[Note: In mechanics, mass, time, energy and constants are scalars, pretty much everything else is a vector. For those of you familiar with standard physics notation, be aware that **bold** type here is not necessarily being used to denote vector quantities.]

Newton's Laws

In the *physical world*[1] only forces can cause change. Newton's first two laws describe change; specifically if and when it will occur, and how much.

The 2nd Law tells us that when a net force is present there will be change. Mathematically it is usually written as **Fnet = m a** where we understand this to be a causal relationship such that **net force causes acceleration --** which is the effect. Acceleration is just a more compact name for change in velocity (or more precisely, rate of change of velocity). **Fnet** is the sum of all forces and is usually written as **Σ F** , so the 2nd Law becomes: **Σ F = m a** . When written in this form some students mistakenly take "**a**" as apparently the independent variable, or cause, and **Fnet** the dependent variable, or effect. But acceleration absolutely does not cause net force!

In the physics simulations presented here we use a knowledge of the net force to calculate acceleration as: **a = Fnet/mass** , and then apply the **kinematics equations** to determine the change in the object's motion – that is, its velocity and position.

The **a = Fnet/m** form of the 2nd Law identifies the correct cause-effect relationship and emphasizes the influence of the mass in determining the amount of change that will occur. The mass of an object is a measure of its **inertia**, where inertia is resistance to change[2]. A force acting on an object with a small mass, and hence small inertia or resistance to change, will experience a much greater change than an object of larger mass acted on by the same force because the larger mass is much more resistant to change.

If we are dealing with a 2-dimensional situation – which is usually the case in our simulations, there will be separate 2nd Law equation for each direction: $\Sigma F_x = ma_x$, $\Sigma F_y = ma_y$ from which the x and y components of acceleration are determined.

The 1st Law indicates the obvious: if there is no cause for change, meaning no net force present, then there won't be any change.

This seems straightforward enough: if a book on a table is not acted on by a net force, then clearly it will remain motionless, or **static**: it will experience no change. What confuses many people is that an object moving with constant speed in a straight line, that is, at constant velocity, is also experiencing no change. Yet how can that be? Surely it's undergoing change since it's moving from one location to another?

The confusion arises because the change being considered here -- as described by the acceleration, is change in velocity, not change in position. From the physics point of view then, an object moving at constant velocity undergoes no change.

The formal definition of the **1st Law** involves both the static and the constant velocity aspects: **If there is no net force acting, an object at rest will remain at rest, and an object in motion will continue in motion in the same direction at the same speed**[3]**.** (If either the direction or the speed varies, then there has been change, and the net force could not have been zero.)

The mathematical statement of the 1st Law does not relate a cause to an effect as the 2nd Law does since there is obviously no cause present; it merely identifies the condition for no change -- that the net force must be zero: $\Sigma \mathbf{F} = \mathbf{0}$ **,** which seems almost trivial and of little possible use.

In fact it's of great use. The first step in analyzing a physical situation from a mechanics point of view is to decide whether change is occurring, in which case the 2nd Law would be applied, or if no change is occurring, in which case $\Sigma \mathbf{F} = \mathbf{0}$ would be applied. As most situations occur in two dimensions this is a vector equation that would be written in component form: $\Sigma \mathbf{F_x} = \mathbf{0}$, and $\Sigma \mathbf{F_y} = \mathbf{0}$. From these two equations we can calculate any two unknowns.

Misunderstanding of the 1st Law can lead to some serious misconceptions, and bad physics, as described in **note 4** below.

Newton's 3rd Law is conventionally described as "action-reaction, equal and opposite forces". Yet it's a bit deeper than that. What it's saying is that there are no single forces in nature – they come in pairs; all forces arise out of a simultaneous interaction between two things such that the force on one has the same magnitude as the force on the other but is oppositely directed. When a frustrated athlete punches their fist into the wall of a locker room and breaks it, they've demonstrated ignorance of the 3rd Law imagining that there's only a single force present – due to their hand. But the wall is part of the interaction, and will always "punch" back.

Many students think that the 3rd Law is not really useful. In fact, the process of constructing force diagrams as a prelude to applying the 1st or 2nd laws relies heavily on recognizing 3rd Law pairs to obtain the correct force directions. Indeed, once force diagrams have been constructed, and a decision made as to which of the 1st and 2nd Laws is applicable (and it may be both, but in different directions), the physics is pretty much complete, and you could turn the rest of the analysis over to an assistant: "Siri, finish solving this problem …"

The following notes are enlightening, but can be skipped:

Note 1 There are plenty of other "worlds": the financial world, the political world, the social world, the school and classroom worlds, even your own individual world. And in these worlds there are many different causes of change which are not forces as we understand them in physics, but which are metaphorically forces if we broaden the definition of a force to be anything that causes change. For example, market "forces" caused stock XY to crash, social "forces" caused the government to clamp down, etc".

Note 2 The concept of inertia can be applied broadly, not just to physics. A student who enters a class with a poor attitude likely has a high resistance, or mental inertia, to receiving new ideas in that subject. A company with a lot of corporate inertia will be resistant to changing the way it operates.

