Biomathematics

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Lecture No. # 1
Introduction

Hi all. I am Ranjith Padinhateeri. I am a faculty in the department of bioscience and bioengineering at IIT Bombay. I will be teaching this course– biomathematics. So, essentially, these courses will deal with various mathematical methods that is used in life sciences. So, we will take mainly, we will mainly concentrate in biology. So, different mathematical methods that is needed and useful to understand and explain various biological phenomena will be discussed in this course.

So, the first lecture of this course is essentially is an introduction to mathematics– biomathematics– and we will discuss why we need mathematics at all. So, that is the first lecture or introduction.

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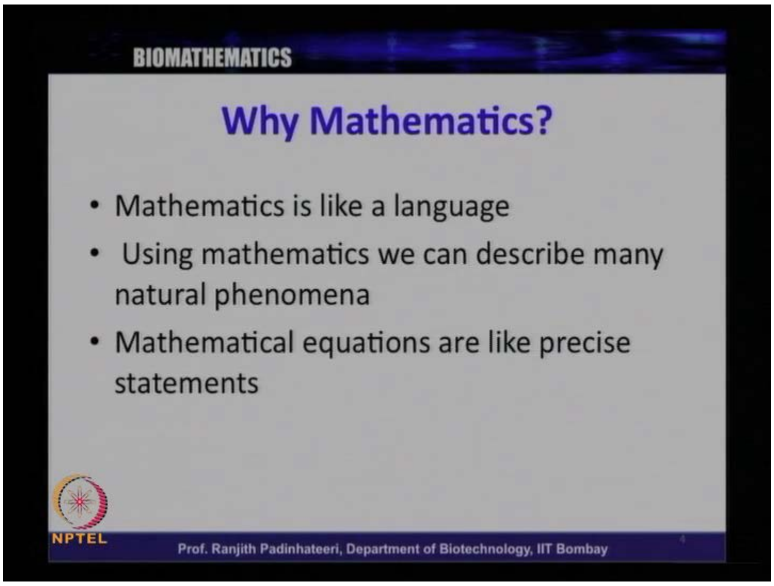

So, the question– when we say mathematics for biology, sorry, mathematics for life sciences, you will have this question that why at all we need mathematics to understand biosciences. As you all know, bioscience– we can do certain experiments– we can understand results from that experiment and reach some conclusion.

Is not that enough? Do we need to know any mathematics at all for studying biology? Conventionally, we do not learn mathematics in biology, for example, BSc biology or in biological courses. So, the… what we want to first discuss is why we need mathematics at all. So, the idea is– the idea is that mathematics is like a language; it is like a language to understand scientific natural phenomena– to explain natural phenomena– and using this mathematics, we can describe, also, biological phenomena.

So, as we go along this course, we will, so, learn many, many things related to why we need mathematics for understanding biology and today, we will discuss some examples where mathematics is used, and in the next other parts of the course, we will describe more and more examples or biological phenomena where mathematics is helpful to understand it, and we will learn the mathematics behind, behind all these phenomena.

So, when we say mathematics, the first thing comes to everybody is mind is some set of equations. So, mathematics is always related equations. So, what are these equations? So, essentially, equations are like some kind of statements. So, they are much more– very precise statements. So, when we say statements in English, we make loud statements. So, to describe an event that we see in day to day life, you– we– use the English or some language– English, Marathi, Hindi– all kinds of languages we use in India, and this can describe some event that we see in day to day life, but mathematics? So, then why need mathematics.

So, the advantages of mathematics are that you can describe things in a very qualitative way– much very precise way. So, let us take an example. So, let us say you want to understand biological phenomena of bacterial growth.

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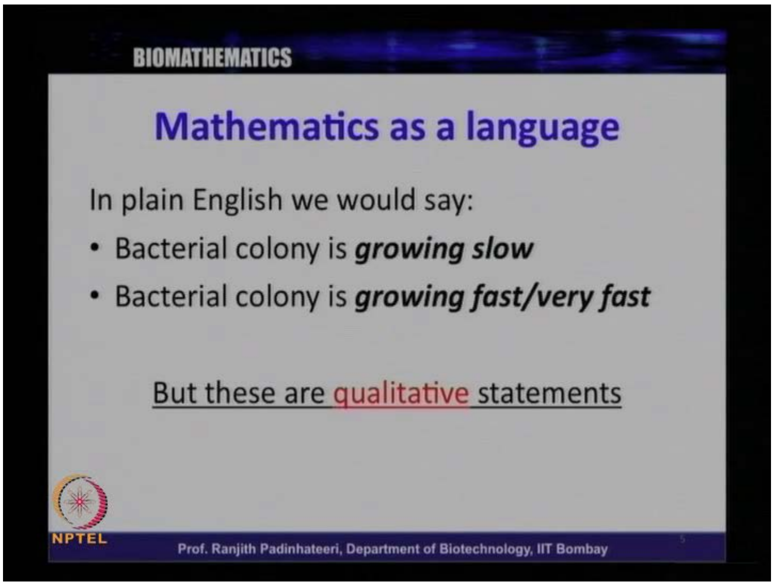

So, you are doing a experiment of growing bacteria. So, we have Petri dish, and you have some bacterial colony which is growing. Now, you see the… you record this experimental observation that this bacterial colony is growing fast, or bacterial colony is going slow; that is all we can say with the language. How fast it is growing– more precisely, what is the speed with which is growing and so on so forth can be much easily described using mathematics.

So, this– that these statements like going growing fast or growing slow, etcetera, are very qualitative statements. On the other hand, using mathematics, one can make much more precise– much more quantitative– statements. So, let us go and take an example of bacterial growth itself.

