Course Name: Newtonian Mechanics With Examples
Prof. Shiladitya Sengupta
Department of Physics
Indian Institute of Technology Roorkee
Week 01
Lecture - 01

Welcome to the course, Newtonian Mechanics with examples. This is the first week and today is the first lecture. My name is Shiladitya Sengupta. I am an assistant professor in Department of Physics, IIT Roorkee. So, in the first week, we are going to start with review of some basic concepts of scalars, vectors and tensors. So, here is the plan for week 1.

So, first we will review the basic definitions of scalars and vectors. So the point is that in usual, usually in textbooks of mechanics that is followed in first year physics courses, the definitions of these quantities, especially the vectors are incomplete. So, we will introduce these concepts at three levels of generality. For each level, we will first give the definition and then we will critically review and see what is missing or this is a complete different.

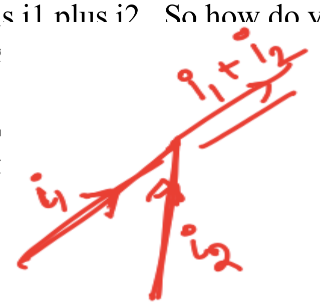
Next, I will tell briefly about the notations and why the notations are important. After that, we will review some basic concepts with vectors like unit vectors and we will cover the elementary operations with vectors like additions and dot, cross and triple products with some examples. So, at the most basic level, scalars are quantities that have only magnitudes. For example, I can say that this mass, so this is a piece of rock, a paper weight and this has a mass and the mass of this rock is 0.5 kg that is 500 gram.

So that is a scalar or I can say that the water, the volume of the water that is present inside this bottle is 1 liter. So this are, the volume is a scalar, mass is a scalar. Note that I have highlighted the units of these quantities in this example. So in general, there are two parts when you describe a scalar. First is the magnitude and the second is the unit.

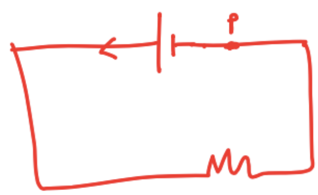
So both are important and we will discuss this more detail later. Now when some quantity has only magnitude, you can increase the magnitude like I can put another paper weight and then the mass has gone up or I can decrease the magnitude. So simple. Then what is a vector? So a vector is a quantity that has magnitudes as well as directions. For example, imagine that you go and stand in front of some highway.

So there are cars which are coming from this side and cars which are coming from this side. So you say that the velocity of this car is 60 kilometer per hour, but that is not enough. We have to mention that going towards right or you can say that the velocity is 60 kilometer per hour going to the left. So that is vector. Here is a list of quantities which are scalars such as density, energy, work, power, etc. and another list of quantities that are vector such as displacement, velocity, acceleration, momentum, force, angular velocity, angular acceleration, torque, etc. So at the moment, so I have mentioned only these as examples because these are the quantities that we shall use in this course. And these are the quantities that people usually study in the context of mechanics. Now it is very easy to find examples which do not fit fully in this definition. So consider electric current that is flowing through a circuit.

So I can, for example, let us say I draw a part of a circuit and this is a piece of wire with some current i1 and another piece of wire in which some current i2 is flowing and these are joined at this point and then in the next part of the circuit, if I ask what is the total current flowing in this part of the circuit, then the answer is i1 plus i2. So how do you get that answer? So you just add the magnitude of the current flowing [illegible] the magnitude of the current that is flowing in the second part of the [illegible] the total momentum. So see that when you describe the circuit, you [illegible] a sense of direction to the electric current, but yet we treat it as a scalar [illegible]

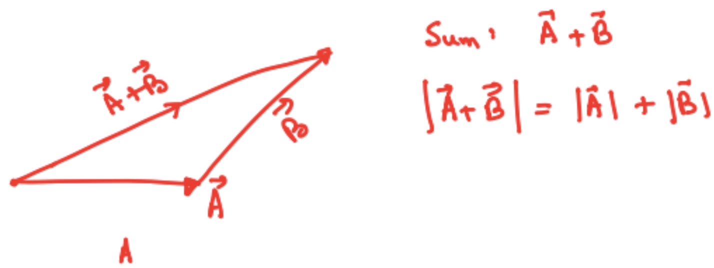


So to continue further, suppose I draw a closed circuit. So you know that in a closed circuit a loop, if you start from some point, let us call it P and then you walk along this circuit and come back to the same point, then if it is a truly, if the electric current is a truly vector quantity, then the total value along a closed circuit will be 0. But we know that the current flowing through a circuit is not 0. So this is because current is a scalar, yet it has a sense of direction. Well, so some of you who are familiar with vectors and scalars already from your high schools, you may at this point say, well, you have to add one more point to define vectors is that vectors obey vector law of addition.

