Chapter 11: Newton's Laws of Motion

Aristotle and the History of Motion

After we have learned how to describe motion mathematically, the next question that comes to mind is why do things move? It is time to turn our attention to the causes of motion.

The actual cause of motion is a question that was pondered many years ago and the history of the development of a theory of motion is actually a very interesting one. Occasionally in science, and especially in Physics, the development of a theory takes on a sort of dramatic effect when told and this story is one of them.

In the time of the Ancient Greeks, a man named Aristotle rose to fame as a philosopher. The Greek culture had a great respect for abilities of the mind, such as philosophy and rhetoric, to a degree that has not been seen since. Aristotle wrote on many subjects and his writings survive to this day. One of the subjects he wrote extensively on was motion.

Aristotle believed that the universe consisted of two separate spheres, the heavens and the earth. The heavens were the perfect realm and the earth was the "corrupt" realm, sort of a good/bad dichotomy. According to his theory, the heavens contained the planets and the stars and the earth was made of fire, water, air and earth (or dirt). Everything on the earth was a mixture of those four elements. In the heavens, everything moved in circles (since the circle was always considered the perfect shape) but on earth things were different. Each of the four elements had their own sphere and if things were perfect, the elements would exist unmixed in these concentric spheres. But things on the earth were not perfect, they were corrupt. Thus the spheres were actually intermingled and earth existed alongside fire, water and air. When an object contained a mixture of elements, the object would naturally try to go "home" to the sphere of the most prominent element. Thus smoke (mostly air with a little earth thrown in) would naturally rise to the sphere of the air and a rock (earth) would fall towards the sphere of the earth. In short, everything wanted to go home. This type of motion was called "natural motion": circles in the heavens, going home in the corrupt earth.

Motion on the earth could be changed if a force was involved. You could throw a rock up in the air, for instance, and cause it to go away from the sphere of the earth. Aristotle said that any motion that was not natural required a force; someone pushing or pulling it.

Although today Aristotle's view of motion seems strange, you must look back with the eyes of an ancient Greek and realize that Aristotle's theory was both beautiful and philosophically sound. It contained one major flaw, however, and that was that in many cases it did not match the reality of how things moved. To the Greeks, this was no big deal. They abhorred experimenting and felt that the truth could be reached simply by thought and that you should never have to condescend to checking your theories against reality. There was some motion that Aristotle's view couldn't explain satisfactorily, but improvisations of sorts (which were very complicated and in fact ridiculous) were used to cover these areas.

For many years after Aristotle, his theories disappeared from the Western world, but were recovered and translated into Latin beginning in the 1100's. The process of translating and understanding the ancient works lasted for over 200 years. At this time, the Roman Catholic Church was in power and the Pope was the leading authority. At first, the theories were held as heresy, since they came from a pagan mind before the birth of Christ, but later (through the works of Augustine and others) they were reconciled with the church's theory.

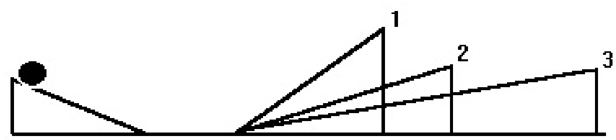
Once again, many years after his death, Aristotle rose to fame and power. Once his theories became part of the church's teachings, Aristotle became the supreme authority on many subjects. The best way to describe the hold of Aristotlean teaching over the minds of this time would be through a sort of exaggerated example. Imagine going to school and your only textbook in all your classes was written by Aristotle (except math and religion). Imagine that a man's intelligence was judged not on his intellectual ability, but by his accuracy in quoting Aristotle on a subject. Aristotle was "the man". If you doubted him you were crazy (and since he was now so tied to the church, you were also a heretic and a legion of Satan). Needless to say, Aristotle's view of motion was accepted without question.

Why was this pagan's view of the universe accepted by the Roman Catholic Church? The answer to that lies in two interesting aspects of this theory. The first is that in the Aristotlean view, the earth was the center of the universe. Obviously the church supported (or wanted to support) that view since it matched the biblical ideas about humans being God's most important creations. Secondly, and much more importantly, the good/bad dichotomy mentioned earlier fit in exactly with what the church was teaching. Aristotle said the heavens were perfect and the earth was "corrupt". The church said God in heaven was perfect and the earth became corrupt when Adam and Eve bit the apple of knowledge. In short, Aristotle's view of motion supported the belief in original sin (which was one of the prime, essential beliefs of the Roman Catholic Church). Religion, politics and philosophy make strange bed-fellows. Aristotle became so enmeshed in Catholic teachings that to doubt Aristotle meant to doubt the Pope and thus to doubt God.

Galileo and Motion

The first person to doubt Aristotle's view of motion (and be taken seriously) was Galileo Galilei. He was a supporter of the Copernican theory of the solar system that said the sun was the center of the Universe. If this were true, Aristotle's view of motion could not be correct. For one thing, the earth was no longer the center and for another, if the earth revolved around the sun it would have to be doing one of two things. Either moving on its own in a perfect circle (oh no, the corrupt earth moving perfectly) or it would have to be pushed, since its motion was unnatural. This lead Galileo to carry out a simple experiment (Aristotle is turning over in his grave right now).

