Section 10 – Newton's Laws of Motion

Section Outline

1. Newton's First Law - The Law of Inertia
2. Newton's Second Law - $\sum F=ma$
3. Newton's Third Law - The Law of Action/Reaction

We can now thoroughly describe what do objects do? The question that remains is, "Why do they do what they do?" We will address this topic for the rest of the course. In this section the why is explained in terms of the concept of force.

1. Newton's First Law – The Law of Inertia

Here's the thing with laws: they can't be derived by manipulating some equations. They can only be postulated and then verified by lots of experimental tests. So, it takes a great deal of genius and creativity to produce and valid law. Newton first presented his laws of motion near the end of the 17^{th} century and they still are a challenge to understand. Nonetheless, Newton's Laws do a great job of explaining why objects do what they do. Our challenge is to understand the concept of force and apply these laws.

Newton's First Law - The Law of Inertia "Every object will move with a constant velocity unless a force acts on it."

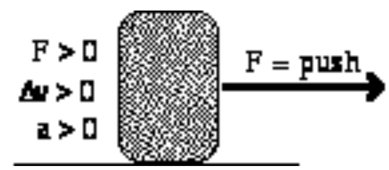
The First Law establishes two key concepts associated with the idea of force. First, contrary to nearly everyone's intuition, the "natural state" of motion of all objects is not rest, but any constant velocity. That is, objects left to their own devices don't come to rest. They keep moving with whatever velocity they had when they were finally left alone to do what they do naturally. In our everyday life, objects tend to come to rest. Newton's genius is that he realized that this was due to the action of a force we call friction. In space, far from the effects of gravity and air resistance, objects float along with whatever velocity they have from their previous interactions illustrating the First Law.

Second, force is defined to be the agent that causes velocity to change. You can tell that a force is present because the velocity of an object will change. Conversely, if the velocity of an object changes, you can be sure a force is acting.

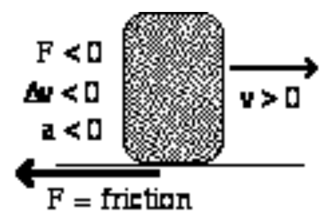
Example 10.1: For each situation listed describe the motion in terms of Newton's First Law and draw a sketch indicating the forces on the object. Ignore the force due to gravity and any forces due to surfaces. (a)A block at rest on a table. (b)The block is being pushed. (c)The block skids to rest. (d)A hockey puck sliding across frictionless ice. (e)A ball on a string twirling around in a circle.

(a)Since there are no forces acting on the block, it will maintain a constant velocity. Since the velocity starts as zero, it will remain at rest.

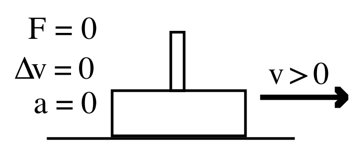
(b)While the block is being pushed, it changes its velocity due to the applied force. It accelerates.



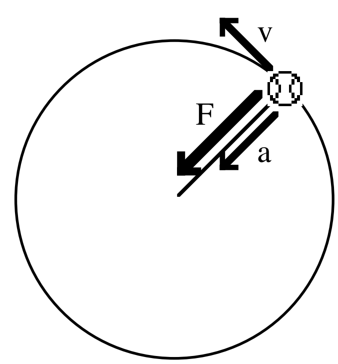
(c)The block skids to rest. This is not the result of it trying to get back to its "natural state." It feels the force of friction that changes its velocity causing it to slow down. Note that the force is indicted with a thick arrow and the velocity with a thin one.



(d)The hockey puck moves along at a constant velocity because no forces act on it. The point here is that objects can continue moving in a straight line with a constant speed even when no force acts on them.



(e)The ball must feel a force, because even though its speed doesn't change its velocity does change. Changes the direction of the velocity vector, even without changing its magnitude still requires a force. In this case, the force is exerted on the ball by the string.



2. Newton's Second Law – ∑F = ma

Now that we know what a force is and what a force does, the next issue is, "How much force do you need to change the velocity by some amount?"

> Newton's Second Law - ∑F=ma
>
> "The acceleration of an object is directly proportional to the net force acting on it and inversely proportional to its mass. The direction of the acceleration is in the direction of the net force."

This can be summarized mathematically as, $\Sigma\vec{F} = m\vec{a}$. Note the vectors, needed to keep track of the direction.

THIS IS NOT AN EQUATION! It is a set of instructions, which will produce an equation that is specific to the object and its motion that we are trying to understand. The instructions are, "Sum the forces acting on the object and set that equal to the object's mass times its acceleration." This will make more sense after we work a few examples.

The Second Law broadens our understanding of force in three ways. First, it establishes the definition of mass as a property of an object that indicates the resistance it offers to changes in motion. A small coin is easier to speed up than an automobile. We use the word "inertia" to describe the resistance an object has to acceleration. For example, a car has much more inertia than a penny. You likely have a sense that mass refers to the weight an object or that mass has to do with the number of neutrons and protons. These things are related to mass, but mass is defined to be a measure of inertia.

> *Example 10.2: Compare the mass of an astronaut on Earth with her mass in space.*
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> According to The Second Law, the mass of an astronaut is determined by how hard it is to accelerate her. It turns out that she is just as difficult to speed up or slow down out in space as she is on Earth. So, her mass is the same in either situation. Mass is a property of an object, and as such, is not subject to change depending upon where the object is located.

The second way our concept of force is expanded is that The Second Law tells us that force is a vector quantity, not a scalar. Therefore, we need to add forces using vector mathematics. Third, The Second Law enables us to calculate the acceleration of an object if we know the forces that act upon it. Recall that once we know the acceleration, the initial position, and the initial velocity, we can predict the motion of any object. Now, we have a way to find the acceleration by using forces.