Note 3 All textbooks I've encountered place the reference to the net force last when annunciating the 3rd Law : "An object at rest will remain at rest, and an object in motion will continue with uniform motion (meaning at constant speed in a straight line), unless acted on by a net force." This may have been Newton's original statement, but I find it inverted and prefer to indicate the condition, no net force, at the beginning of the statement, and not at the end as a condition of when the situation would not be true.

The 1st Law is sometimes referred to as the **Law of Inertia** since inertia is resistance to change, and the law specifies when change won't occur. It might also be called the **Law of the Status Quo** since it stipulates when the status quo (the existing state) will be maintained.

Note 4 Real life experience often misleads people. Here are some common misconceptions arising from a lack of understanding of the 1st Law:

a. "***A force is needed to keep an object moving.***" Most people understand from everyday experience that force (a net force) is required to accelerate an object – which is correct. And anyone familiar with riding a bicycle, or driving a car, knows that they must keep pedalling, or keep their foot on the gas pedal, in order to maintain a constant velocity. Stop doing either and you will definitely slow down. But this observation often leads many people to the false conclusion that "a (net) force is needed to maintain motion at constant velocity".

The source of the misunderstanding is that air resistance has been overlooked. If you didn't keep pedaling, or took your foot off the gas, air resistance (drag)[5] would cause you to slow down. Both pedalling and providing gas to the engine are producing just enough force to cancel out the drag force, or enough to make the net force zero so that the constant velocity motion can continue. Being unaware of the presence of drag makes you think that a net force is being applied.

If there was no air, or road friction with the tires, you would cruise along at constant velocity without pedaling, or could turn the motor off. In another setting, imagine yourself aboard a rocket ship that has used up all its fuel and is travelling at 1 million km/hr in deep space; that is, far from any planet or star that might exert a gravitational force. Your rocket ship will continue to travel at 1 million km/hr in a straight line forever, as long as no net force is present to cause change. It will keep going, and going, and going without needing a net force to propel it. However, if you wanted to change the velocity (either speed and/or direction), then a net force would be required.

b. When a vehicle such as a car is in a collision witnesses will sometimes announce that ***"the force of the collision caused the driver to be thrown forward"***. For example, imagine the driver of an ATV who was not wearing a seat belt crashing into a tree stump, and fortunately landing on some cushioning bushes on the other side of the stump. The driver might exclaim that "the force of the collision threw me forward". Yet if the driver flew through the air and didn't bounce off the steering wheel, there were no forces acting on them (other than gravity).

This was merely a 1st Law situation: both the ATV and the driver were in motion, the ATV was stopped by the collision force with the stump, but the driver was not stopped by anything and so continued moving forward in a straight line until slowed down by the bushes. Had the driver bumped into the steering wheel, they would have received a backward directed force that could only act to slow them down, not hurl them forward.

A related misunderstanding can occur in the following situation:

A person washing their hands shakes the excess water off into a sink before using a towel, much like shaking the water out of a paint brush. But there is no force directing the water into the sink, or off the paint brush. The hands, or paint brush, with water attached, are put in motion; the person then stops their hands from moving forward, but the water keeps on 1st-Lawing forward since, other than a small surface tension between the hands, or brush, and the water, there are no other forces present (though once the water has been shaken off it does move under the influence of gravity).

c. "***Objects, such as vehicles, moving over curved paths experience an outward force."*** As a car moves around a sharp curve, or as a person sits on an amusement park ride that is rotating, they might afterward describe the <u>sensation</u> of "being thrown outward". In reality nothing was throwing them outward. At each point on the circular trajectory there was simply a 1st Law tendency to continue moving in a straight line tangentially off the curve. Still, even scientifically trained people sometimes use the <u>fictitious</u> (meaning not real) outward "**centrifugal**" force to describe the situation since it's much easier than saying "I was being 1st-Lawed off tangentially as I moved around the curve." Though there is definitely the physiological <u>sensation</u> of being thrown outward, it is not due to any force, only the 1st Law.

Indeed, if there was some sort of outward force present the car itself would also experience it, and would turn outward instead of inward as is necessary to continue the circular motion. Friction of the road surface on the tires provides the inward force – known as the **centripetal** force, required to cause the car to turn in the direction of the curve. Were the car to encounter a patch of ice which would eliminate the inward frictional force, it would off course slip tangentially outward off the curve. [A centripetal force is <u>not</u> a specific force; it's the name given to whatever forces, or force components, happen to be causing an object to turn over the circular path.]

Note 5 People often confuse <u>air resistance</u> (drag) and <u>air friction</u>. Air resistance is the phenomenon that you experience if you stick your hand out a car window and hold the palm of your hand perpendicular to the air flow; the drag force can be considerable depending on your speed. Air friction is a high speed phenomenon caused by air molecules rubbing the surface of an object and doing frictional work that creates heat. When a space craft re-enters the Earth's atmosphere at high speed, air friction will heat it up to very high temperatures. You can find videos online of comets entering the Earth's atmosphere and burning up due to air friction.