of the falling body? Surely the force between a ten pound object and the earth is ten times greater than that of a one pound

[23] In fact, if you release it you will see that it does not fly *away* from you, but continues in a *straight line* tangent to the point where you released it.

[24] Actually there is another term in this equation. It is g which is the gravitational constant but it is not important to our discussion at this time.

object. And it is, but don't forget that Newton's second law is also involved. Although the attractive force is ten times greater so is the mass and, acceleration is equal to the force divided by the objects mass. So even though the ten pound object generates a greater force it is canceled by its greater mass. It is probably difficult to accept the fact that even falling bodies resist falling. But they do!

**Exponential Change**

Until now, the changes we have talked about were very straight forward ones. In the case of Newton's laws of motion they were proportional. If something doubled, its result doubled. If something was reduced by one half the result was reduced by one half. The type of change described in the numerator (top portion) of Newton's universal gravitation equation is also straight forward. But the denominator describes something very different. This type of change is known as exponential change. In the case of $d^2$, the distance is multiplied times itself. When something changes exponentially the result can be quite unexpected!

The following exercise will introduce you to the often unexpected results of exponential change. Take a plain sheet of 8.5 X 11 inch copier paper and fold it in half. Continue folding it in this fashion until you have completed ten folds. Go ahead and do it now before reading any further.

If you somehow knew that this is an impossible task, you may already have a good understanding of the exponential function. If, however, you forged ahead on faith alone, you should definitely read on. What you probably saw as you folded the paper was that it went pretty smoothly for the first four or five iterations. The sixth fold was more difficult and the seventh was virtually impossible. In attempting the fold the paper back upon itself you were witnessing the exponential function in action. Each time you folded, the number of layers and therefore its overall thickness doubled. After one fold ($2^1$) there were two layers of paper, after two folds ($2^2$) there were four, after three folds ($2^3$) -- eight layers, and so on.

Had you been able to fold it nine ($2^9$) times there would be 512 layers -- about the thickness of a standard ream of copier paper. The tenth fold ($2^{10}$) would produce the equivalent of two reams! All in all your single sheet folded ten times would be about four inches thick!

If it were possible to continue this process for another 15 folds ($2^{25}$) the result would be a stack a little over one mile high! And, if you could complete 50 folds ($2^{50}$) a 71 million mile high monster would appear before you.

Now, do not scold yourself if you actually tried to fold the sheet of paper. When confronted with such an apparently simple task, most of us will do the same thing. Let it be a lesson though. Numbers can fool us, and especially when they are presented in a way that is not intuitively obvious. In the case of exponents, they may look small but their effect can be monumental. In the gravitation equation, distance is raised only to the second power (squared). But this simple exponent has a tremendous effect on the resulting force. If the distance is doubled, the force of attraction is decreased by four. If d is increased to ten, f is reduced by one hundred. Increase it by one thousand and the force is one million times smaller.

## Gravity & Mass vs Weight

Earlier, I said to consider mass and weight to be the same. Like speed and velocity, mass and weight tend to be used interchangeably but they are different. The weight of an object, on or near the earth's surface, is due to the earth's gravity. Mass, on the other hand, is *intrinsic* to the object itself and represents the amount of inertia it possesses (as in Newton's first law). It is totally independent of weight. It has to do with the atoms that make up an object. The greater their number and the tighter they are packed (density), the greater the mass of the object. Your weight is due to earth's gravity acting upon the mass of your body. The further you move from the surface of earth the smaller your weight becomes, but your mass remains the same. An explanation is in order.

## Gravity & Weight

A simple way of measuring weight is to use a spring scale. You will find them in the produce department of your supermarket. When an object is placed in the basket, its weight either stretches of compresses a spring that is linked to a pointer that displays the objects weight on a dial. The more the spring is stretched or compressed, the greater the weight indicated (your bathroom scales operate on this spring principle also).

The force exerted on an object by gravity depends upon the object's distance from the center of the earth. According to Newton's universal law of gravitation, as our distance from the earth's center increases our weight decreases. Intuitively we know this must be true because we have seen astronauts floating weightlessly in space.[25] But even on the earth's surface the same object will exhibit different weights in different locations. For example your weight at sea level will be slightly greater than it will be on Mount Everest. After all the peak of the mountain is some twenty thousand feet higher than the earth's surface at sea level.

Even weights at sea level differ slightly. The centrifugal (outward) force due to the rotation of the earth about its axis has caused its diameter to increase slightly at the equator. This increase is known as the equatorial bulge. A very sensitive scale would indicate a slightly lower weight for an object at the equator than it will at the North or South poles.

