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UNIT 2
(2 hours of theory and 2 hours of exercises)

Newton's First Law

In the previous two lessons we discussed the different ways by which motion can be *described* (words, graphs, diagrams, numbers, etc.). This unit (Newton's first Law of Motion) will concern the ways through which motion can be *explained*. Isaac Newton (a 17th century scientist) put forward a variety of laws that explain why objects move (or don't move)and as they do. These three laws are known as Newton's three laws of motion. The focus of the first part is Newton's first law of motion - sometimes referred to as the **law of inertia**.

Newton's first law of motion is often stated as

an object at rest stays at rest and an object in motion stays in motion with the same speed and in the same direction unless acted upon by an unbalanced force.

In other words

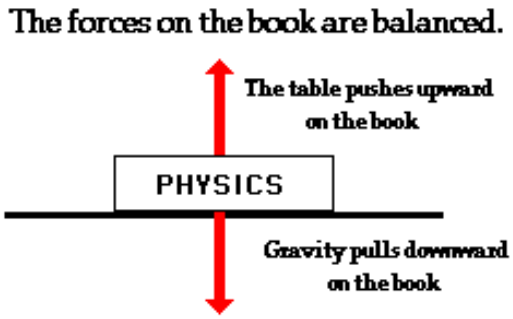
An object at rest or in uniform motion (at a constant velocity) remains so unless acted upon by an unbalanced force (net force).

Now we will see this video as far as minute 3.30

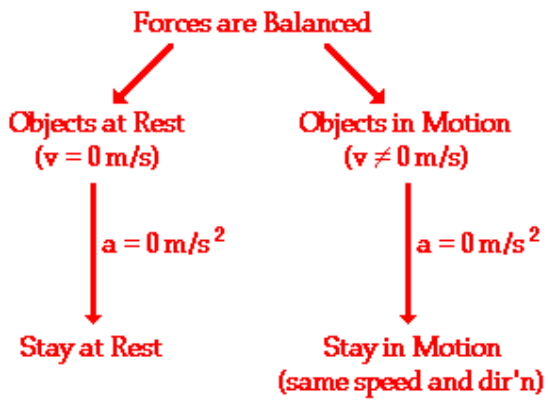
http://www.youtube.com/watch?v=M_8w-dD4RBE

This allows us to listen to Galileo's statement and Newton's statement about the law of Inertia. Then we will deal with the frame of reference and the conditions for a correct application of the law of inertia.

But what exactly is meant by the phrase **unbalanced force**? What is an unbalanced force? In pursuit of an answer, we will first consider a physics book at rest on a tabletop. There are two forces acting upon the book. One force - the Earth's gravitational pull - exerts a downward force. The other force - the push of the table on the book (sometimes referred to as a *normal force*) - pushes upward on the book.



There are two parts to this statement - one that predicts the behaviour of stationary objects and the other that predicts the behaviour of moving objects. The two parts are summarized in the following diagram.



The behaviour of all objects can be described by saying that objects tend to "keep on doing what they're doing" (unless acted upon by an unbalanced force). If at rest, they will continue in this same state of rest. If in motion with an eastward velocity of 5 m/s, they will continue in this same state of motion (5 m/s, East). If in motion with a leftward velocity of 2 m/s, they will continue in this same state of motion (2 m/s, left). The state of motion of an object is maintained as long as the object is not acted upon by an unbalanced force. All objects resist changes in their state of motion - they tend to "keep on doing what they're doing."

Suppose that you filled a baking dish to the rim with water and walked around an oval track making an attempt to complete a lap in the least amount of time. The water would have a tendency to spill from the container during specific locations on the track. The water spilled when:

- the container was at rest and you attempted to move it
- the container was in motion and you attempted to stop it
- the container was moving in one direction and you attempted to change its direction.

The water spills whenever the state of motion of the container is changed. The water resisted this change in its own state of motion. The water tended to "keep on doing what it was doing." The container was moved from rest to a high speed at the starting line; the water remained at rest and spilled onto the table. The container was stopped near the finish line; the water kept moving and spilled over the leading edge of the container. The container was forced to move in a different direction to make it around a curve; the water kept moving in the same direction and spilled over its edge. The behaviour of the water during the *lap around the track* can be explained by Newton's first law of motion.