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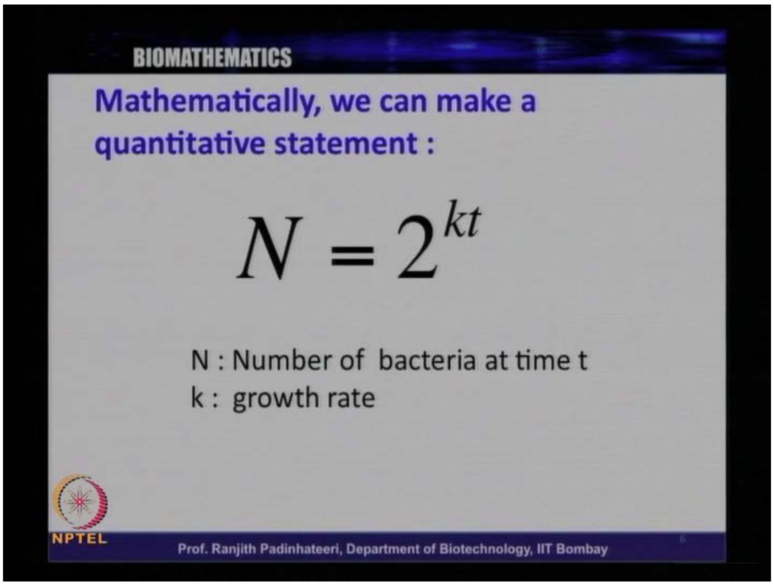

So, this is one equation which is valid in some particular regime of bacterial growth, that is N is equal to 2 power kt is an equation which is valid in one of the phases of bacterial growth. Now, what is this equation convey to you? So, this equation essentially tells that how the N, which is the number of bacteria at a particular time t, so, what is the… how many bacteria are there in this Petri dish at a particular time t is what this is describing.

So, using this, so, this is just one equation, like what one, like five, six letters, one can convey lot of things– this already conveys what is the speed with which it is growing; after five minutes how many bacteria are there; after ten minutes how many bacteria you can find.

So, many, many large information is embedded in this one little line. So, this is the power of mathematics, where you can… you can– we can– convey a lot of information in just very tiny statements– equations– like this, and we will. Our aim of this course is to understand these equations, and if you do an experiment, how to express those experimental results in using appropriate equations or in the language of mathematics that is precise and quantitative.

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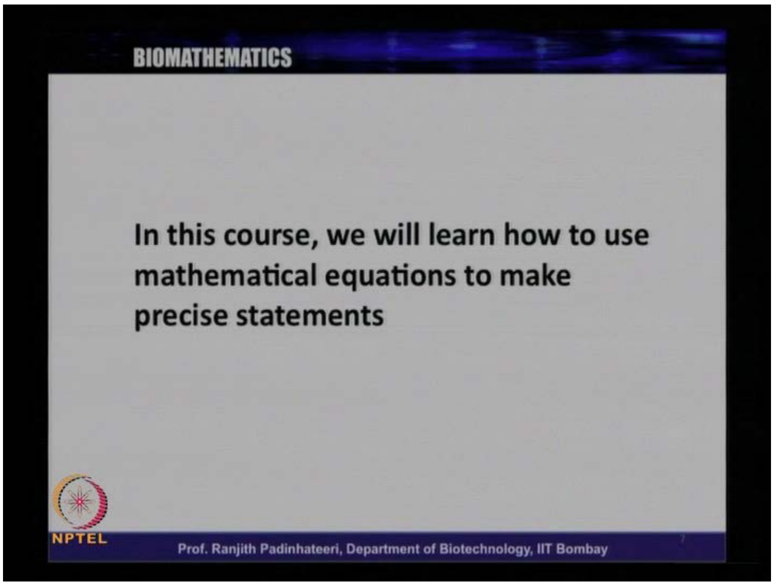

So, with this aim, we will study– study; we will go and understand the study this course. So, let us say, in this course, we will learn how to use mathematical equations to make precise statements.

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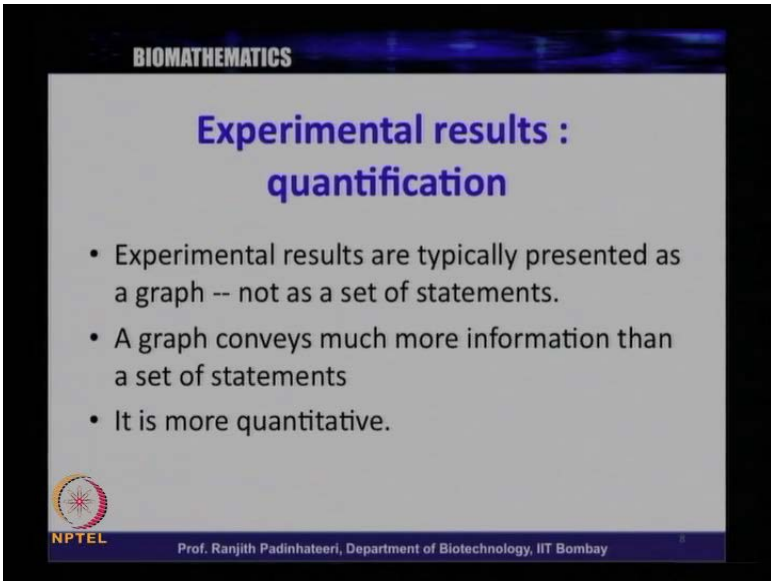

So, now, let us go and understand how, and learn how to use mathematics in some certain examples. Let us go and take some examples. So, in biology, what we typically do are we, we usually do lot of experiments. So, and as… how do we represent this experimental data? For example, as I said, we… you measure the bacterial colony. So, or when you, you do some other experiments, basically, as an experimental data, what you get is some table.

So, let us say, number of… at a particular time, how many bacteria are there in the Petri dish, or something is growing, or polymer is growing. So, what is the length of the polymer at a particular time? So, this is an experimental data.

So, you have…. Basically, you will have, basically, time in one column and the length of polymer in another column. So, you basically you get a table in a lot of experiments as a result of experiments. You, essentially, at the end of the experiment, you make some table– at a particular concentration you have this value; at some other concentration, you have some other value. So, you vary concentration, and you need an interval of point micro molar and you get some results. So, essentially, you get a table at the end of each experiment and you plot this table as a graph.