> *Example 10.3: For a block at rest on a table, draw a sketch indicating all the forces on the object. Use Newton's Second Law to compare their magnitudes.*
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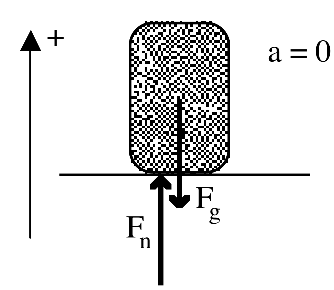
> 
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> Example 1 is actually incomplete, there are forces acting on the block. Gravity pulls the block downward and the table pushes upward. Since the block remains at rest, the net (or total) force on the block is zero. The upward (positive) force exerted by the table is called the "normal force." Applying the Second Law,
>
> $$\Sigma F = ma \Rightarrow F_n - F_g = 0 \Rightarrow F_n = F_g.$$
>
> Note that following the instructions of the Second Law leads to an equation that can be solved to answer the question. This equation only applies to this situation. It is not true in general, just for this case.

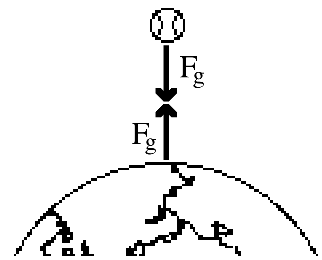
COMMENT ON PROBLEM SOLVING:
When you want to use the Second Law to attack a problem, use your sketch to identify the object to which you want to apply the Second Law. Then draw just the forces that **act <u>on</u> this object** due to other objects. Then choose a convenient coordinate system. Finally, use the Second Law to write an equation for the object.

<u>3. Newton's Third Law – The Law of Action and Reaction</u>

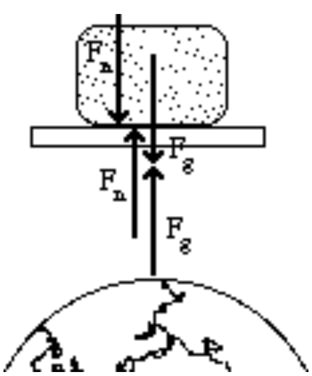
> Newton's Third Law - The Law of Action and Reaction
> "When one object exerts a force on a second object, the second object exerts an equal, but opposite force on the first object."

The Third Law completes the description of the concept of force. It does so by pointing out that force is not a property of an object, it is a mutual interaction between two objects. We never say an object "has" or "possesses" force, we say it "feels" or "experiences" a force exerted by some other object or objects. Keep in mind that the motion of an object is determined only by the forces that **act <u>on</u> the object** and not by forces the object exerts on other objects. The forces that go into the Second Law are only forces acting **<u>on</u>** the object under study.

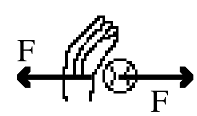
Example 10.4: For each of the following situations, list the forces acting on each object, name the object exerting the force, describe the reaction force and name the object that feels the reaction force; (a)a falling ball, (b)a block at rest on the table, (c)a fielder throws a ball.



(a)The force of gravity acts on the ball. The Third Laws requires that since Earth exerts this force, there must be an equal force of gravity that the ball exerts on Earth as a whole. Why does the ball do the falling? (Think about the 2nd Law)



(b)Earth exerts the force of gravity on the block so the block must pull upward on Earth. The table exerts an upward normal force on the block, so the Third Law requires the block to exert a downward force on the table. Are F_g and F_n and action/reaction pair? They can't be because they act on the same object, the block. Action/reaction pairs act on different objects.



(c)The fielder's hand exerts a force on the ball, so by the Third Law, the ball exerts an equal force back on the fielder's hand. Can the fielder throw it harder by exerting a force on the ball that is greater than the force that the ball exerts back on her? The fielder can throw the ball harder by exerting a greater force on it, but the force back on the hand will be larger as well. The Third Law requires that both forces always be equal. Just remember that the force of the ball makes the ball speed up, while the force on the hand changes to the motion of the hand. Forces on the hand don't make the ball go.

Example 10.5: A horse tries to pull a cart. Since Newton's Third Law requires the force that the horse exerts on the cart to always be equal to the force that the cart exerts on the horse, the total force is zero and the horse and cart can never move. Find the flaw in this argument.

Actions and reactions act on different objects. The first force acts on the cart and influences, along with other forces, the motion of the cart. This force on the cart doesn't affect the horse. The reaction force is on the horse and affects the motion of the horse. The forces don't cancel because they act on different objects.

Section 10 - Summary

The exciting news in this chapter is that we have started to answer the question, "Why do objects do what they do?" The answer is, in part, force. The concept of force was introduced by Newton using three laws:

Newton's First Law - The Law of Inertia
"Every object will move with a constant velocity unless a force acts on it."

The key concepts associated with the First Law are:

- the "natural state" of motion of objects is not rest, but motion at any constant velocity.
- force is defined to be the agent that causes velocity to change.

Newton's Second Law - $\sum F=ma$
"The acceleration of an object is directly proportional to the net force acting on it and inversely proportional to its mass. The direction of the acceleration is in the direction of the net force."

The key concepts associated with the Second Law are:

- it is not an equation, but a set of instructions, which will produce an equation specific to the object who's motion we are trying to understand.
- it establishes the definition of mass as a measure of the inertia of an object.
- force is a vector quantity.
- it lets us be able to calculate the acceleration of an object if we know the forces that act upon it.

Newton's Third Law - The Law of Action and Reaction
"When one object exerts a force on a second object, the second object exerts an equal, but opposite force on the first object."

The key concepts associated with the Third Law are:

- force is not a property of an object, it is a mutual interaction between two objects.
- the motion of an object is determined only by the forces that act on the object and not by forces the object exerts back on other objects.