Everyday Applications of Newton's First Law

There are many applications of Newton's first law of motion. Consider some of your experiences in an automobile. Have you ever observed the behaviour of coffee in a coffee cup filled to the rim while starting a car from rest or while bringing a car to rest from a state of motion? Coffee "keeps on doing what it is doing." When you accelerate a car from rest, the road provides an unbalanced force on the spinning wheels to push the car forward; yet the coffee (that was at rest) wants to stay at rest. While the car accelerates forward, the coffee remains in the same position; subsequently, the car accelerates out from under the coffee and the coffee spills in your lap. On the other hand, when

braking from a state of motion the coffee continues forward *with the same speed and in the same direction*, ultimately hitting the windshield or the dash. Coffee in motion stays in motion.

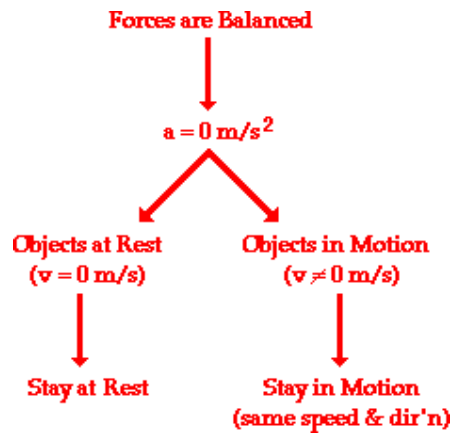
Have you ever experienced inertia (resisting changes in your state of motion) in an automobile while it is braking to a stop? The force of the road on the locked wheels provides the unbalanced force to change the car state of motion, yet there is no unbalanced force to change your own state of motion. Thus, you continue in motion, sliding along the seat in forward motion. A person in motion stays in motion with the same speed and in the same direction ... **unless acted upon by an unbalanced force** of a seat belt. Yes! Seat belts are used to provide safety for passengers whose motion is governed by Newton's laws. The seat belt provides the unbalanced force that brings you from a state of motion to a state of rest. Perhaps you could speculate what would occur when no seat belt is used.

There are many more applications of Newton's first law of motion. Several applications are listed below. Perhaps you could think about the law of inertia and provide explanations for each application.

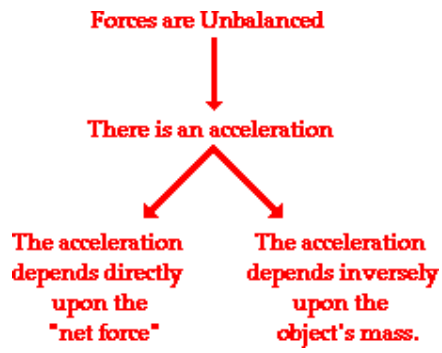
- Blood rushes from your head to your feet while quickly stopping when riding on a descending elevator.
- The head of a hammer can be tightened onto the wooden handle by banging the bottom of the handle against a hard surface.
- A brick is painlessly broken over the hand of a physics teacher by slamming it with a hammer. (CAUTION: do not attempt this at home!)
- To dislodge ketchup from the bottom of a ketchup bottle, it is often turned upside down and thrusted downward at high speeds and then abruptly halted.
- Headrests are placed in cars to prevent whiplash injuries during rear-end collisions.
- While riding a skateboard (or wagon or bicycle), you fly forward off the board when hitting a curb or rock or other object that abruptly halts the motion of the skateboard.

Newton's Second Law

Newton’s first law of motion predicts the behaviour of objects for which all existing forces are balanced. The first law - sometimes referred to as the law of inertia - states that if the forces acting upon an object are balanced, then the acceleration of that object will be 0 m/s/s. Objects at **equilibrium** (the condition in which all forces balance) will not accelerate. According to Newton, an object will only accelerate if there is a net or unbalanced force acting upon it. The presence of an unbalanced force will accelerate an object - changing its speed, its direction, or both its speed and direction.