You now know that the force of gravity and one's weight depends upon our distance from the earth's center. It is greatest at the earth's surface and diminishes as we move away. But, what about gravity inside the earth? Is it greater, less, or the same? Does gravity inside the earth follow Newton's law?

[25] Not truly weightless, but OK for now

Suppose we could bore a large hole straight down through the earth's center and out the other side and then outfit it with a very long ladder that extends from surface to surface. I know that this is a bit of a stretch, but humor me for a while. As we climb "down" the ladder we weigh ourselves occasionally and notice that or weight is decreasing. If we continue our decent it continues to diminish and then begins to increase again until we exit the hole on the other side. There we notice that it is back to normal again. What does this event tell us about the force of gravity inside the earth?

Well, first it tells us that Newton' law must not apply for, if it did, our weight would be greatest at the center of the earth. In fact, had we measured our weight at precise intervals we would have noticed that it varies directly with respect to our distance from the center. At the very center it becomes zero. Why is this so?

Above the earth or on its surface, we are pulled in one direction only -- toward the center of the earth. But as you travel into the earth its mass begins to pull in many directions. Half way to the center you are still being pulled *down* but you are also being pulled *up* by that portion of the earth's mass above you. At the very center forces are pulling you in every conceivable direction and, since each force is exactly equal, they cancel one another and your weight becomes zero.[26] Simply stated, the force exerted by gravity within the earth is directly proportional to the distance from its center.

How strong of a force is gravity? It seems quite large but, when it is compared to the other attractive forces, it is actually quite small. If you hold two small stones a few inches apart they will attract one another but the force is too small to detect. Even the attraction between two aircraft carriers docked side by side is impossible to measure. After all, it takes a body the size of the earth just to give us our own body weight. But if you hold two small magnets, like the ones on your refrigerator door, close together you will notice their pull immediately. Their attraction to each other is many times stronger than their earthly attraction via gravity. And, the attractive forces within an atom can be thousands of times stronger still.

**Gravity & Mass**

Once we understand Newton's Universal Law, the change in the weight of an object based upon its distance from the center of the earth becomes pretty straight forward, but what about mass? Why does it remain the same regardless of distance?

I said that mass is the measure of the amount of *inertia* a body possesses. According to Newton's first law, a body at rest tends to remain at rest and one in motion tends to remain in motion unless they are acted upon by some outside force. This tendency is often referred to as the inertia of a body. The amount of inertia (read mass) a body possesses can be measured by the amount of force required

[26] Our example assumes a perfect sphere with uniform density throughout. Although this is not the case with the earth, it is close enough to illustrate this point.

to get it moving or stop it.  Lets look at an example.

A compact automobile is sitting on a level parking lot.  You get behind it and push with all your might.  Finally it begins to move and slowly picks up speed until its rolling at a steady pace.  You notice that once you get it moving it doesn't take nearly as much energy to keep it moving.  Did the weight of the car have anything to do with how much effort it took you to get it moving and keep it moving?

The answer is very little.  Remember that the weight of an object is due to the force of the earth's gravity.  Since gravity is pulling the car toward the earth's surface, the parking lot is taking the brunt of its weight.  Because weight is a result of the earth's gravity, it manifests itself only in the direction of the earth's center.  Now surely the car's weight did have some impact on you because its weight creates friction and you had to overcome that friction.  It was the car's mass; however, that required most of your effort.  Remember how you noticed that it took less effort to keep the car moving than it did to get it started initially?  That was Newton's first law in action.  The car tended to stay at rest initially, but once you overcame its *stationary* inertia its *moving* inertia tended to keep it in motion.

On the earth's surface weight and mass are equivalent.  Note that I did not say they are the same.  They also tend to be proportional.  By this I mean that an object that is twice as heavy as another will have twice the mass.  This is not the case as our distance from the earth increases.  As we move further and further away from the earth's surface weight decreases because the force of gravity decreases.  Once we reach the area above the earth where satellites are in orbit we will experience *weightlessness*.[27]  We will not; however, experience *masslessness.*  The mass of a body remains constant throughout the universe regardless of the earth's, or any other object's, gravitational force.  This was illustrated, dramatically, in 1997 when an unmanned and *weightless* supply ship damaged the Russian Meir space station during an attempted docking.  Since weight was not a factor, it must have been the ships mass that caused the damage.

