Statics and Dynamics
Dr. Mahesh V. Panchagnula
Department of Applied Mechanics
Indian Institute of Technology, Madras

Lecture – 02
Newton's Laws

Hello, welcome back. We are going to begin our discussion of the theoretical constructs – theoretical concepts that govern the motion of bodies. These are the three famous laws that are attributed to Newton that were introduced to us in high-school physics. We are going to begin with the… by stating the three laws of motion and understanding them from a couple of different perspectives.

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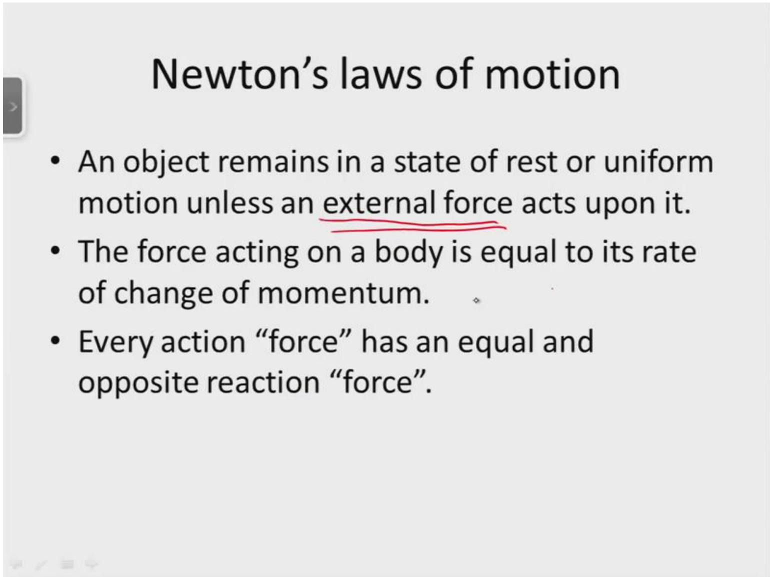

So, let us start by writing down the Newton's laws of motion. The first law as we are familiar with it states – an object remains in a state of rest or uniform motion unless an external force acts upon it. So, essentially, what this law states is that, if a body is moving in a state of uniform motion that is, where the velocity is constant or is at rest, those two states or equivalent. So, this is the first contribution. This is the contribution that Newton made through the first law; that is, to state an equivalence between a body that is actually just sitting at rest – no motion and a body that is moving at a constant velocity are the same. Now, if you think about it for a moment, it is not very obvious that a body that is moving at a constant velocity and a body at rest are both the same or similar in their state. And so, this is… We will come back to this point one more time.

But, again the first law essentially makes an equivalence between these two states. The second part of the first law talks about the idea of an external force. So, an external force in this sense is essentially a way of bringing in a concept called force to tell you what a force would look like when it acts upon it, or more precisely, what a force would look like when it is not acting upon a body or a system. So, essentially, the first law is telling us that, a body would remain at a state of rest or uniform motion if 0 force is acting upon it – if no external force is acting upon it. This is a nice and elegant way of understanding the Newton's first law.

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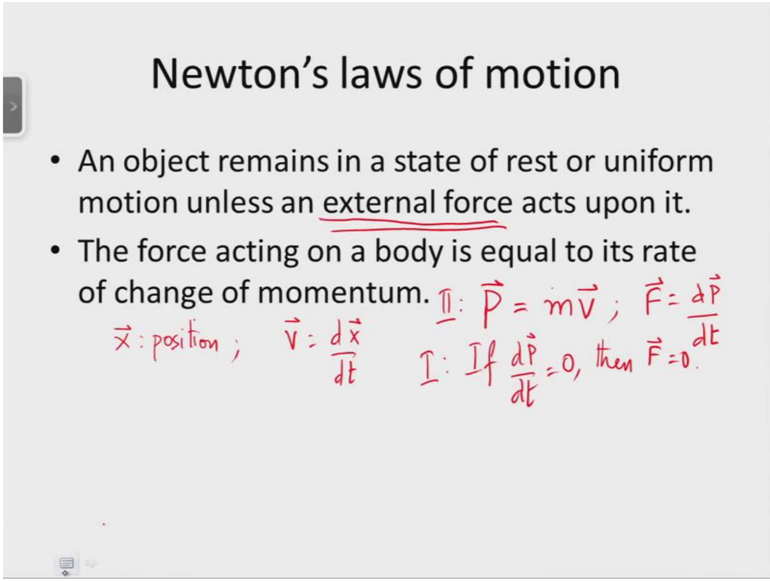