So, the basically experimental results are typically presented as a graph and not a set of statements, and why is it? Why are we presenting the tables? Why do not we present just this table and not any graph at all for all experiments? Why do we need graphs?

The answer is that the graph can convey much more information than a table can convey. So, that is the idea. So, basically, this is the… and the graph is much more quantitative. So, instead of more than what we see in a set of statements, the graph can give much more quantitative– a graph can convey much more quantitative information in a quantitative way.

So, that is why we use graph, and this verify idea of plotting graph is kind of the first step or first use of mathematics, essentially, using your… using while your… when you are plotting a graph, essentially, you are using some ideas of mathematics, already. So, graph and mathematical equations are very closely connected.

So, as you know that most of the graphs in principle can be represented by a mathematical equation. So, actually, all graphs in principle can be represented by a mathematical equation; the equation may be very complex equation.

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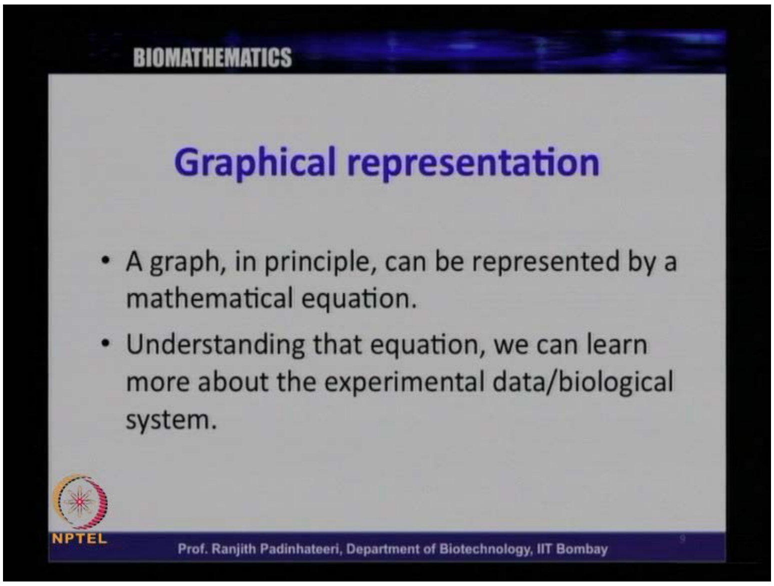

But however, it is possible to write down an equation for almost all graphs that you see, and the understanding that equation by through… and by understanding that equation, we can learn much more information about this data and about these phenomena, and about this biological system. So, in this course, as we… as I said, we will learn how to write down these equations, and we will learn how to understand from this equation how to understand this– a biological phenomena– in a better way.

So, the next question obviously comes to mind is: using mathematics, how do we extract more information from experimental data? So, let us say you have an experimental data, and how do we get more information that, that what we know from the graph? So, let us take a simple example of fish growth– growth of fish, for example. So, this is some experiment done by a very famous biologist many years ago.

So, let us take an example that you have a lake, and this lake you are growing fish. So, you put lot of fish, and then it is like a fish farm. So, your aim is that you want to grow a lot of fish and sell these fish. So, you will be happy if you get lot of fish every day; per day, you want to get, let us say, this many kg or this many number of fish every day, and then you will be happy. So, as a person doing farming or growing fish, your aim is that you should have maximum yield.

So, the question comes to your mind is that how can we get maximum yield? So, let us say you are doing an experiment of growth and you get a particular curve, as we see in the graph here.

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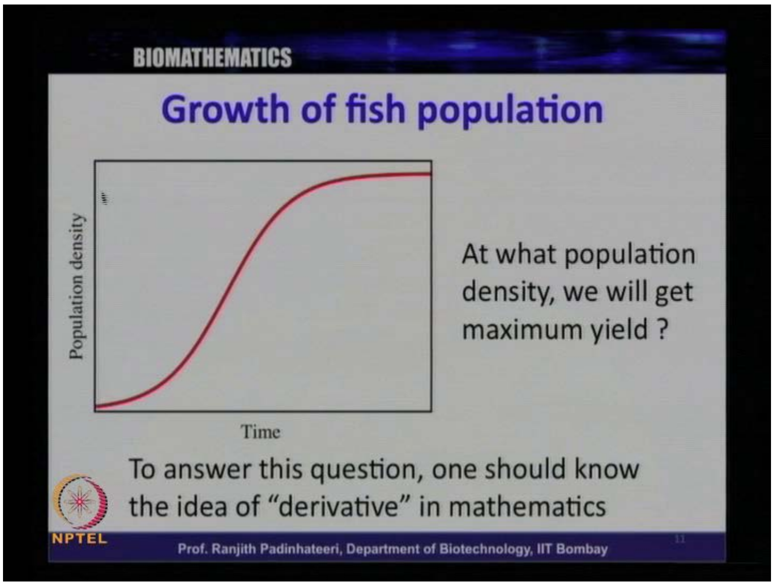

So, let us see this graph: this is a typical growth curve; many of you might have seen already. So, what is plotted here is population density in the Y-axis versus time. So, as we start growing fish, at the early stage, the… you have very little population. So, by population density, we mean how many number of fish per square unit area or unit volume.

So, that is the population density. So, at the early time, we have very small population density and the population density increases, and as the time goes, it reaches a maximal value and kind of saturates here. So, this is the typical growth curve which is applicable for many different kinds of phenomena, including bacterial colony, yeast cell division, and so on and so forth.

So, let us take in this fish case, now, let us ask this question– at what population density you will get maximum yield. So, to understand this– that when we get maximum yield, one has to understand the mathematical idea– mathematical idea called derivative.

So, this is a mathematical idea in the field of mathematics called calculus, which is… which can be used here to understand this question– to answer this question– and by answering this question, you can basically learn– you can basically get lot of hints, and you can also, if it is applied to a different experimental context, we can understand more about the experiments in this system.