Newton's second law of motion pertains to the behaviour of objects for which all existing forces are not balanced. The second law states that the acceleration of an object is dependent upon two variables - the net force acting upon the object and the mass of the object. The acceleration of an object depends directly upon the net force acting upon the object, and inversely upon the mass of the object. As the force acting upon an object is increased, the acceleration of the object is increased. As the mass of an object is increased, the acceleration of the object is decreased.



Newton's second law of motion can be formally stated as follows:

The acceleration of an object as produced by a net force is directly proportional to the magnitude of the net force, in the same direction as the net force, and inversely proportional to the mass of the object.

This verbal statement can be expressed in equation form as follows:

$$a = \frac{\vec{F}}{m}$$

The above equation is often rearranged to a more familiar form as shown below. The net force is equated to the product of the mass times the acceleration.

$$F = m \cdot a$$

We will now see this video from minute 6.53 as far as minute 10

http://www.youtube.com/watch?v=M_8w-dD4RBE

In this entire discussion, the emphasis has been on the *net force*. The acceleration is directly proportional to the *net force*; the *net force* equals mass times acceleration; the acceleration in the same direction as the *net force*; an acceleration is produced by a *net force*. The NET FORCE. It is important to remember this distinction. Do not use the value of merely "any 'ole force" in the above equation. It is the net force that is related to acceleration. The net force is the vector sum of all the forces. If all the individual forces acting upon an object are known, then the net force can be determined.

Consistent with the above equation, a unit of force is equal to a unit of mass times a unit of acceleration. By substituting standard metric units for force, mass, and acceleration into the above equation, the following unit equivalency can be written.

$$1 \text{ Newton} = 1 \text{ kg} * \frac{\text{m}}{\text{s}^2}$$

The definition of the standard metric unit of force is stated by the above equation. One Newton is defined as the amount of force required to give a 1-kg mass an acceleration of 1 m/s/s.

Test

The F_{net} = m • a equation is often used in algebraic problem solving. The table below can be filled by substituting into the equation and solving for the unknown quantity. Try it yourself and then use the click on the buttons to view the answers.

	Net Force (N)	**Mass (kg)**	**Acceleration (m/s/s)**
1.	10	2	
2.	20	2	
3.	20	4	
4.		2	5
5.	10		10

The numerical information in the table above demonstrates some important qualitative relationships between force, mass, and acceleration. Comparing the values in rows 1 and 2, it can be seen that a doubling of the net force results in a doubling of the acceleration (if mass is held constant). Similarly, comparing the values in rows 2 and 4 demonstrates that a *halving* of the net force results in a *halving* of the acceleration (if mass is held constant). Acceleration is directly proportional to net force.

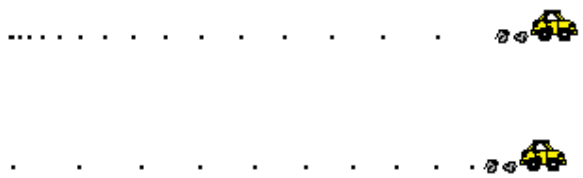
Furthermore, the qualitative relationship between mass and acceleration can be seen by a comparison of the numerical values in the above table. Observe from rows 2 and 3 that a doubling of the mass results in a *halving* of the acceleration (if force is held constant). And similarly, rows 4 and 5 show that a *halving* of the mass results in a doubling of the acceleration (if force is held constant). Acceleration is inversely proportional to mass.

The analysis of the table data illustrates that an equation such as F_{net} = m*a can be a guide to thinking about how a variation in one quantity might effect another quantity. Whatever alteration is made of the net force, the same change will occur with the acceleration. Double, triple or quadruple the net force, and the acceleration will do the same. On the other hand, whatever alteration is made

of the mass, the opposite or inverse change will occur with the acceleration. Double, triple or quadruple the mass, and the acceleration will be one-half, one-third or one-fourth its original value.

Test

As stated above, the direction of the net force is in the same direction as the acceleration. Thus, if the direction of the acceleration is known, then the direction of the net force is also known. Consider the two oil drop diagrams below for an acceleration of a car. From the diagram, determine the direction of the net force that is acting upon the car.



In conclusion, Newton's second law provides the explanation for the behaviour of objects upon which the forces do not balance. The law states that unbalanced forces cause objects to accelerate with an acceleration that is directly proportional to the net force and inversely proportional to the mass.