A simple yet effective way to demonstrate the mass of different objects is the hang them on a string.  Take a couple of objects of similar size but differing weights and suspend each of them by a string.  Using a feather or a broom straw, push each one sideways just until they begin to move.  The heavier (and more massive) one will cause the feather bend more than the lighter one.  Since the string is supporting all of the weight, it is the object's mass (inertia) that actually causes the bending.[28]

**The Moon's Gravity**

Throughout history our moon has played an important role in our lives.  It has been the subject of songs and poetry, it causes our tides to rise and fall, and it

[27] Actually we only appear weightless.  We will learn why when we discuss satellite motion.

[28] Of course once the object moves even a single degree, weight once again becomes a factor.

illuminates an otherwise dark night.[29] If we were to visit the moon, what would be the relationship between mass and weight based upon our familiar earthly frame of reference?

The moon's orbit about the earth is due in part to the earth's gravitational attraction. A person on the moon, therefore, will still be affected by earthly gravity. He would not notice it; however, because he will be closer to the moon's center than that of the earth. Although we will not go into it here, one can calculate the gravitational field of an object if we know its mass. We know that the mass of the moon is about 1/81 that of the earth. Because of this its gravity is reduced to only 1/6 of the gravity we experience on earth.

How will this affect a person on the surface of the moon? To begin with, someone who weighs one hundred twenty pounds on the earth will weigh 1/6 as much or just twenty pounds on the moon. He will be able to jump six times higher than the same jump on the earth. And, lifting a one hundred twenty pound object on the moon will take no more effort than lifting a twenty pound object on the earth.

So far our lunar examples have been related to weight and an object's weight on the moon is due to the moon's gravity. What about mass? Well, as you now know, mass does not change regardless of where an object or a person is in the universe. Since mass is equivalent to weight on earth, an object on the moon will *appear* to have six times its normal earth mass. Although that one hundred twenty pound object will feel like twenty pounds, its movement will appear in slow motion. Why? Because the same amount of force is still required to move it. That jump to six times normal height will also appear in slow motion, but the impact will be the same as it is on earth.

How about your weight elsewhere in our solar system and beyond? Remember that your weight is due the gravity produced by an object and its gravity is a result of its mass. On both Mars and Mercury, that 120 pound earthling will weigh about 45 pounds. On Pluto it is reduced to just 8 pounds and on Jupiter it increases to a whopping 304. On our sun we will seem a bit over weight at a little over 3200 pounds and on one of the larger stars we will top 156 million![30]

## Einstein's Theory of Gravity

In the early 1900's Albert Einstein literally pulled the rug out from under our understanding of gravity when he introduced a fourth dimension into the equation. According to his theory of relativity, gravity causes time to slow down. Because of this Einstein visualized gravity as a force that occurred in four dimensions as opposed to the three dimensional model of Newton. That fourth dimension is time. Newton's model is still accurate for bodies with weak gravitational fields. For example, the

[29] If you live along the coast, you may be interested in how the moon's gravity (and sometimes that of the sun) causes our tides to rise and fall. You will find an excellent presentation at www.class.unl.edu/geol109/tides.htm

[30] If you would like to see your own weight at various places go to www.exploratorium.edu/ronh/weight

planets in our solar system qualify. But, when stronger fields, such as that of a collapsed star, are involved Einstein's theory prevails.[31]

## Motion In More than One Direction

Except for a brief example of the earth's orbit about the sun, our discussion of motion has centered around a single force that propels a body in one direction only. Many events, both on earth and in space, are the result of two or more motions occurring simultaneously.

This was a difficult concept for many early scientists to accept. One of the reasons that Copernicus' theory (that the earth orbits the sun) was rejected was because in order to explain the occurrence of night and day, the earth would also have to rotate about its own axis.[32] Many thought this impossible because an object thrown straight up would not land in the same place from which it was thrown. Instead it would land some distance away because the earth's surface would have moved while it was in the air.

Both Copernicus and Galileo believed it was possible for a body to possess two different motions at once. An object thrown into the air not only moves up and down but also moves with the earth. Obviously this is true or we couldn't toss a bag of nuts across the aisle of a moving airplane and expect it to reach our intended recipient. Actually this may not be a good example because some of us cannot do this in an airplane sitting at the gate. Maybe a better one is that the flight attendants could not pour coffee because no one would know where to hold the cup.

A simple example of *two motions* resulting in a *third overall motion* is the trajectory of a bullet fired from a rifle. When a rifle is fired, the powder ignites and accelerates the bullet down the barrel. Once the bullet exits the muzzle it is no longer accelerated because there is no longer a charge behind it. Immediately the bullet begins to drop even as is speeds away from the rifle. The outward motion is due to the force of the powder charge and, of course, the falling motion is due to gravity. The *resultant* motion is a smooth downward curve that starts at the rifle's muzzle and ends at the target.