EX CJ.) Consider Galileo's incline plane experiment, where a ball was rolled down one incline and allowed to roll up another. On the three ramps below, how high would it rise? What would happen if there was no ramp?



Galileo carried out this experiment, but realized something that Aristotle did not. He realized that friction was a problem. To counteract this he attempted to make the ramps as smooth as possible. It is sort of amazing just how well he did this task (according to his notes) and his ramps can still be seen today at a museum in Florence, Italy (along with his finger!).

Galileo came up with the concept of inertia. All objects have inertia and once moving, they will move continuously until that inertia is "overcome". This solved the problem of how the earth moved. Since it had inertia, once it was moving it would continue moving (there are some problems with this explanations, but we will ignore them for the moment).

Galileo's views were obviously counter to the Church's teaching. He published his paper on the motion of the earth and all hell broke loose (no pun intended). Galileo, however, was a deeply religious man and he meant no harm to the church, in fact he was trying to help them, in his own, unique way. Galileo thought (with the naivety of a child) that if he just pointed out to the Pope that the church was wrong, they would change their teachings and be a "truer and better" church. Three things happened that compounded his predicament. First, Galileo was friends with the Pope, but just before his manuscript was published, his friend died and a new Pope was elected. Secondly, Galileo published his manuscript in Italian, not Latin. Most scholarly works were published in Latin, which was only read by scholars. By writing in Italian, everyone could read his work. In a second act of his own self destruction, he wrote the book as a dialogue between the church and the "new philosophers" and called the Church's character Simplicio (akin to Stupid). Thirdly, the Church had just barely begun to recover from the Reformation. Rome had lost authority over much of the Northern lands and England and had just begun to regain its numbers and prominence. There was no way that the church could let him get away with this heresy. They were actually afraid that it might snowball into another reformation. They had been hit once and were not going to be hit again. Galileo was put on trial and forced to admit in public that his theory was wrong and the earth did not move. Because he was old, he was sentence to house arrest (instead of being put to death) which meant he had guards at his door and was not allowed to leave his house. Legend has it that he mumbled as he was being led up his steps, "Nonetheless, the earth moves."

Galileo died eight years later in his home, still labeled a convicted heretic. He managed, before he died, to finish his writings on motion and he had them smuggled out to Holland where they were published. We should be forever grateful for his courage and insight.

In 1993, Pope John Paul II reversed the church's teachings on Galileo , but until then he was still labeled a heretic in the Church.

It was Galileo's concept of inertia that opened the way for the complete destruction of the Aristotelian view of motion. In fact, Galileo can be said to have been the person who first opened the door and paved the way for the scientific revolution to follow. Aristotle was a dead end, as far as science was concerned and because of his credibility, science had stagnated for almost 2000 years.

The same year that Galileo died, a man was born in England who would, arguably, be one of the most important men in the history of the world. It is my belief that with the possible exceptions of Jesus Christ, Mohammed and Buddha, this one man altered the course of human events more than any other man, battle or government. The man was Sir Isaac Newton.

When he was only twenty-three years old, he was a teacher and a student at Cambridge University. Because of an outbreak of the Black Plague, the school was closed to avoid contamination. Newton spent the break on his Aunt's farm and it was there that he first formulated the Universal Law of Gravity, began his work on inventing a new type of mathematics (Calculus) and formulated his three laws of motion that would overthrow Aristotle for good.

His works were published later and he enjoyed a popularity that was singly unique to science until that time. Newton became a sort of popular "superstar" in his own lifetime. He was admired by (almost) all and held in awe by most. If they had tee shirts at that time he would have been one of the most popular and best selling designs (a handful of other scientists have received this honor, among them Ben Franklin and Albert Einstein). Newton, however brilliant he was, was not a particularly nice man. He used his power and influence to destroy the life of a German mathematician who also invented Calculus at the same time as he did. Newton did want to share the spot light, so he accused the man of plagiarizing his work, used his fame to have him found guilty and shamed the man for life (he died in a gutter, a penniless beggar). Newton never married and died (supposedly) without ever so much as kissing a woman.

These personality quirks aside, Newton was the man responsible for the invention of Physics as we know it and his theories opened the way for all the science that was to come after. When he died he was buried at Westminster Abbey. His gravestone reads, "Let men rejoice that so great a one has existed".

Newton's First Law of Motion

The first of Newton's Laws of Motion reads,

> "Every material object continues in its state of rest, or of uniform motion in a straight line, unless it is compelled to change that state by forces imposed upon it."

Today we are used a sort of translated form of that law,

> "Objects at rest stay at rest, objects in motion stay in motion in a straight line with a constant speed unless acted on by an outside force."

The law itself is relatively self explanatory. If an object is just sitting there, it will continue to sit there unless an outside force acts on it. The second part rests heavily on Galileo's concept of inertia and the student can see that it is very much at odds with Aristotle. It says that once an object is moving, it will stay moving at a constant velocity unless something makes it stop. Aristotle, you will remember, said that if the motion was unnatural, you needed a force to move. <u>Newton says that you don't need a force to move once you are moving.</u>

Once the object is moving, it will resist a change in motion. Consider a cannon ball flying by you. If you want to change its motion, it requires a great deal of effort. This resistance to a change in its state of motion is what we call <u>inertia</u>. The more inertia something has, the harder it is to change its state of motion. Inertia is measured by mass and there is a direct relation. More mass means more inertia. The student should take special note of the wording in this paragraph. Mass and inertia are not the same thing, but are closely related. Inertia is a property of an object and mass is a <u>measure</u> of that property.