So, this is one example. So, as we go along in this course, we will answer this question we will answer a… we will learn about derivatives, and then we will have this– we will answer; we will get the answer to this question that where do we get maximum yield; where do we get maximum speed, and so on and so forth.

So, this is one aim of this course, for you to do the derivative and understand this experimental data in and out. So, the next aim is basically, so, now, what we do next is let us see some examples– some biological examples– where a graph– a curve– is used to represent some data or some phenomena. So, we will take about five, six examples, all related to biology or our day to day life, where we have some experiment or some, some phenomena going on, and this will be described using a curve.

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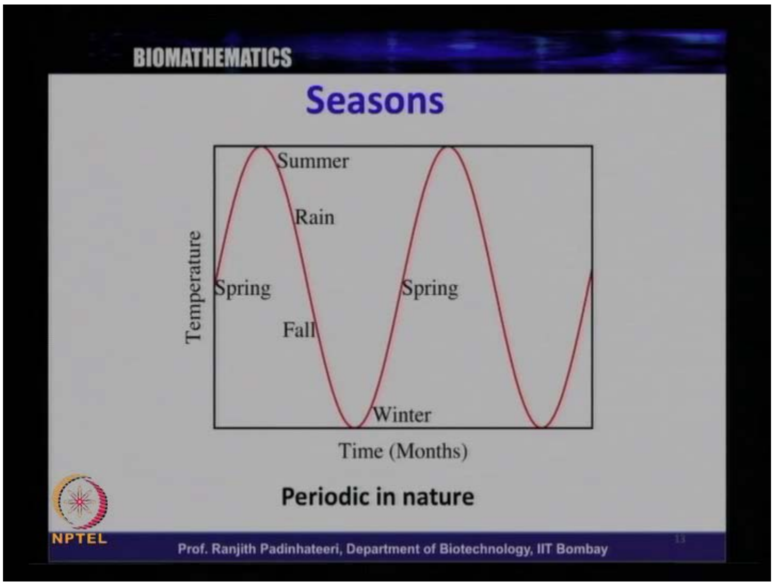

So, let us go to the first example. So, the first example is seasons. So, as you can see in this graph here, so, whenever here something season comes to your mind, what comes when you whenever you listen about seasons? What comes to your mind is basically something in periodic in nature.

So, summer– every year, May is like peak– like it is very hot; it is very warm. So, May every year is like repeating year by year. So, it is like periodic natures keeps repeating. Similarly, rain at some particular time of every year– the monsoon arrives in India and it rains, and similarly, in January, every year, it is winter.

So, the temperature, for example, is varies very low. So, if you let us take temperature as some kind of a measure for a season, and we, we are plotting some temperature, here. This is a very schematic plot of temperature as a function of time, and see this plot– at some point, let say, spring, you have some value of temperature. So, this is just give you some idea; I am not taking numbers here, and none of these examples where numbers as a… As of now, I will give you some overview of this idea. You… I want you to get the idea of this graph– how to represent the particular phenomena using a graph, and once you get this idea, we will put in numbers and try and extract more and more information from this graph.

So, that is the aim. So, let us look back this to the graph, and this temperature here in the Y-axis and time in the X-axis. So, at spring, at a particular time, you have some temperature. So, spring is typically March, and as the time goes, it goes to May and an all that. So, this temperature increases and that is where the summer is.

So, in summer, the temperature is the peak of the temperature in summer, and then it most part of India, rain arrives at some point– July or so, and then the temperature somehow decreases– June, July, the July-August temperature decreases and the temperature decreases further, and at winter is the… you have minimum temperature.

And again, the temperature increases. So, winter is like January. So, we have the minimum, probably, of the temperature, and then temperature slowly increases and again, you have spring– March-April. So, March in most part of India. So, this is the basic idea of this graph. So, this graph essentially represents temperature over seasons, and we can get the… we can… you get the idea of periodicity in this. So, this is periodic in nature.

So, let us go and see the next example; next example is the biological example, where let us say you have a molecular motor– you might of heard of molecular motors like kinesin, dynein, etcetera.

So, every cell has certain motors. Like trucks in a real life, they carry cargo from one part of the… this cell to the other part. So, now, here we are looking at the motion of these motors.

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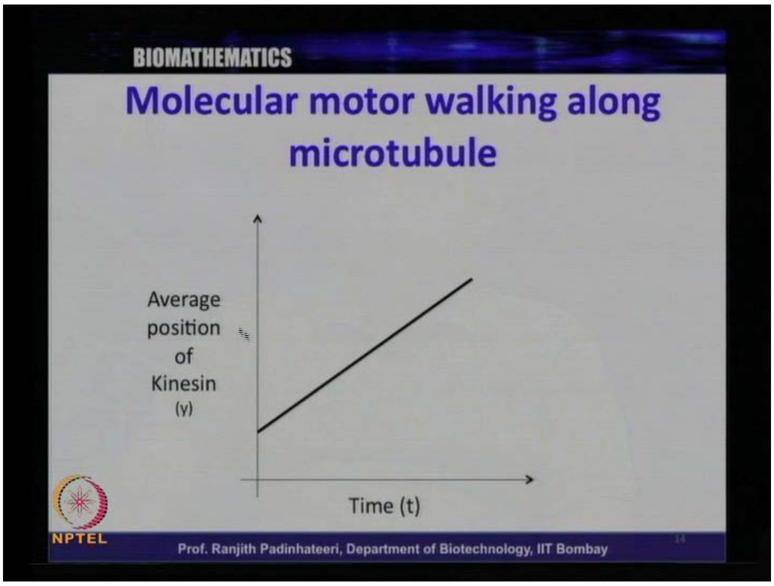

So, let us say, let us have a look at this graph. So, what is plotted in this graph is average position of a particular motor called kinesin in Y-axis as the time progresses. So, at a particular time, it is in a particular position, and along the microtubule track it moves. So, the distance from, let us say, from the center of the cell the distance increases.