This resultant motion is known as a *vector*. If we know the velocities of two motions and the angle between them, it is relatively easy to calculate the resultant velocity (vector). It is the use of vectors that allows a naval gunner to hit a target thirty miles away and NASA to launch a spacecraft into orbit.

How far a bullet travels in a unit of time depends upon the force of the powder charge behind it and how long it is subject

[31] Even our space program uses Newtonian theory for their calculations. Unfortunately they sometimes don't use the same units of measure!

[32] Aristotal's belief that the sun orbited the earth easily accounted for periods of light and dark. Since the earth was stationary, light occurred when the sun was in view and night fell when the sun circled over the horizon.

to that charge.[33] How quickly it falls, however, is quite straight forward. Newton found that, near the surface of the earth, the acceleration a body experiences due to gravity is equal to 32 feet/second/second.[34] If you will recall our discussion of acceleration, this translates to a velocity of 32 feet per second for each second that it falls. At the end of one second it is falling at 32 feet/second but since its initial velocity was 0, it traveled only 16 feet. At the end of two seconds it is falling at 64 feet/second and dropped a total of 48 feet. Therefore the bullet, regardless of its velocity, will fall 16 feet in one second. If we aim a rifle horizontally, sixteen feet above level ground and fire a shell that creates a muzzle velocity of 600 feet/second the projectile will hit the ground 600 feet away. This assumes, of course, that we neglect any resistance offered by the atmosphere.[35]

Suppose, during the example above, we experience a strong wind that is blowing ninety degrees to the path of the bullet. What will the resultant motion be in this case? Before we had two separate motions resulting in a third. When we add a cross wind, we now have three separate motions (forward, down, sideways) that when combined result in a separate, fourth motion.

**Coriolis Force**

I said earlier that one of the reasons a rotating earth theory was rejected is because an object thrown into the air would not land from whence it was thrown. In other words, two motions (up/down and rotation) would result in a third motion. Actually there is an instance when this will occur; however, the ancients knew nothing of it at the time! The Coriolis force was first described by the French mathematician Gaspard Coriolis in the early nineteenth century. It is something we call an apparent or false force and, although it seems very real, it is a function of the earth's rotational velocity. It is yet another example of resultant motion.

The earth rotates to the East at a fairly constant angular velocity (360 degrees or one full rotation every 24 hours). Different latitudes, however, experience different linear velocities (feet traveled per rotation) because of differences in the earth's diameter (and hence its circumference) at those latitudes. For example, a point on the equator travels quite a bit farther in a day than one at the latitude of London. If I were to toss a ball upwards into the air from either of these locations, it would fall back to earth in the very same location. If, however, I toss it toward London from a point on the equator that is due South, and with sufficient force for it to reach London, it will not land there. In fact, it will land somewhere in central Europe!

[33] The force of the charge depends on the quantity of powder and the duration depends upon the length of the barrel. Assuming the same cartridge is used in a rifle and a pistol, the one fired from the rifle will travel farther because it is in contact with the barrel for a longer period of time and therefore accelerated to a higher velocity. That is why battle ships had those long guns. We will cover this in more detail in Chapter 2 when we discuss work and energy.

[34] This assumes a vacuum but its pretty close for the first couple of seconds.

[35] Go to http://www.glenbrook.k12.il.us/gbssci/phys/mmedia/vectors/hlp.html for a view of a cannon ball fired horizontally from a cliff

The reason for this discrepancy is credited to the Coriolis force. Actually it is due to the higher linear speed of the earth at the equator compared to that of London. When I toss the ball, it leaves my hand heading due North at the velocity necessary for it to land in London. But in addition to that Northern velocity it also has an Easterly velocity equal to the point on the equator where I launched it. Since that velocity is much greater than that of a point in London, my toss will veer to the right as it heads north. In other words London is just not keeping pace with the Easterly travel of my ball. That same toss made from London, due South, towards me on the equator will land to my left by about the same amount. The Coriolis force does not require a great distance to demonstrate its effect. Naval and artillery gunners must correct their calculations when firing just a few miles in a Northerly or Southernly direction.[36]

**Orbital Motion**

The earth, our moon, and all of the other major bodies in the universe move about via something we call orbital motion. Orbital motion is another kind of resultant motion that arises from two separate motions.

The moon circles the earth at a relatively constant speed.[37] Its velocity, however, is changing constantly because its circular travel requires its direction to change continuously. What keeps the moon in orbit? Why doesn't it come crashing down to earth or fly off into space? The answer, of course, is that its resultant motion keeps it there.