In some ways, Newton's first law is a restatement of Galileo's principle of inertia. It simply says that all matter has a property that causes it to continue in its motion until something from the outside affects it. Often, this law is called the Law of Inertia.

Newton's first law can also be viewed as saying that motion is inconsequential. In other words, objects can't tell if they are moving or not. When you are in an airplane, you are moving with the plane (you started moving and you don't need anything to keep you moving) thus you don't really notice the motion. The fact that you can't notice your motion is very strongly related to the concept of a frame of reference (although the connection requires a rather deep philosophical understanding).

To resummarize, objects will keep their constant velocity as long as they are left alone.

Newton's Second Law of Motion

The first law told us what happens to an object if no forces act on it. The second tells us what effect forces have on the motion of objects. Newton's Second Law is mathematical in nature and it explains exactly what happens when an outside force is applied to an object.

> "When a net force is applied to an object, it will cause the object to be accelerated in the direction of the force. The acceleration will be proportional to the force and inversely proportional to the mass of the object."

Translated, this says:

$$\sum \underline{F} = m\underline{a}$$

This is another example, like the conservation of energy, of a law that carries with it incredible beauty and power. In fact, all we will be doing for the next month or so will be examining some of the consequences of this law. We could spend two or three years on this one law alone and still have much ground to cover before we exhausted the possibilities.

A few things should be noted before we proceed to examine exactly what this law means. The first thing we need to do is to define a force, since this our first real encounter with forces. The easiest and best definition of a force is: a push or a pull. The only better definition would be to use the law itself as a definition and say that a force is a phenomena that causes a change in the state of motion of an object (this is actually the proper way to do it). Forces are measured in (appropriately) Newtons, where 1 N = 1 kg.m/s^2. The second thing to do is define the $\sum$ sign. It is the Greek letter sigma and it stands for the summation. In other words, you add up all the forces and the sum of the forces equals mass times acceleration. Thus if many forces act on an object, we must add them together as vectors before we use the law. Notice if two or more forces add together to equal zero, then the acceleration must be zero. Often $\sum \underline{F}$ is called the net force (total force). If the forces add up to zero they are called balanced, and if they don't they are called unbalanced. The last note to make is that this is a vector equation. It states that the direction of the force is the direction of the acceleration. If the force points north, the acceleration must point north. Notice it does not say that the object moves in the direction of the force, only that it accelerates in the direction of the force (can you think of an example where the force is not in the direction of the motion?).

What this law really says is that if there is a net force, there is an acceleration. If there is not net force, there is no acceleration. If there is no acceleration, there must be no net force (no unbalanced forces) and if there is an acceleration, there must be a net force.

Newton's Second Law (of which the first law is simply a special case [why?]) tells us that motion does not need a force, acceleration does. It tells us that motion is inconsequential, acceleration is not. Going back to our plane example, when you ride in the plane, you don't notice when you are moving (since you don't need a force) but you do notice when you are accelerating, because you do need a force in those cases.

To sum up the second law, a force is required to speed up, slow down or change direction (cause acceleration) of an object.

Before we do any examples, we should first mention an important distinction. There is a difference between mass and weight. Mass is a measure of the amount of matter in an object (or alternatively, a measure of an objects resistance to a change in its state of motion, a measure of an objects inertia) whereas weight is a measure of the force of gravity on an object. Thus weight is measured in Newtons and mass in kilograms. The weight of an object is given by:

$$W=mg$$

where m is the mass and g is the acceleration due to gravity at that particular location (9.8 m/s^2 at the surface of the earth). With this knowledge we can see that by using Newton's Second Law and substituting the weight for the force;

$$W=ma$$

$$mg=ma$$

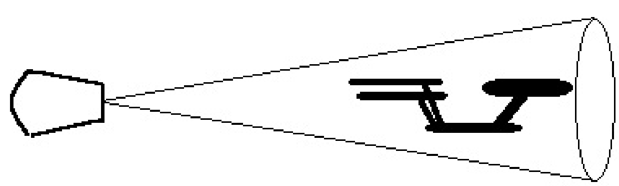
$$g=a.$$

Since the masses canceled, we know that the mass of the object has nothing to do with its acceleration. Therefor, all objects accelerate at the same rate. (In reality, there is a philosophical problem with canceling the masses here. The m in mg stands for an objects "gravitational mass", which is a measure of the amount of material that is affected by the force of gravity. The m in ma is the "inertial mass" which was discussed earlier. If they are the same (and all experiments point to them being so) then they can cancel. If they are for some reason not the same, they will not.) A conceptual understanding of why the masses cancel and why the acceleration is the same is helpful and enlightening. We might think heavier objects fall faster because gravity pulls on them harder. However, heavier objects have more inertia and thus are harder to get moving (they put up more resistance to falling). These two factors exactly cancel each other out, giving the same acceleration all the time.

Let us now do some very simple examples of using Newton's Second Law.