So, let us now move on to Newton's second law, which states that, the force acting on a body is equal to its rate of change of momentum. Now, momentum is defined as a product of the mass of a body times its velocity. So, if we go back and relate the second law to the first law, what we find is that, if the momentum of a body, which is the mass times velocity of a body is not changing, then the force acting upon the body is 0. So, in other words, if the rate of… if the momentum of a body defined as… If the momentum of a body p is equal to mass times velocity; if the momentum of a body is changing; then, the force acting upon the body is equal to dp dt. This is our common notation of a derivative. So, the rate of change of momentum of a body is exactly equal to the force acting upon the body. This is a mathematical statement that captures the essence of Newton's second law. Now, we would like to… Whenever we state a pair of laws in sequence, we want to make sure that, the second law has the first law encapsulated in it. So, another way of stating it is that, if the rate of change of momentum of a body is 0; if dp by dt is 0; then, F is 0. If you think of this, this is essentially a first law of motion and this is our second law of motion. So, the first law follows from the mathematics that is used to describe the concept captured in the second law.

So, a second way of thinking of the Newton's second law is as follows. Momentum has two variables in it: mass and velocity; a mass is measurable. So, I can place an object in a weighing pan and get an estimate of its mass, velocity is also measurable. Velocity is defined as the rate of change of position that is written as velocity equal to dx dt; where, x is the position vector or position of a body. So, we first know the position of a particular object; we know its velocity as the rate of change of position and momentum as a product of a body's mass times its rate of change of position. And, if the mass times the rate of change of position is not changing with time; time is also another measurable quantity; then, the force acting on that body is 0. And, if the momentum defined as mass times velocity is changing with time, then that is equal to the force acting on that body.

Now, if you go back and think about all the quantities that we have in red ink on this slide, mass velocity, mass position velocity and time are all measurable quantities. Force as a matter of fact is not independently measurable without measuring one of these quantities. So, what another way of thinking of Newton's second law is that, it gives us a way of measuring force itself. Let us do a simple thought experiment; let us say I go up against a wall and push the wall. So, essentially, we all know by intuition that, I am exerting a force on that wall. Now, if the wall is not moving, does that mean I have no way of estimating the force exerted by me on the wall? So, typically, we measure force by measuring either rate of change of velocity or rate of change of momentum or some other measurable quantities such as displacement or you know there are many other ways of measuring force now. But, what Newton's second law gives us is essentially a way of relating force, which is a more abstract concept to more measurable quantities such as mass, velocity, displacement and rate of change, which includes time.

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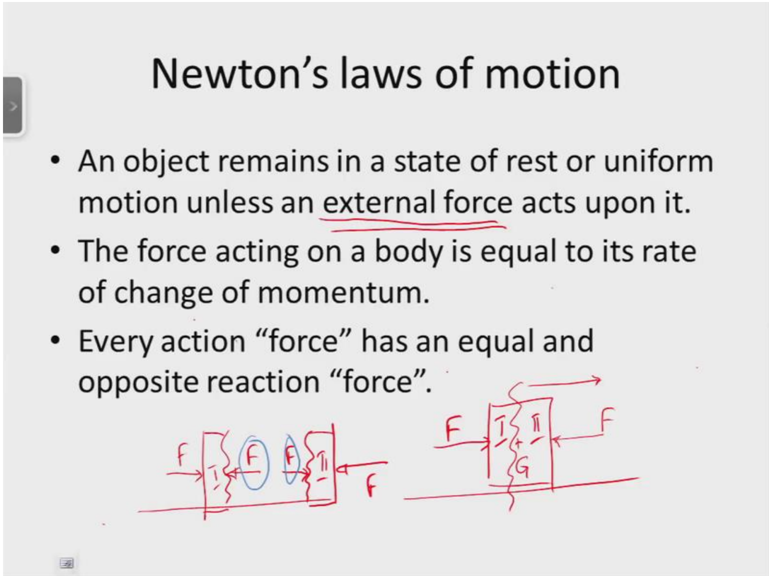

So, let us now move on to stating the third law; Newton's third law that we know; that says that, every action has an equivalent and opposite reaction. So, let us look at what this means for us in the context of engineering systems and mechanics. If you think of Newton's third law, it says that, if I have an action force, there is an equal and opposite reaction force that is generated. So, a simple way of thinking of this is the wall example. So, if I push the wall, the wall is pushing me and the fact that the force generated by me pushing the wall is exactly equal in magnitude, but opposite in direction to the force are exerted, is an important concept. So, you could think of this another way.