At any instant in time the moon's inertia is trying to move it in a straight line. If it were to continue in a straight line it would leave its orbit and fly off into space. But, at the very same instant the earth's gravity, which is in action at a ninety degree angle to the moon's straight line path, is trying to pull it to earth. If gravity were successful it would bring it crashing to the earth.

Fortunately for we earth dwellers, what happens is something in between. At any instant in time the moon's velocity moves it forward a bit while in the same instant the earth pulls it down a bit. This, of course, explains why it doesn't fly off into space but why doesn't it eventually fall to earth? Well, since the earth itself is a sphere its surface falls away from the moon by the same amount the moon falls toward the earth. The result is an almost circular orbit with the moon continuously falling and the earth's surface continuously retreating at the same rate.

Satellites that circle the earth do so in a similar manner. The difference is that their smaller mass (lower inertia) and closer proximity (not as good a vacuum) causes their velocity to diminish over time and fall back to earth. Fortunately most burn up due to friction upon entering the earth's atmosphere.[38]

[36] Go to http://www.windpower.dk/tour/wres/coriolis.htm for a good demonstration. Click on the image to restart the action.

[37] Actually its orbit is an ellipse which causes its speed to vary slightly

[38] For an animated look at an orbiting satellite where you can adjust the eccentricity of its elliptical orbit go to www.ronkurtus.com/physcin/orbit1.htm

Earlier, we spoke of the "weightlessness" one experiences when orbiting about the earth. I suspect that from the paragraphs above you now know that our astronauts are not truly floating but, like the moon, *falling* at the same velocity as their spacecraft. This gives the appearance of weightlessness, but were their craft to halt in its orbit, it and its inhabitants would suddenly "gain" weight and plummet toward the earth. If it did not, we would still have a bunch of very old astronauts up there somewhere.

In our introduction, I mentioned that ski jumping would not be a very popular sport if one's impact with the ground were due merely to the height of one's jump. Although it is not truly orbital motion, the ski jumper experiences something very similar for a short period of time. If you take a careful look at the hill side immediately following the end of the jump, you will notice that it recedes ever so slowly. In fact, for a while, it recedes just slightly more than the jumpers fall. At some point the two paths become almost parallel and the jumper lands with almost no impact at all. The resultant motion is similar to orbital motion in that the hill side is falling away at almost the same rate the jumper is falling to the earth. Were his landing zone horizontal, the impact of his landing would do great bodily harm!

**Summary**

So what have we learned so far. Well, we started out by defining physics and learned that it is the most basic of all the sciences even though many still think it is something to be studied later. We took a look at the Scientific Method and its most important tool, the hypothesis. We now know that it is this process that not only separates science from non science, but also maintains the integrity of the findings of all true science. We learned of the difficulties faced by early physicists due to the lack of even the simple tools that could allow them to test their theories. We have seen that the lack of even simple experimentation by these early scholars and the influence of the church slowed the learning process and inhibited the advancement of certain theories for many centuries.

We started our study of motion by reviewing some of the studies of Galileo and how he was able to demonstrate that all objects, regardless of their weight, fall at the same rate. Another important contribution was his finding that the acceleration a falling body experiences is constant throughout its fall. We also compared speed with velocity and then discussed acceleration, the rate of change in velocity. After Galileo we moved on to Newton and his classic laws of motion. Here we learned the three basic laws that define the relationships between both moving and stationary objects and the forces that act upon them. We continued with a discussion of the two basic types of motion, translational (linear) and rotary (angular).

Next, we began our discussion of gravity by saying that we really cannot define it. We know that it is due to an object's mass, we can describe its effects, and predict its consequences but that is about the extent of our current understanding. We reviewed some of the preliminary studies of planetary motion performed by Brahe and briefly reviewed the laws Kepler developed from these data. We followed with an explanation of Newton's most famous discovery, his universal law of gravity, and its direct and inverse square relationships. We also took a look at exponents and how they can unexpectedly magnify the effect of some change.

We continued our discussion of gravity by comparing weight and mass. We said that mass is an intrinsic quantity and is invariable while weight is due to gravity. We compared the effects of gravity at several places on the earth's surface and also within. Additionally, we used several examples to show that mass is totally independent of gravity and weight. We also explored gravity, weight, and mass on the moon and several other bodies in our solar system and beyond.

Our final topic in this section was motion in more than one direction. We used an example of a rifle bullet to illustrate the resultant motion that arises when two separate motions are combined. We discussed the Coriolis force and how it is not a true force but merely a resultant motion due to the earth's rotational velocity at different latitudes. Finally we discussed orbital motion and the resultant motions of planets and satellites.

In the next chapter we will take our new understanding of motion and apply it to work and energy.