EX CK.) Suppose you are in an accident at an intersection. You were originally going 35 mph (15 m/sec) when a car runs a stop sign in front of you. You hit the car in the side and your car stops in 0.7 sec. What force would you need to give with your arms (if you weren't wearing a seat belt) to give you the same acceleration as the car (to hold you in place). Take your mass to be 70 kg.

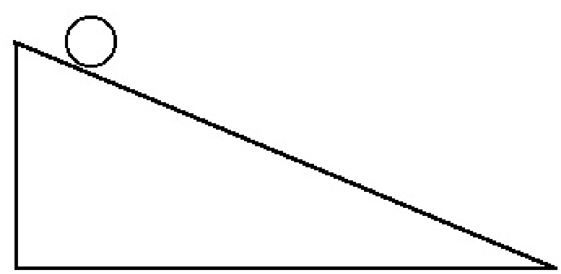
EX CL.) During a battle with Romulan warships, the USS Enterprise loses it's engines. If they are originally 20 km away from the Romulan ship and coasting at a speed of 1700 m/sec away from the Romulans, will Jean Luc (or Kirk) and the crew escape the Romulan tractor beam that can pull with a force of 8.71×10^8 N and has a range of 40 km? Assume the mass of the Enterprise to be 1.3×10^7 kg.



Besides being able to be done in a multitude of manners, the last problem contains an interesting error. If the problem were carried out in real life, it would not work out the way we calculated. I leave it to the student to determine why it couldn't work. If you have difficulty now, keep it in the back of your mind as we discuss the third law. After that, you should be able to answer it easily.

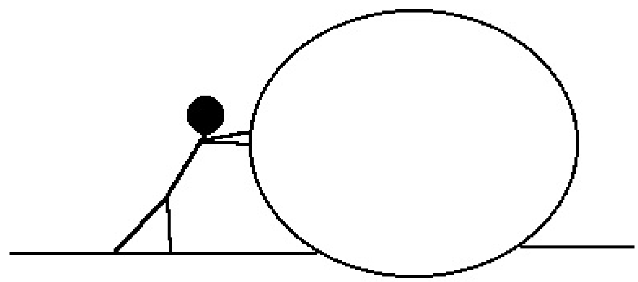
Conceptual applications of the second law are very useful to gain some practice inferring information and predicting outcomes. The examples below require you to use F=ma to determine some information which is not specifically spelled out.

EX CL.) Consider the ball rolling down an incline plane as shown below. What forces act on the ball? What is the direction of the acceleration? What is the direction of the net force? What does this tell you about the forces acting on the object?



We see from the above example that we can use Newton's Second Law to infer that there must be a force other than gravity acting on the object, since its net force is down the plane and yet gravity points straight down.

EX CM.) Imagine that you push on a boulder as shown. Does the boulder accelerate? What forces are acting on the boulder?



Here we have no acceleration, thus no net force on the boulder. Since you are exerting a force on the boulder, something else (the ground) must be exerting an equal and opposite force back.

EX CN.) A car travels down a straight and level highway at a constant speed. What forces (if any) act on the car.

Here is yet another case where the acceleration is zero and thus we must have cancelling forces. It also explains why you need to keep the engine going on the highway when inertia tells you that you don't need forces to keep moving.

EX CN.) An airplane lands and comes to a stop. Where are the forces? What direction is the acceleration?

Another good example showing us that forces point in the direction of the acceleration, not the motion.

The next example is slightly tricky and we need to use a little logic to determine the answer. As you attempt to answer this question, think along these lines: Acceleration is a change in velocity, thus you can imagine the acceleration as an arrow that "pushes" the velocity from one direction to another (or as an arrow from the end of an initial velocity to the end of the final velocity arrow). If you know the direction of the acceleration, you know the direction of the force.

EX CO.) A car rounds a turn at a steady speed. Ignoring the forward thrust of the car and the backwards friction (as determined in a previous example), what other forces act on the car and in what directions?

Newton's Third Law of Motion

Now, onto the final law. Newton's Third Law reads as follows:

> "When one body exerts a force on another, the second body exerts a force equal in magnitude, but opposite in direction back on the first."

Sometimes this is shortened to "every action has an equal and opposite reaction," or as Paul Hewitt puts it in his book Conceptual Physics, "You cannot touch without being touched."

Newton's Third Law is a very powerful and interesting law, but one that is rarely truly understood. Part of the confusion arises from an incomplete understanding of forces. I implore the student to pay close attention and understand the following simple statement. It seems like common sense, but it is not.

> Every force must have a source and an object and they must be two separate things. For example, if a boy pushes a wagon, then the boy is the source of the force (the cause) and the wagon is the object (or the object being affected). In the case of gravity (or weight) of an object, say a bowling ball, the source is the earth and the bowling ball is the object. Every force must have a source and an object.

> Restated: The source of the force acts on the object. This force then exists on the object of the force.

What Newton's Third Law says is that if object A is a the source of a force on object B, then automatically there must be an equal force on object A caused by object B. If A pulls on B, B must pull on A. This tells us that whenever we see a force, there must also exist a second force. We can locate this force by switching the source and object of the first force.