Let us say I take a block sitting at rest on a friction less surface. If I exert the force of some magnitude F, this block is going to begin moving to the right. This is again fairly intuitive. We are going to look at this in a more quantitative way a little later. But, if I want to keep this block from not moving, there is only one way of making sure that, the block is either not moving or moving in a state of constant velocity, and that is by exerting a force that is exactly the same magnitude F in the opposite direction. If I now took this system and let us say I cut this system in the middle; so, before I cut the block, there were two forces that were equal in magnitude and opposite in direction acting on this block; which means that, the sum total external force acting on this body is 0; F and minus F. We will look at this in more detail a little later. But, if I now cut this block into two halves; I will call this half 1 and half 2. If I look at what is happening at the interface between these two; if a whole block is in equilibrium with that also automatically means that, every piece of that block is in equilibrium.

And, if I now look at just the first part; if I now have a force F acting on the first part and if this piece is in equilibrium; that automatically means that, there is an effective force F acting in the opposite direction on this piece that I have titled with Roman numeral 1. Likewise, if I now take the other half, this was already the external force acting on the block; there is an equal force, but in the opposite direction acting on the piece number 2 as well. And, these two forces if you notice, are created, are essentially inside the block and they are equal and opposite under all circumstances. As long as we are dealing with a block that is at rest or in uniform motion. And if I cut the block, the force is created at the interface – at the cut section would be exactly equal and opposite. And, that comes from the requirement that, if the whole block is in equilibrium, then each piece of that block is also in equilibrium. So, if we go back and relate the third law to the first law, you can now look at the third law as essentially first law applied to pieces of a larger system. So, if the first law is applicable to a block, then the third law comes from the fact that, I will apply the first law to every piece of that block, which produces these equal and opposite forces. A second… So, this is kind of brief introduction to understanding Newton's laws of motion. But, I want to close by talking about a definition of this to what we know or what we were introduced to in high school as the number line.

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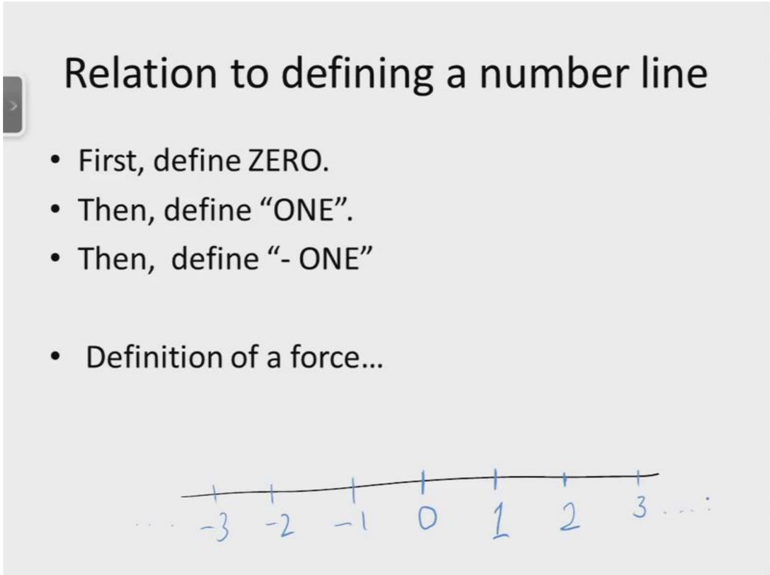

So, let us say I have a line on which I want to draw, I want to define a number line; how do I go about it? The very first act of defining the number line is to define a 0. I need to mark a point on this number line and mark this as my origin or 0. After I define a 0, I need to define what I call one unit; I need to define a 1; what I mean by 1 unit. And, the moment I define 1 unit, I can use other rules of mathematics to define a 2; I can define a 3 by simply saying that, I add one unit to the previous unit and I get at the number 2. So, the fact that, the first law – Newton's first law defines what 0 force would look like when you make observations on a moving system; that, if the body is moving either with the constant velocity or is just simply at rest, then define that as 0 force. Then, if the rate of change of momentum defined by dp dt is 1; then, that is essentially the definition of 1 Newton of force. If dp dt for a given system is 1; then, that defines what 1 Newton of force means.

Now, once I have moved in the positive direction of the number line, the next thing to do is to define what my minus 1 would look like, which is what would give me the complete number line. So, I can define a minus 1; I can define a minus 2, minus 3, etcetera. So, you could think of the three laws of mechanics as being analogous to the rules we use to define a number line. In that, we invoke what is our origin, what is a 0 and define what a unit distance is. So, it is kind of like defining a system of units to measure force as a matter of fact and then defining what the negative of the force would mean. And, these are concepts for a scalar number. Now, we will learn later on that, force is actually a vector – a vector force has a magnitude and a direction. And, the direction in three-dimensional space can have three scalar components. So, essentially three such number lines would complete our definition of a force in three dimensions. Good, we will come back and extend the Newton's laws of motion to Euler's laws of motion which are applicable to rigid bodies in the next lecture.