Gravitational force and the Newton's second law

Another means of representing the proportionalities is to express the relationships in the form of an equation using a constant of proportionality. This equation is shown below.

$$F_{grav} = \frac{G * m_1 * m_2}{d^2}$$

where G represents the universal gravitation constant

$(G = 6.67 \times 10^{-11}\ N \cdot m^2 / kg^2)$

The constant of proportionality (G) in the above equation is known as the **universal gravitation constant**. The precise value of G was determined experimentally by Henry Cavendish in the century after Newton's death. The value of G is found to be

$$G = 6.673 \times 10^{-11}\ N\ m^2/kg^2$$

When the units on G are substituted into the equation above and multiplied by **m1 (earth mass)** and divided by **d2**, the result will be **g**, so an object on the earth will be actracted by a force or in other words it will have a weight of

F= m -

g

Newton's Third Law

A force is a push or a pull upon an object that results from its interaction with another object. Forces result from interactions! As discussed, some forces result from *contact interactions* (normal, frictional, tensional, and applied forces are examples of contact forces) and other forces are the result of action-at-a-distance interactions (gravitational, electrical, and magnetic forces). According to Newton, whenever objects A and B interact with each other, they exert forces upon each other. When you sit in your chair, your body exerts a downward force on the chair and the chair exerts an

upward force on your body. There are two forces resulting from this interaction - a force on the chair and a force on your body. These two forces are called *action* and *reaction* forces and are the subject of Newton's third law of motion. Formally stated, Newton's third law is:

For every action, there is an equal and opposite reaction.

The statement means that in every interaction, there is a pair of forces acting on the two interacting objects. The size of the forces on the first object equals the size of the force on the second object. The direction of the force on the first object is opposite to the direction of the force on the second object. Forces always come in pairs - equal and opposite action-reaction force pairs.

A variety of action-reaction force pairs are evident in nature. Consider the propulsion of a fish through the water. A fish uses its fins to push water backwards. But a push on the water will only serve to accelerate the water. Since forces result from mutual interactions, the water must also be pushing the fish forwards, propelling the fish through the water. The size of the force on the water equals the size of the force on the fish; the direction of the force on the water (backwards) is opposite the direction of the force on the fish (forwards). For every action, there is an equal (in size) and opposite (in direction) reaction force. Action-reaction force pairs make it possible for fish to swim.

Consider the flying motion of birds. A bird flies by use of its wings. The wings of a bird push air downwards. Since forces result from mutual interactions, the air must also be pushing the bird upwards. The size of the force on the air equals the size of the force on the bird; the direction of the force on the air (downwards) is opposite the direction of the force on the bird (upwards). For every action, there is an equal (in size) and opposite (in direction) reaction. Action-reaction force pairs make it possible for birds to fly.

Consider the motion of a car on the way to school. A car is equipped with wheels that spin in a clockwise direction. As the wheels spin clockwise, they grip the road and push the road backwards. Since forces result from mutual interactions, the road must also be pushing the wheels forward. The size of the force on the road equals the size of the force on the wheels (or car); the direction of the force on the road (backwards) is opposite the direction of the force on the wheels (forwards). For every action, there is an equal (in size) and opposite (in direction) reaction. Action-reaction force pairs make it possible for cars to move along a roadway surface.

The Big Misconception

So what's the *big deal*? Many people have known Newton's first law since eighth grade (or earlier). And if prompted with the first few words, most people could probably recite the law word for word. And what is so terribly difficult about remembering that F = ma? It seems to be a simple algebraic statement for solving story problems. The *big deal* however is not the ability to recite the first law nor to use the second law to solve problems; but rather the ability to understand their meaning and to believe their implications. While most people know what Newton's laws say, many people do not know what they mean (or simply do not believe what they mean).