This also says that every force in the universe must have a mirror twin somewhere else. Forces in the universe must exist in pairs - if you counted up the total number of forces in the universe, the answer must be even. Every force has its equal and opposite out there somewhere.

Let us take a closer look at this law.

EX CQ.) Consider the two magnets shown below, both of the same mass and size, resting on a frictionless plane. If:

a.) both magnets were free to move,and
b.) magnet A was held in place,

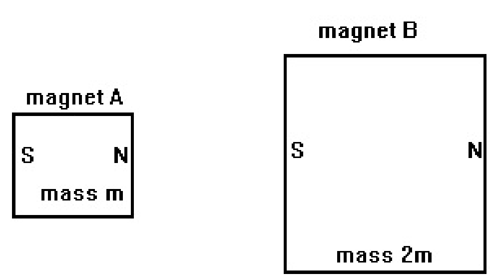
What would happen? Describe the forces and the accelerations involved.

We see from this that we already knew that Newton's Laws had to exist, it just makes sense. The same effect can be felt during a tug-o-war or when you fire a gun. We also see a very important fact that helps us to understand forces. When we are interested in the motion of magnet B, we only consider the forces acting <u>on</u> magnet B, not the forces that magnet B <u>causes</u>. In other words, we are only interested in one of the two forces predicted by Newton's Third Law. Let us look at it again, in a slightly different light:

EX CR.) Consider the two magnets shown below, resting on a frictionless plane. If:

a.) magnet B was held in place, and
b.) both magnets were free to move,

What would happen? Describe the forces and the accelerations involved.



This example brings up a point that will come back time and time again. Just because two objects have the same forces does not mean they will be affected the same way. Because of their different masses, even though the forces are the same, the effects will be different. It brings up another excellent point and that is that this pair of forces we have been discussing can never cancel each other. The pair of forces that arise because of Newton's Third Law is often called an action-reaction pair. This term, however, is somewhat misleading since it suggests that one force came first and caused the other one to appear. In fact, they must arise together, simultaneously. <u>The two forces in an action reaction pair must exist on different objects, they never exist together on the same object.</u> This is a major source of confusion for many students (a note to the astute student is in order: There <u>are</u> times when a-r forces exist on the same object. This situation arises when one has what is called an "internal force". Imagine a large system, such as a space ship. If an astronaut throws a ball in the ship, both he and the ball have equal and opposite forces on them, but he and the ball are part of the space ship "system", thus it might seem that the a-r forces are on the same system. However, in this case the forces are internal to the system and thus can have no effect on the system of the space ship. Internal forces always cancel each other out and thus we don't have to worry about them. They are rarely of real interest.)

In short, remember these things about forces and Newton's Third Law:

<u>Notes on Newton's Third Law</u>

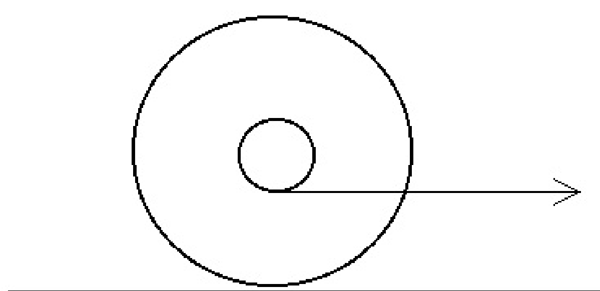
1.) The forces in an action-reaction pair are always equal.
2.) The forces in an action-reaction pair are always on two different objects.
3.) Every force has a source and an object, when we are interested in the behavior of an object, we only concern ourselves with the forces on that object, not the forces caused by that object.

Let us now consider a number of examples of Newton's Laws.

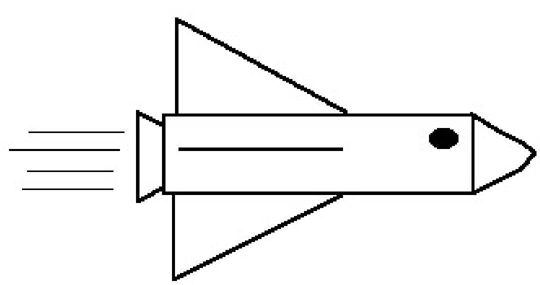
EX CS.) Imagine jumping off a chair. What force causes you to fall down? Where is the reaction force to this force? What is it's effect?

This past example shows us why we often ignore the reaction force, since it can sometimes be on an object which is of no real consequence to the problem.

EX CT.) Below is a length of string wrapped around a spool with two large wheels (the string is wrapped so that is comes off the bottom). If the string is pulled horizontally, which way will the spool move?



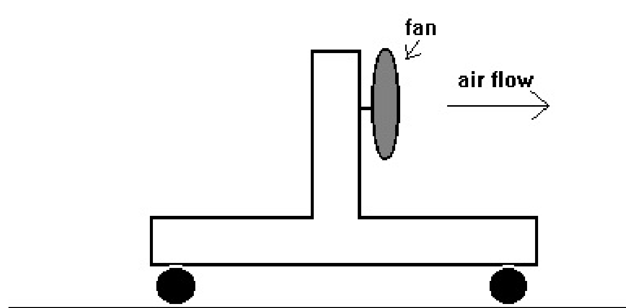
This example shows us that $\underline{F}=m\underline{a}$ tells us that the force and the acceleration must be in the same direction.