So, the distance increases with time. So, this is a simplified version of the reality so, but the aim here again is to convey you the idea that this phenomena of motor walking and the distance from the center of the nucleus, as we go along the microtubule to the periphery of the cell, the distance increases. So, the position– the distance or position increases. So, this is the idea of this graph. Through this graph, I want to convey you and we will learn the mathematics of this graph, and we will get more and more information from this graph, and similar graph in the context of real experimental– in the real experimental context, we will discuss similar graph.

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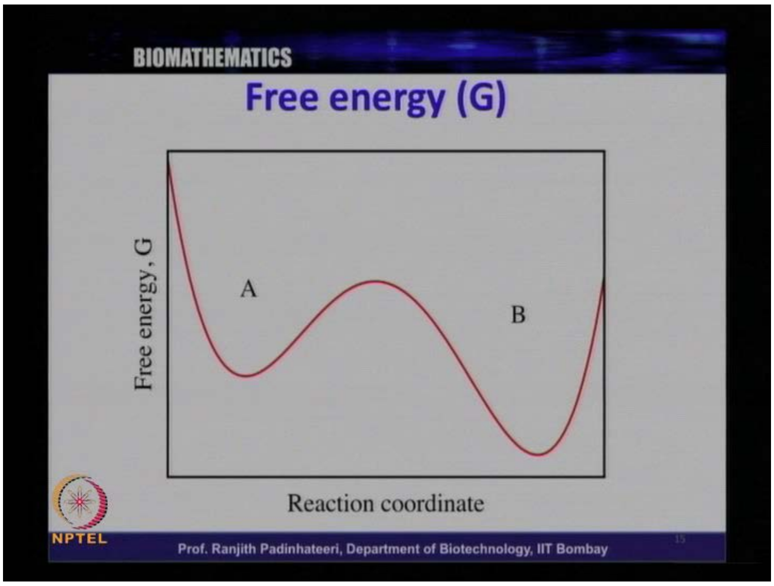

And then, let us see what all we can learn from this graph. So, again, the next example is basically free energy. So, in thermodynamics, you might have heard of free energy and you might heard that proteins can have two states– state A and state B, and similarly, something else– some other things have two states– a reaction, where A goes into to B, and you might a heard that B is preferred because B has lesser free energy.

So, you might have seen this particular graph– let us have a look at this graph. So, free energy is plotted with some reaction coordinate, and you have two states– A and B– and this typical shape of this graph you might have seen in various courses that you have studied, and to understand this very well, one needs to understand some mathematics behind this way– this particular shape– what is the meaning of this particular graph? What is the meaning of states A and B and all that?

To understand all this, basically, one needs to understand the mathematics behind this. Again, in general, thermodynamics itself, to understand thermodynamics itself, one needs to get… get some understanding– gain some understanding– of mathematics.

It is good to know some mathematics so that we can have a better understanding of the thermodynamics, which is an important theoretical framework. Thermodynamics is an important theoretical framework to understand biology, in general, and biophysics, in particular. So, basically, one needs to…. To understand thermodynamics, one needs to know some simple, at least, at least elementary mathematics, and through this course we will learn all mathematics that is required to understand thermodynamics, for example.

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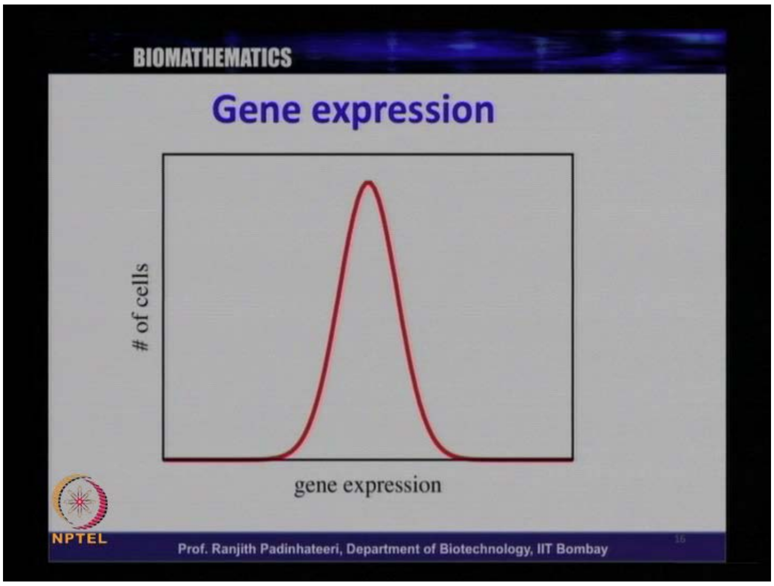

So, now let us go to the next case, which is basically the case of gene expression. So, let us say, you have an experiment– you have lot of cells, and each of the cells, here, measuring how much of particular gene is being expressed.

So, let us take the example of each cell, and take the example of gal gene or any, any gene you have, particularly your favorite gene, and the question we are asking is how much this gene is being expressed? Why it is a… how much the amount of gene expression?

So, cells, you can imagine, will have lots of gene expressed; some other cell will have only very little of this gene expressed. So, there is variability in this gene expression– some cells will have lot of gene expression; some cell lesser gene expression. So, basically, we are counting how many cells have this amount of gene expressed.

How many cells have lot of gene expressed? How many cells have little gene expressed? If you do this counting and we do this plot, we will see this graph that you can have– you have here.

Let us have a look at this graph, where the X-axis is the amount of gene expression and the Y-axis is the number of cells having that amount of gene expression. For example, so, take this value around this peak. So, you have some, some amount of gene expression, and this peak means you have lot of cells.

So, the number of cells is very large– a lot of cells with this particular value of amount of gene expression. If you go to the left and right of the peak, the gene number of cells decreases. What is it mean that only few cells– you have only a few cells with lot of gene expression and a few cells with little gene expression. So, there is an average gene expression amount, and lot of cells have this… this many… this much of gene expression. So, basically, this again is a well-known curve in biology, in mathematics, and to understand a lot of things, one can learn by understanding the equation of this curve and the mathematics behind this curve, one can learn much more things about these experiments.