Cognitive scientists (scientists who study how people learn) have shown that physics students come into physics class with a set of beliefs that they are unwilling (or not easily willing) to discard despite evidence to the contrary. These beliefs about motion (known as misconceptions) hinder further learning. The task of overcoming misconceptions involves becoming aware of the

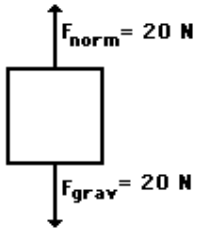
misconceptions, considering alternative conceptions or explanations, making a personal evaluation of the two competing ideas and adopting a new conception that is more reasonable than the previously held-misconception. This process involves self-reflection (to ponder your own belief systems), critical thinking (to analyze the reasonableness of two competing ideas), and evaluation (to select the most reasonable and harmonious model that explains the world of motion). Self-reflection, critical thinking, and evaluation. While this process may seem terribly complicated, it is simply a matter of *using your noodle* (that's your brain).

The most common misconception is one that dates back for ages; it is the idea that sustaining motion requires a continued force. The misconception has already been discussed in a previous lesson, but will now be discussed in more detail. This misconception *sticks out its ugly head* in a number of different ways and at a number of different times. As your read through the following discussion, give careful attention to your own belief systems. View physics as a system of thinking about the world rather than information that can be dumped into your brain without evaluating its consistency with your own belief systems.

Newton's laws declare loudly that a net force (an unbalanced force) causes an acceleration; the acceleration is in the same direction as the net force. To test your own belief system, consider the following question and its answer as seen by clicking the button.

Are You Infected with the Misconception?

Two students are discussing their physics homework prior to class. They are discussing an object that is being acted upon by two individual forces (both in a vertical direction); the free-body diagram for the particular object is shown below.



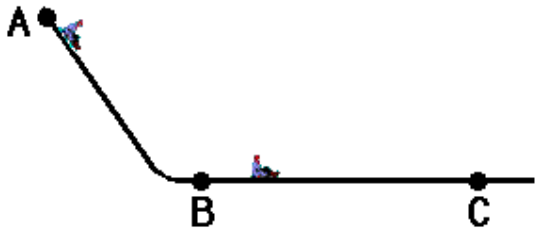
During the discussion, Anna Litical suggests to Noah Formula that the object under discussion could be moving. In fact, Anna suggests that if friction and air resistance could be ignored (because of their negligible size), the object could be moving in a horizontal direction. According to Anna, an object experiencing forces as described above could be experiencing a horizontal motion as described below.

. . . . . .

Noah Formula objects, arguing that the object could not have any horizontal motion if there are only vertical forces acting upon it. Noah claims that the object must be at rest, perhaps on a table or floor. After all, says Noah, an object experiencing a balance of forces will be at rest. Who do you agree with?

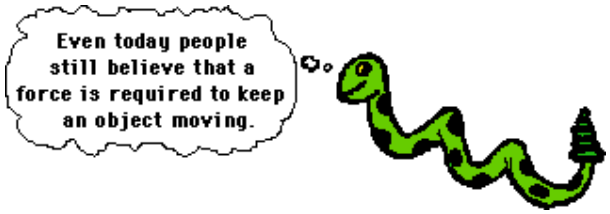
(Anna is correct. Noah Formula may know his formulas but he does not know (or does not believe) Newton's laws. If the forces acting on an object are balanced and the object is in motion, then it will continue in motion with the same velocity. Remember: forces do not cause motion. Forces cause accelerations.)

Remember last winter when you went sledding down the hill and across the level surface at the local park? (Apologies are extended to those who live in warmer winter climates.)



Imagine a the moment that there was no friction along the level surface from point B to point C and that there was no air resistance to impede your motion. How far would your sled travel? And what would its motion be like? Most students I've talked to quickly answer: the sled would travel forever at constant speed. Without friction or air resistance to slow it down, the sled would continue in motion with the same speed and in the same direction. The forces acting upon the sled from point B to point C would be the normal force (the snow pushes up on the sled) and the gravity force (see diagram at right). These forces are balanced and since the sled is already in motion at point B it will continue in motion with the same speed and direction. So, as in the case of the sled and as in the case of the object that Noah and Anna are discussing, an object can be moving to the right even if the only forces acting upon the object are vertical forces. Forces do not cause motion; forces cause accelerations.