EX CU.) A space ship flies straight ahead in outer space with a steady speed. What is the direction of the force on the space ship?

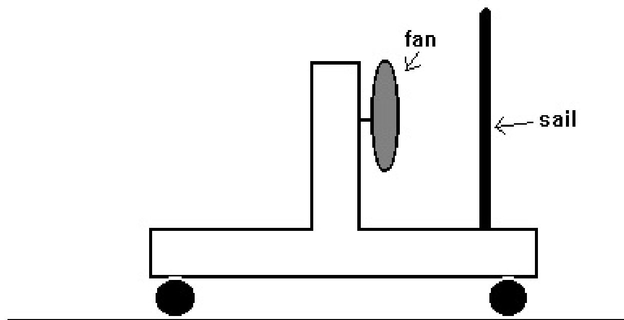
EX CV.) Explain what happens to the earth when you walk. What would occur if the earth were the same mass as you are? (Hint: Consider trying to run on a log in a lake.)

EX CV.) Below is an example of what is commonly called a fan cart. It is a low friction cart with wheels and connected to it is a fan. If the air is blowing in the direction indicated, what direction will the cart move?



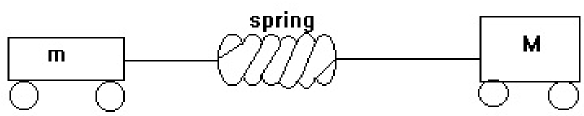
The above example illustrates how a turbine engine on a plane works (these used to be called "jet" engines, not to be confused with rocket engines). In fact, the engines on a large commercial airliner (747, DC-10) are simply large, very efficient fans.

EX CW.) What will happen to our fan cart if a small, sturdy sail is fastened in front of the fan?

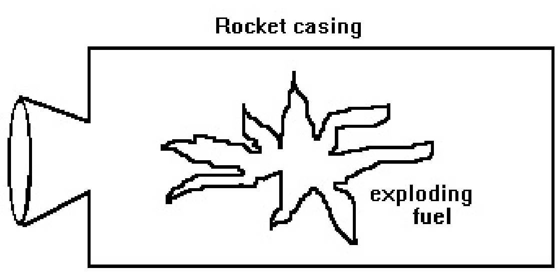


These past examples show us the importance of focusing on what exactly is the object of each and every force and they also show us that for forces to cancel, they must be on the same objects. The second cart example is interesting in that is shows us to question our assumptions at all times. It is natural to assume that the forces on the sail and the fan are equal and will thus cancel, but in fact they are not equal and thus do not cancel. A similar mechanism is used to bring an airplane to a stop during landing. When it touches the run way, it needs a backwards force to acquire its backwards acceleration to stop. Instead of running the fans in reverse, a "sail" of sorts is dropped on the back of the engines to divert the air flow towards the front of the plane.

EX CX.) Discuss the forces, accelerations, and energy changes that go on in the system below. The system consists of two carts on a frictionless surface that are connected by a spring. The carts are pulled apart and then released. (m<M)

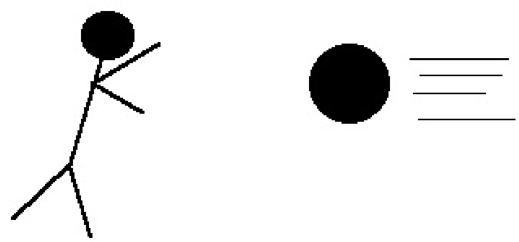


EX CY.) Explain how a rocket engine works in terms of Newton's Third Law. Usually, a rocket engine consists of a sturdy container with an opening in one end. Inside the container, fuel is ignited and it explodes.
Compare this example to the case of inflating a balloon and releasing it without tieing the end.



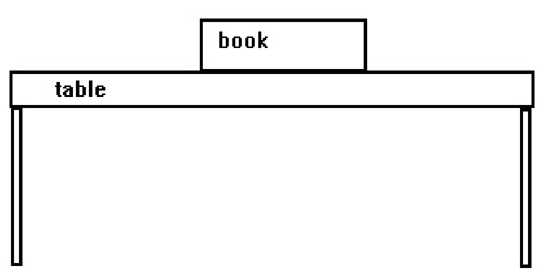
Thus we see that the principle behind a rocket engine is actually very simple (the implementation and efficiency is another story), and we see how rockets don't "push off" the launch pad, they don't really need a launch pad at all. The fuel pushes the engine up and the engine pushes the fuel down and out.

EX CY.) Describe all the forces and effects on the motions of an astronaut catching a ball in outer space. Explain these forces by breaking the situation into three different situations; before the catch, during the catch, and after the catch.

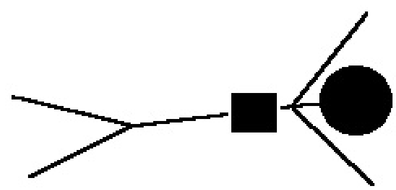


The middle situation, during the catch, is a good example of internal versus external forces. There are no external forces in the situation (if the system is both the ball and the astronaut) but there are internal forces and the <u>overall</u> motion is unaffected. If the system is either just the ball or just the astronaut, then there are external forces and their motion is affected.