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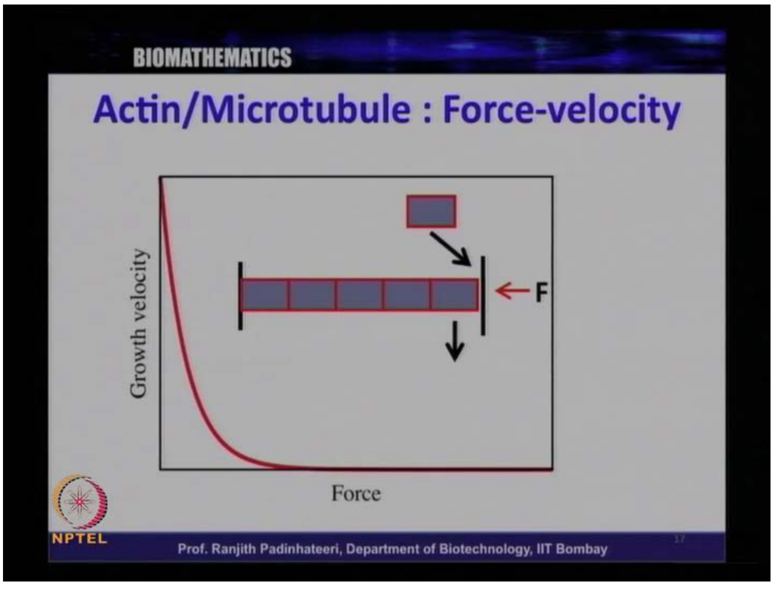

So, now, let us go to the next example, which is basically force-velocity relation; this is also a modern experiment. Then, in a case of growth of actin or microtubule, so, let say you have actin or microtubule growing.

So, let us think of a typical case in biology where you have actin or microtubule growing against the membrane of the cell. So, as they grow, they will exert some force– take, for example, the acrosome region where actin needs to grow and it has to protrude; it has to go through a some…. So, it has to apply some force against a membrane. So, the more the rigid the membrane, it is difficult to push this. So, imagine such as a situation in an in vitro experiment. So, that is shown here in this cartoon here. So, you have a filament here and the filament is growing against a wall here, and you are applying some force here. So, if you apply a lot of force F, it is difficult for this filament to grow.

So, now, if somebody can plot, there are many such experiments. In such experiments, one can plot growth velocity versus force. So, if you apply a force– lot of force– the filament cannot grow. So, the…. So, that is clear. So, the growth velocity will be very small; on other hand, if you do not apply any force at all, then the growth velocity will be large.

So, this is what this graph shows, and again, by studying about this graph and the idea– the mathematics behind this graph, one can understand a lot about this experiment and one can understand, in general, about the mechanism of actin or microtubule growth itself. So, this is another example where one represents their idea– something that you observe in our experiments– through a graph, and this can be studied through mathematical equations.

And as we go along, we will try and understand how to try and study– how to understand these experiments and the mathematics behind it, and using mathematics, how we gain more insight to these experiments. So, the next experiment– next experiment– is measuring the membrane potential. So, you know that ions pass through membranes– the pores of the membranes– and these ions– charged ions– will cause some membrane potential, and this is important in various different, different contexts in biology.

So, now, and you also might have studied at some point that this membrane potential depends on the concentration of the ions. So, the concentration difference or the ratio of the concentration is more, the more the membrane potential is. So, now, the… if we represent… if you do an experiment on measuring the membrane potential as the function of… by varying the concentration of ions, we will get some data, and if you plot this data, we get this particular curve as seen here.

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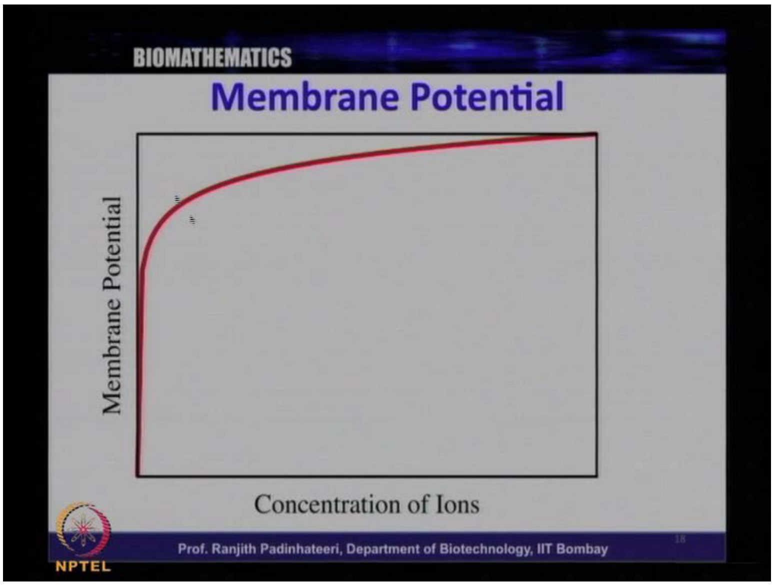

So, let us look at this graph again. So, here it is membrane potential on the Y-axis and concentration of ions of the X-axis. So, you can see that as the concentration increases, the membrane potential increases, and kind of, so, this is some sort of increase, like a logarithmic increase. This is called logarithmic increase in mathematics, but we will understand this– what does this mean? Why does it mean to say it is a logarithmic increase, and so far, and what exactly it… what precisely it means, we will learn as we along this course, but at this point, what I want to tell you is that this curve– the curve that we see in this graph, is an experimental result, and one can learn a lot about these experiments and the phenomenon behind this by learning the nature of the curve– the logarithmic nature– and so on and so forth.

So, that is the… and this is one example in biology, where this is another example one biological… one biological, biological experimental result is described using a graph. So, now, again, we saw growth curve. So, we had seen the fish growth; again, similar thing applies for yeast each cell.