Newton's first law of motion declares that a force is <u>not</u> needed to keep an object in motion. Slide a book across a table and watch it slide to a rest position. The book in motion on the table top does not come to a rest position because of the *absence* of a force; rather it is the *presence* of a force - that force being the force of friction - that brings the book to a rest position. In the absence of a force of friction, the book would continue in motion with the same speed and direction - forever (or at least to the end of the table top)! A force is not required to keep a moving book in motion; and a force is not required to keep a moving sled in motion; and a force is not required to keep any object horizontally moving object in motion.



<u>Exercises</u>

1. Determine the accelerations that result when a 12-N net force is applied to a 3-kg object and then to a 6-kg object.

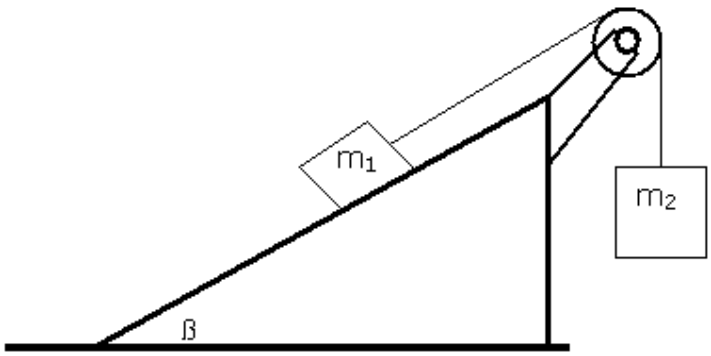
2. A net force of 15 N is exerted on an encyclopedia to cause it to accelerate at a rate of 5 m/s2. Determine the mass of the encyclopedia.

3. Suppose that a sled is accelerating at a rate of 2 m/s^2. If the net force is tripled and the mass is doubled, then what is the new acceleration of the sled?

4. Suppose that a sled is accelerating at a rate of 2 m/s^2. If the net force is tripled and the mass is halfed, then what is the new acceleration of the sled?

5 The pulley shown below is weightless and frictionless. The block of mass m1 is on the plane, inclined at an angle β with the horizontal. The block of mass m2 is connected to m1 by a string. m1= 100 kg m2= 50 kg β= 30 °

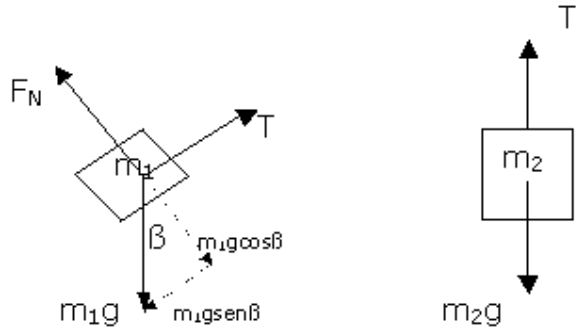
a) Assuming there is no friction, calculate the acceleration of the system in terms of m1, m2, β and g.
b) What condition is required for m1 to go up the incline?
c) Assume that the coefficient of kinetic friction between m1 and the plane is 0.2, m1 = 2 kg, m2 = 2.5 kg and the angle β = 30º. Calculate the acceleration of m1 and m2.
d) What is the maximum value of the friction coefficient so the system can still move.



Before attempting to solve a Second Newton's Law problem like this it is very useful to take into account the following considerations:

Free Body Diagram.- In every problem where the Second Newton's Law applies it is fundamental to draw what is called the **Free Body Diagram**. This diagram must show **all** the external forces acting on a body. We **isolate** the body and the forces due to that strings and surfaces are replaced by arrows; of course, the friction forces and the force of gravity must be included. If there are several bodies, a separate diagram should be drawn for each one.

FREE BODY DIAGRAM



- The force that m_1 exerts on m_2 through the rope has the same magnitude T. This is so because a rope only changes the direction of a force, not its magnitude assuming a weightless rope.

- The magnitude of the acceleration is the same at both ends of the rope assuming an inextensible rope.

6 Criticize the following incorrect statement:
If an object is at rest and the total force on it is zero, it stays at rest. There can also be cases where an object is moving and keeps on moving without having any total force on it, but that can only happen when there's no friction, like in outer space."

Fonti:

http://www.physicsclassroom.com/Class/newtlaws/

http://www.jfinternational.com/ph/second-newton-law-exercises-2.html