EX CZ.) Label all the forces on a book sitting on a table and identify their reaction forces.



EX DA.) Explain what happens when a skydiver jumps out of a plane and eventually reaches terminal velocity (a speed after which they will fall no faster). Draw a graph of v vs t for the skydiver and a vs. t. (You need to know one further piece of information to understand this problem; the force of air resistance increases as the velocity increases.)



Now that we have completed our discussion of Newton's Third Law, the student should go back to the "Star Trek" problem and see if they can do the problem correctly with their new found knowledge.

Before we leave this section, I would like to take a moment and remind the student just how important these laws were in the development of Physics. These three laws overturned the great oppression of Aristotelian thinking that had kept science stagnant for 2000 years (with all due respect to Aristotle, he was one of the first "modern" thinkers and experimentailsts. He was one of the only Greeks that really looked at nature. However, the effects of his works in later years actually served to hold back scientific thought.). It might not be obvious to the student, but they counteracted Aristotle in two ways.

First, along with Galileo's concept of inertia, they showed that it does not take a force for an object to move, it only takes a force for an object to accelerate. Forces don't cause motion, they cause acceleration.

Secondly, by showing that the earth is not "corrupt", they united the heavens and the earth. This was monumental. Before Galileo and Newton, no one ever believed that the laws that applied to the stars were the same as those that applied to the earth. It was a revolutionary concept to think of Natural Laws as "universal". This contribution was best expressed in his Universal Law of Gravitation, but his Laws of Motion helped to further this idea.

A final comment, before you begin the exercises. Earlier it was mentioned that frames of reference were essential for discussing motion. Although they do not appear directly in Newton's Laws, do not think he was unaware of them. In fact, he even considered creating a fourth law of motion which discussed frames of reference, but later removed it from his manuscript.

Assignment #11

1.) If a body is acted on by only two forces and is accelerating, which of the following must be true?
a.) The body cannot move with constant speed.
b.) After the first instant, the velocity can never be zero.
c.) The sum of the two forces cannot be zero.
d.) The two forces must act in a straight line.

2.) A force of 10 N acts on an object and accelerates it from rest at a rate of 4.0 m/sec^2.
a.) What is the mass of the object ?
b.) What is its weight ?
(N2)

3.) If a 35 kg. object is accelerated from rest by a force of 4 N for 35 sec., what will be its velocity at the end of this time period ? (N3)

4.) A rocket accelerates to 1500 m/s in 2 sec.
a.) What is the acceleration (in m/sec^2) ?
b.) What force is required if the rocket has a mass of 500 kg. ?

5.) Imagine an experiment where a neutron is fired at an atom and captured by the nucleus. Assume the force that captures the neutron only exists only inside the nucleus. As the neutron enters, it is attracted to the center, and then pulled back as it tries to leave on the other side. Considering only the time during which it is pulled back,
a.) What acceleration does the neutron experience ? (give your answer in units of "g's")
b.) What is the magnitude of the force, presumed constant, that acts on the neutron ?
Use the following information: neutron mass = 1.67×10^{-27} kg, diameter of nucleus = 5×10^{-15} m, speed when it passed the center = 2×10^{7} m/s

6.) Suppose that Jim-Bob is cruising in his pick-up on Northwest Highway at a velocity of 32 m/sec when he sees one of Dallas' finest parked on the side of the road. Immediately Jim-Bob slams on his brakes. If his brakes can exert a force of 4000 N and his truck has a mass of 2000 kg, will Jim-Bob be under the legal speed limit of 45 mph in the three seconds it takes for the officer to put down his coffee and turn on the radar ? (N9)

7.) If you have a mass of 70 kg, the earth pulls down on this mass in the form of gravity. By Newton's Third Law, you also pull up on the earth. When you jump off a chair the earth gives you an acceleration of 9.8 m/sec^2. What acceleration do you impart to the earth ? (N6)

8.) Suppose you jumped off a chair (upwards) and landed on the ground. Make a graph of force versus time, acceleration versus time and velocity versus time for this event. The time should begin an instant after you left the chair and end a second after you hit the ground.

9.) Mr. Ed (the talking horse) is urged to pull a wagon. Ed refuses to try, citing Newton's Third Law as a defense. The pull of the horse on the wagon is equal but opposite to the pull of the wagon on the horse. "If I can never exert a greater force on the wagon than it can exert on me, how can I ever start the wagon moving ?" asks the bewildered horse. In other words, if the forces are equal but opposite, why don't they always cancel out and stop the wagon from moving ? How would you reply to Ed?
(also, how did they make his lips move in the TV show?)

10.) Consider a bullet being fired from a gun into a thick block of wood. In the barrel the bullet is suddenly accelerated in the first few centimeters and then the acceleration dies off quickly, stopping when the bullet leaves the barrel. The bullet travels straight (ignoring air resistance and gravity) and then imbeds itself into the wood, coming quickly to a stop a few centimeters into the target. Draw a rough graph of acceleration versus time, force on the bullet versus time, and velocity versus time for the path of the bullet. On each graph, label the end of the barrel point A, and the point where it enters the wood point B.