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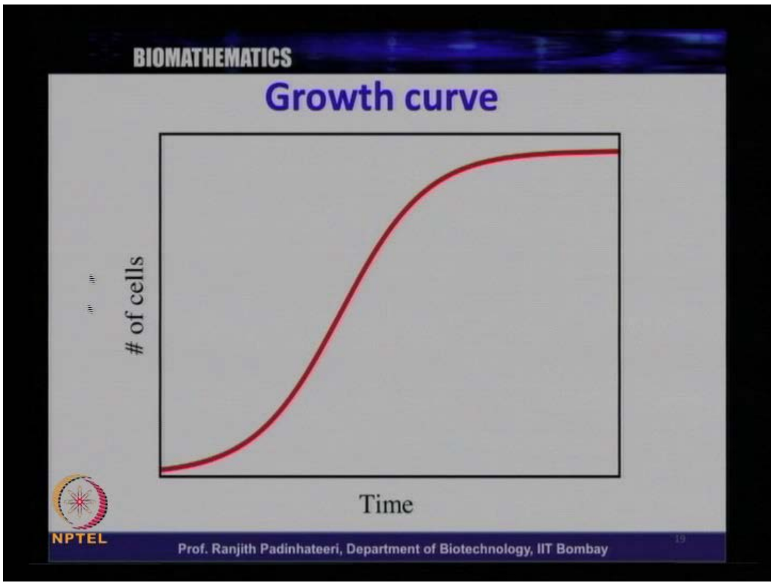

So, you get a growth curve, for example, have a look at again: here– the number of cells versus time– you have a typical growth curve. Again, one can learn a lot of information by understanding the questions behind this, the mathematics behind this and all that.

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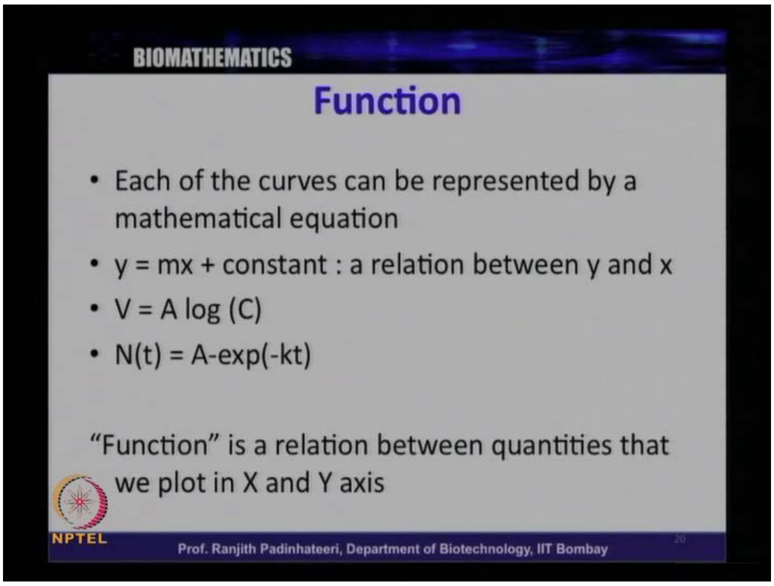

So, now let us go. So, what we have learned, so far, is basically something called an idea. So, idea of a function… So, have a look at this slide. So, each curve that we saw here can be represented by a mathematical equation.

So, we had about six, seven examples, each of the… and we saw different kinds of curves– growth curves, we saw; we saw force-velocity relation; we saw possession as a function of time; we saw concentration velocity; we saw membrane potential as the function of the concentration. So, all this can be represented by some sort of an equation.

So, basically, by representing this through an equation, one can understand a lot about these experiments in these phenomena. For example, let us say, y is equal to mx plus a constant: this is well known equation. Many of you might know this is an equation of a straight line, but in the next course, we will go and learn about this equation. So, and another equation could be V– the potential could be log of concentration, which was C.

And another equation be the number of bacteria is a times a minus x exponential of minus kt. So, all at this point, I am just writing some equation; I do not expect you to understand this equation, but the aim of this course is to make you understand all these equations and getting you familiarized with these equations, and enable you to write these equations yourself and explain the experimental data using these equations. So, basically, when I say an equation, also, mx– y is equal to m x– this is a function.

So, this is the… here, I want to introduce you the idea of the function. So, when I say a function, when you say a function in mathematics, it is the relation– it is relation in two quantities. So, when you plot a graph, it is a basically relation between two quantities– membrane potential versus concentration.

That is what you plot: in X-axis, you plot concentration; in Y-axis, you plot membrane potential. So, basically, a table or a graph gives you some relation between quantities in the X-axis and quantities in the Y-axis. So, and you plot this in a graph. So, the function is essentially this relation: how this particular quantity is related to the other quantity. So, how this Y-axis is related to the X-axis? So, this is the mathematical idea of the function. Intuitively, you already know this, that is why you drew a graph. So, this graph essentially tells you about this function– the nature of the function. Now, what we need to understand the equation behind this graph– behind this curve in the graph. So, in this course, we will go along. So, let us relook couple of examples we looked.

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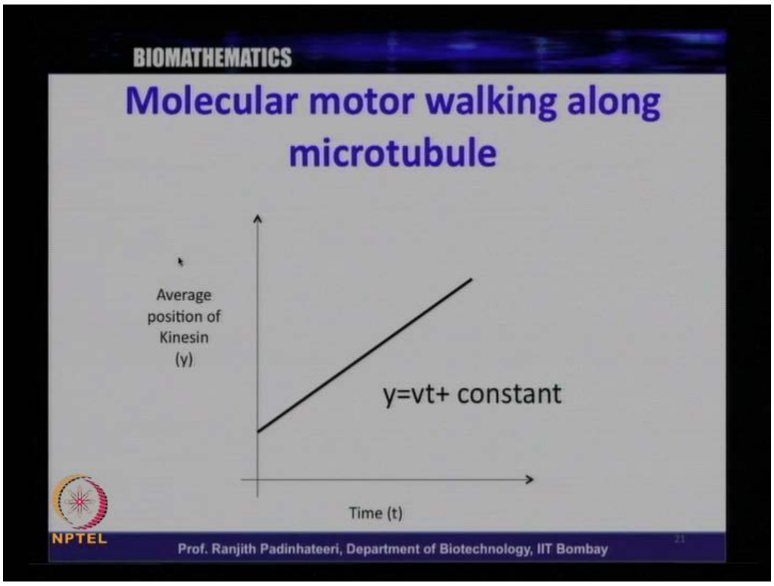

So, let us look the next slide, where you have next curve, we have… we already saw this kinesin position versus time. So, this is like a straight line; you can see, it is like a straight line. So, you can see, the position y is equal to velocity times time t plus some constant.