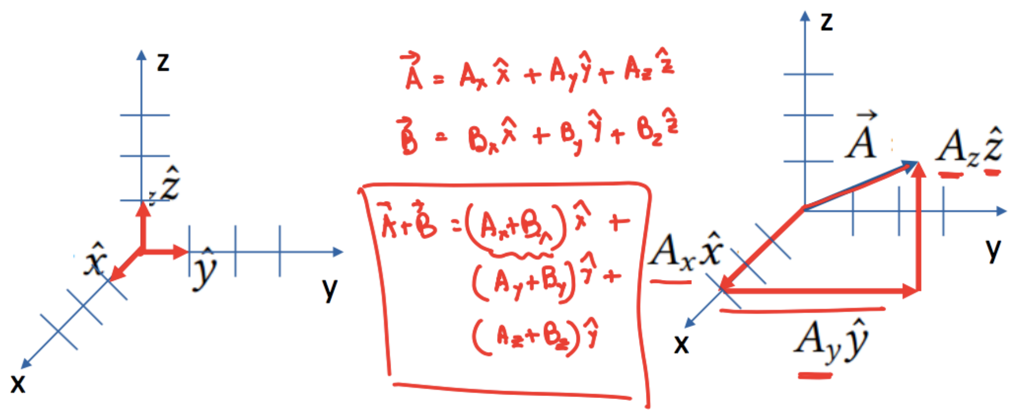


So they obey vector law of addition, whereas scalars do not. So this gives you a more precise, mathematically more precise definition of vectors and scalars. What do I mean by that? So let us illustrate this. So suppose if I draw a vector, let us call it A, so you can represent a quantity, so the length of this arrow is the magnitude of this vector and the direction of this arrow represents the direction of this vector. And then if I have another vector, let us call it B, which is started, so the tail of B is attached to the head of A, then you know, some of you may have already be aware that, if you draw now the head of A to the tail of B, this new vector is represents the sum of A and B.

So note that the length, so the magnitude of A plus B, so this symbol vertical pipe that represents the magnitude is not in general the magnitude of A plus magnitude of B. So this is the vector law of addition. Now I will argue that we can represent the vectors by, in a component notation. And if we represent the vectors in the component notation, then the vector law of addition is nothing but the simple scalar addition of components. So what do I mean by that? Let us say I want to do the same thing again.

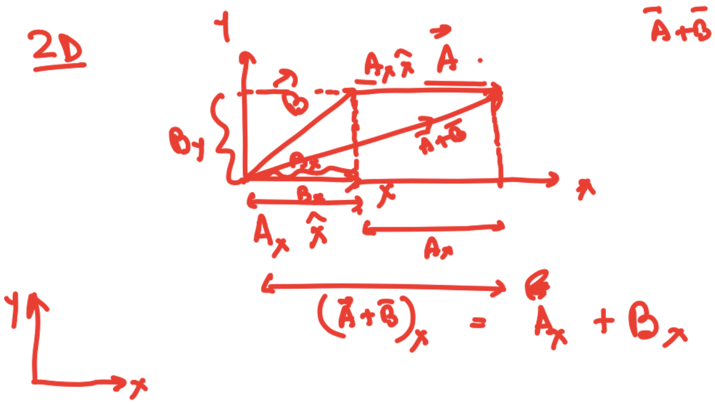


So here is a quick recall of what do we mean. So when it represents a vector, so vector is an arrow, the length of the arrow is the magnitude and the direction of the arrow is the direction of the vector, magnitude and direction. So first we choose an origin, a point and from the origin we choose a coordinate system. So here is the my x-axis, y-axis and z-axis and this little red vectors they represents the direction of the coordinate axis. Now I can write, so and now I want to describe the vector A in terms of its components.



So what do I mean? It means that we can find a piece, a vector which is along the x-axis with certain length which is given by Ax, its direction is Ax, is along x-axis. Another piece which is whose direction is along y-axis and it has some length which is given by Ay and the third piece, whose direction is along z-axis, and whose magnitude is given by Az. So if we have these three pieces and if we apply the vector law of addition, then we get back our vector A. so this A is written as the vector sum of three pieces. Now I am going to show you that suppose I have another vector B, then let us say this vector B is sum of three pieces, these are pieces Bx times x hat, Bx along x direction, By along the y direction and Bz along the z direction.