11.) Suppose two men are engaged in a version of tug-of-war where they both sit on skate boards (no friction)and try to pull each other so that they meet somewhere in the middle by use of two ropes. Each has rope tied to the belt on which the other person pulls. The loser is the one that ends up having moved the furthest distance when they meet. If they are 10 m apart at the start and Chuck, who has a mass of 60 kg, pulls with a force of 10 N and Linus, who has a mass of 90 kg, pulls with a force of 7 N, who will win ? (support your answer by explaining why)
b.) How far will the loser have moved ?
c.) Is this a fair game ? Why or why not ?

12.) A rambunctious lad falls overboard from his row boat. A friend throws him a rope when he is 6 m from the boat and begins to pull him in with a force of 75 N. If the boy in the water has a mass of 65 kg and the other boy combined with the boat has a mass of 190 kg, how far from the starting point of the boat will they meet (assume that friction will affect them equally, thus can be ignored - a terrible assumption, but one we will improve upon later)? (N10)

13.) Decipher: "Individuals who make their abode in vitreous edifices would be advised to refrain from catapulting petrous projectiles." (DNCTHWG)

Lab #8 - Newton's Second Law

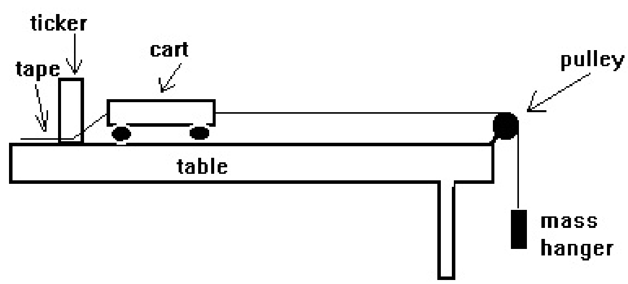
In this experiment we will attempt to verify Newton's Second Law of Motion. This law states that the sum of the forces on an object is equal to the mass time the acceleration of the object. Mathematically:

$$\Sigma \underline{F} = m\underline{a}$$

The set up that we will use is pictured below. We will apply different forces to a kinematics cart by means of masses suspended by a string and attached to the cart via a pulley. We will then use a ticker and ticker tape to analyze the motion of the cart as was done in lab #1.

Procedure:

1.) Set up an incline plane track and level it to the best of your abilities (with a bubble level). Attach a pulley and set up the cart and ticker as shown below.



2.) Place 400 g of slotted masses on the cart. When the procedure calls for you to put a mass on the mass holder, use the masses on the cart. It is important that the masses on the cart and on the holder add up to 400 g at all times (there is a reason for this will be apparent in a few chapters).

3.) Remove a 50 g mass form the cart and place it on the mass holder, release the cart and start the ticker.

4.) Mark the tape as 50 g, and be sure to mark which side represents the starting end.

5.) From this tape you will determine the acceleration of the cart as you did in lab #1. However, you only need to use 7 data points from the tape. You should get these data points from the entire length of the tape. When you get your data you should do a graph of position versus time squared. Assume the period of the ticker is 1/40 of a second.

6.) Repeat the above procedure four more times with different masses (however, be sure not to put too much mass, as the cart will accelerate too fast to get good readings). This should yield five separate graphs, from each graph you should determine an acceleration.

7.) Use a spring scale to measure the mass of the cart.

8.) Plot a graph of force applied to the cart versus acceleration caused. This graph will only have four points, one acceleration from each previous graph, paired with the force that caused that acceleration. Remember, the force causing the acceleration equals the weight of the masses hung on the hanger during that trial.

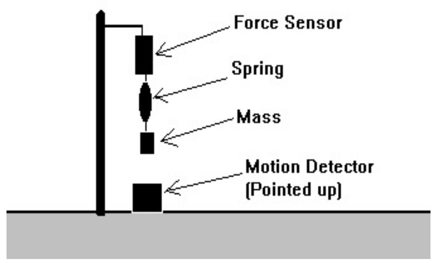
Hints on Analysis and Conclusions: What is the shape of your last graph ? Why does this make sense according to Newton's Second Law ? How could you determine the mass of the cart from your graph ? Compare the experimental mass of the cart (when you determine the mass of the cart from your graph, it will include the 400 grams from the slotted masses) with the accepted value measured in lab (percent error). How effective was this lab in demonstrating Newton's Second Law ?

Activity #11 - Forces and Springs

In this activity, you will use the computer interface to make a number of graphs of a mass hanging from a spring and bouncing up and down. By comparing these graphs, you should try to make some conclusions about the interrelationships between the variables. The varibales you will be comparing will be force of the spring, acceleration of the object and position of the object.

Procedure:

1.) Set up the equipment as shown below (set the counting rate at 50 Hz).



2.) Set the mass in motion and begin recording data from both the motion detector and the force detector. Continue for five or six full cycles of the masses motion. If the motion detector is not registering properly, put a piece of cardboard on top of the mass to give it a better reflecting surface.

3.) From this data, construct five graphs:
   1.) Force versus time
   2.) Position versus time
   3.) Acceleration versus time (turn off “connect points” to get a better graph.
   4.) Force versus acceleration
   5.) Force versus position

4.) Using these graphs and you own “little grey cells” try to determine as many conclusions as possible. In some cases it might be possible to determine equations relating the different variables.