Newton’s Laws of Motion Notes

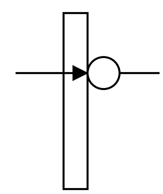
Isaac Newton developed three laws of motion which explained why and how objects move. Here are his laws of motion as translated from the original Latin in “The Principia”:

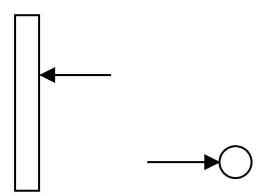
I. Every body perseveres in its state of rest, or of uniform motion in a right line, unless it is compelled to change that state by forces impressed thereon.

II. The alteration of motion is ever proportional to the motive force impressed: and is made in the direction of the right line in which that force is impressed [,and is inversely proportional to the mass of the object].

III. To every action there is always opposed an equal reaction: or the mutual actions of two bodies upon each other are always equal, and directed to contrary parts.

Newton’s third law of motion is probably the best recognized and the least understood. It is the explanation of the origination of forces. A **force** is simply a push or a pull due to the interaction of two objects. In order to push on something there has to be something that pushes as well as something to be pushed. Think about it this way, could you hit nothing? No. Could something be hit by nothing? No. If there is one force, there is always another. This is the main purpose of the Third Law, interesting since there is no motion mentioned. The pair of forces, action force and reaction force, is known as an action-reaction pair and will always exist when there is an interaction between two objects. As stated in the law they will always have the same magnitude (if I push with 50 pounds the wall will push back with 50 pounds), in opposite directions (if I push right the wall pushes left), and the pair is always acts on the two objects independently (I push the wall…the wall pushes me). Think of this last part in terms of relative motion: am I moving past the car or is the car moving past me? It depends on your frame of reference: I would see the car go past me and the car would see me go past it. So just because I initiated the push on the wall does not eliminate the wall’s part in the interaction. At this point you should be able to identify some action-reaction force pairs. One big suggestion…do not think about any motion, just the actual objects and the interaction. Example: ACTION FORCE: a bat hits a ball…REACTION FORCE: the ball hits the bat. The forces have the same size and are in the opposite direction. Look at the first diagram to the right. Most people see this and cannot tell that the force pair is not acting on one object. The second diagram shows each object separated from the other, allowing you to see how each object has one force acting on it. Clearly each object is experiencing one part of the action-reaction pair.

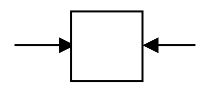




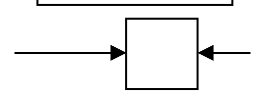
Now about actual motion. Galileo used inclined planes to determine the acceleration of falling objects and developed the concept that, without friction, a moving object on a flat plane would continue in a straight line forever at the same velocity -- Galileo called this “tendency” of matter **inertia**. Inertia is a property of matter, the tendency of an object to remain in its current state of motion; the resistance of an object to a change in its velocity. The amount of inertia an object has depends on how much matter it has, or its **mass**. Mass is simply a measure of how resistant on object is to changing its state of motion. Galileo recognized that the reason a rolling cannonball eventually came to rest was due to a resistive force, **friction**. Since friction was always present in daily life it had been overlooked in previous explanations of motion. Gravity is probably one of the most obvious forces we experience daily and always. Near the earth’s surface gravity accelerates the mass of an object at a rate of 9.8 m/s^2 (which we call $\boldsymbol{g}$) towards the earth. All objects, regardless of their mass, will accelerate at this rate without any interference from air or other things. This force is commonly referred to as **weight** when it pulls on an object's mass. So your weight is simply the pull of earth's gravitational force on your mass. The point here is to recognize that mass and weight are not the same quantity. A rock's mass is relatively constant anywhere it goes, but its weight can change dramatically depending on the gravitational field it is in. Here on the earth it may weigh 6 pounds, but the same rock would weigh 1 pound on the moon due to a weaker gravitational field. Most people will interchange mass and weight without a second thought because the gravitational field they live in does not change noticeably at any time. As a result the heavier object is more massive because there is more matter for the gravity to pull. With that in mind, think about inertia again. More mass = more inertia and here on earth more weight = more inertia.

With this in mind we can now take a look at **Newton's First Law of motion**, which actually does deal with motion…due to forces or the lack of them. The first law is an explanation of inertia's role in the motion of objects and is often called the law of inertia. Basically objects tend to stay as they are. As we have already seen, the motion of an object can be completely measured at any instant by its velocity. The first part of the First Law tells us that whether at rest or moving, an object will tend to keep a constant velocity. The more inertia the object has, the more likely it is to keep that velocity. In this part there is no acceleration: an object is (a) not moving, **static equilibrium**, or (b) moving with a constant velocity, **dynamic equilibrium**. It is not clear why equilibrium occurs until you look at the second part of this law. The second part of the First Law was the breakthrough in Newton's time...when an object is in equilibrium the forces acting on it are **balanced** and an **unbalanced** force is required to ***change*** an object's velocity or an acceleration will result only if there is more force in one direction than in another. Before Galileo and Newton it was commonly accepted that for an object to be moving there must be a force acting on it and it only stopped moving when there were no forces acting on it. Now it was understood that even without any forces acting, an object could have a constant velocity. The role of force is to accelerate an object, not keep it moving. There has to be extra force in one direction over another in order to change an object's velocity. This extra force is known as an unbalanced or **net force**. If all the forces on an object cancel out, then there is no net force and the forces are balanced. If the forces do not cancel out, there is a net force and they are unbalanced. Force is a vector quantity so you can visually measure net force with vectors. Look at a tug-of-war: if each team pulls equally (balanced) on the rope, no one moves. When one team applies more force in their direction (unbalanced) everything accelerates that direction. If there is no acceleration there is no net force and if there is acceleration there must be a net force. As you sit in your chair you have a net force of zero acting on you. You know this because you do not accelerate. You do still have forces acting on you. Gravity is pulling down on you and there must be a balancing force pushing back up on you, resulting in no acceleration. That force pushing back up on you comes from the chair, it is balancing out the force of gravity on you (no net force). If you remove the chair only gravity is acting on you (net force) and you accelerate down to the ground. When you push a chair across the room at a constant velocity the chair slides over the floor. There is an opposing force of friction that balances your pushing force...no net force, not no force. When you stop pushing the friction accelerates the chair until it stops. If there were no friction the chair would continue at a constant velocity after you stopped pushing it.

Balanced - no net force



Unbalanced - net force



Newton's second law of motion is basically the mathematical verification of the second part of his First law. The greater the net force, the greater the acceleration. The more inertia, or mass, an object has the less the acceleration. It also indicates that acceleration occurs in the same direction as the net force. With this in mind a force can also be defined as anything that can accelerate an object, as long as it is not balanced by other forces. Please note that any net force will cause any object to accelerate, no matter how massive it is. The more massive object will accelerate less than the less massive object (given the same net force)…but it will accelerate.