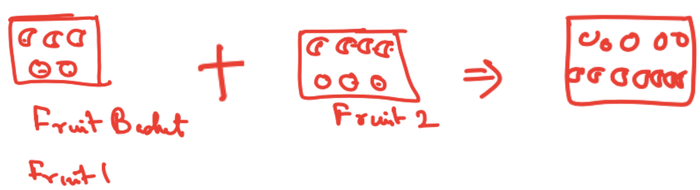
Then what is the sum of A plus B? So the A plus B will be given by the, so the piece that represents the A plus B is made up of three pieces which is represented by this particular rule. So let me convince you, demonstrate you this rule in a simpler situation in two dimension. Suppose I have a vector which is, so this is a 2D, I have a vector Ax which is in the direction of x-axis. So this is my x-axis, this is y-axis and another vector, suppose this is another vector, this is y-axis, this is B. Now what is the piece of B that is along the x-axis? So you know that this is given if you draw a perpendicular on the x-axis and draw a perpendicular on the y-axis.



So this piece represents the component of B along the y-axis and this piece represents the component of B along the x-axis. Now if I add, so let us make the A, the vector A little bit bigger. So let us say this is my A. Now I want to find the component, the resultant vector A plus B. So if you apply the vector law of addition, then A plus B is given by this new vector.

So the simple rule that we just used before is that we want to apply the vector addition of two vectors A and B, then all you have to do is find the components of the vectors along x-axis, y-axis and z-axis and then add the components. So this part is a simple scalar addition. So this is the meaning of the statement here that vector law of addition is nothing but simple scalar addition of components. Now I will give you examples of objects that has components and obey vector law of addition. But they do not have a sense of direction and are not vectors in our usual sense.

So here is a very simple example. So suppose you have one basket with fruits. So this is a basket with fruits. And let us say you have two kinds of fruits, apple and mango. So this is like an object fruit with two components, apple, first component is apple, the second component is mango.



So now you have two baskets. So let us we denote that. So in first basket, there are two apples and three mangoes. And we describe that as fruit 1. In the second basket, so this is fruit 1. So three mangoes and two apples.
Let us take another basket, fruit 2. So fruit 2 has four mangoes and three apples. So now I want to combine the fruit in both the basket in a single basket. Then what will be the total number of fruits in the single basket? So if I add them. Evidently, the new basket will have five apples, and seven mangoes.

So you see that how do you compute that? So you add apples to apples and mangoes to mangoes. So this is a vector addition. Why? Because you apply this rule to compute the total fruits in the common basket. But now if I ask you is fruit a vector? What is the direction of fruit? So it does not have a sense of direction, yet it obeys the vector laws of addition. So even if we add the this extra clause that vectors are quantities that obeys vector law of addition, that is not enough.

More importantly, for our course, we shall come across some quantities which has more than one sense of direction. So the quantity that we will be describing in great detail in this course is moment of inertia. However, it is easy to illustrate this concept, so what do I mean by more than one sense of direction using another quantity which is called stress or more commonly pressure. So I am trying to sort of demonstrate that to define pressure or stress, so usually what we say that pressure is force per unit area. So I have written it in a slightly different way that force is stress times area.
Which are mathematically equivalent but conceptually different. The point is that suppose I have a surface, so this is a book. So this has a surface. So this has certain area, so if I look at the cover of the book.

Now the area has a orientation. So for example, this is an area, this is another same area in a different orientation. So that is why and when we calculate the pressure or stress, the orientation is important. So that is why we consider area as a vector. It has a magnitude which represents the area, surface area and the perpendicular to the area, the surface gives the direction. And obviously you know from experience that force has a direction.

Now the point is that if I apply some force, so if I put this area in this orientation and the perpendicular direction is, this is the perpendicular direction. So this is the direction of the area. Now if I apply some force like this, so the force as you know that has two components. So this is the force by this finger on the book, it has two components. One component is perpendicular to the direction of the surface.

Other component is tangential, parallel to the plane of the this area. So that means the force that I am applying is in this direction and the area, the normal to the area is in this direction. So then you can see that this particular equation is not a simple scalar equation in the sense that the direction of area and direction of force, they are not in the same. In general, the force can be in a different direction than the area. That means you can think of this way, so this quantity stress, it sort of takes the area as an input and produces the force as an output.

But it has to deal with the fact that it takes both the magnitude of area as well as the direction of the area and gives you the magnitude of force as well as the direction of the force. So to define stress, so it sort of to define stress, you need to have information about the direction of force as well as direction of area. So this is an example of a quantity that is neither a scalar nor a vector with a single direction. So that is why the usual definitions which is the textbooks which stops usually at this point to define scalar and vector, they are incomplete. In the next lecture, we shall give a more general definition of scalars and vectors that covers all the mechanical quantities that we shall encounter in this course as well as in other courses that you will be taking parallely.