So, this is… I call y– the position is the function of time. So, y is equal to vt is a relation, and y, one can say, the position y is a function of time. What does it mean? It means, as the time varies, the position also varies; in this case, the average position y increases with time. So, that is… that is why we represent y is equal to vt; the more the t, the more the y is. The numerical value of y will be increased by increasing the y as we increase the value of time.

So, we will see, this is the next. As we go along this course, in the next lecture, we will have a closer look to all this equations, but again what I wanted to say is that– what I wanted to tell you here is the idea of a function– the idea that the position changes with time and this called a function.

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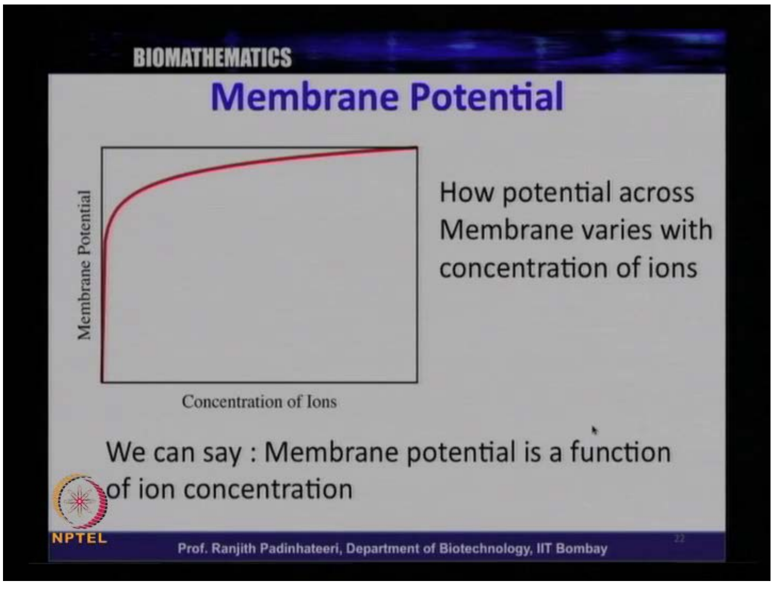

So, now, let us look the next example: the membrane potential. So, at this membrane potential we had, we vary the concentration, and as we vary the concentration, the potential difference across the membrane increases. So, again, if you look at the graph, one can say that as we increase the concentration, the potential increases; therefore, the membrane potential is a function of concentration of ions. So, the question is how the potential across the membrane varies; that is what this function describes. When I say an equation, this equation describes to you how the membrane potential across the… potential across this membrane varies with concentration of ions, and we can say that membrane potential is a function of ion concentration.

So, I hope you get this idea of a function here also; how the membrane potential varies with ions; and this idea– the relation between concentration of ions and the membrane potential– is described by a mathematical function. So, this is the idea of a function. So, let us look the next example of a growth curve again. In the growth curve, we saw that as we go the time the curve, the number cells increases.

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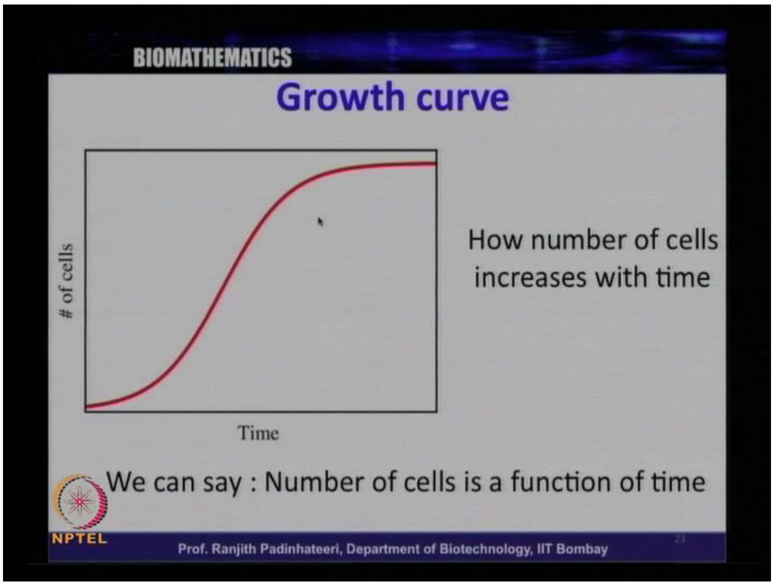

So, if you look at this curve– this graph– the number of cells again increases as a function of time. So, how the number of cells increases with time? They can increase in different ways– linearly; they can increase logarithmically; they can increase exponentially. So, there is a particular way, which… which this number of cells increases, and this precise information that how exactly– whether it is logarithmically, whether it is linearly, whether it is exponentially. So, when I say exponentially, when I say linearly, there all this have some precise meaning.

So, aim of this course, again, is to tell you and make you understand what exactly is the precise meaning of this when somebody says something is increasing exponentially; when somebody else says something is increasing linearly; when somebody says something is increasing logarithmically; what exactly one means? So, to… this course will help you to understand this. So, the all this logarithm, log, exponential, linear– all these are functions. So, linear function, exponential function, logarithmic functions. So, in the next course, again, we will see more closely all these functions.

And we will do an exercise, where to plot all this function by here, you can plot yourself and there will be a clear exercise, where you… you plot yourself this function and understand that how exactly this function behaves in different– in each case by case– we will learn this.

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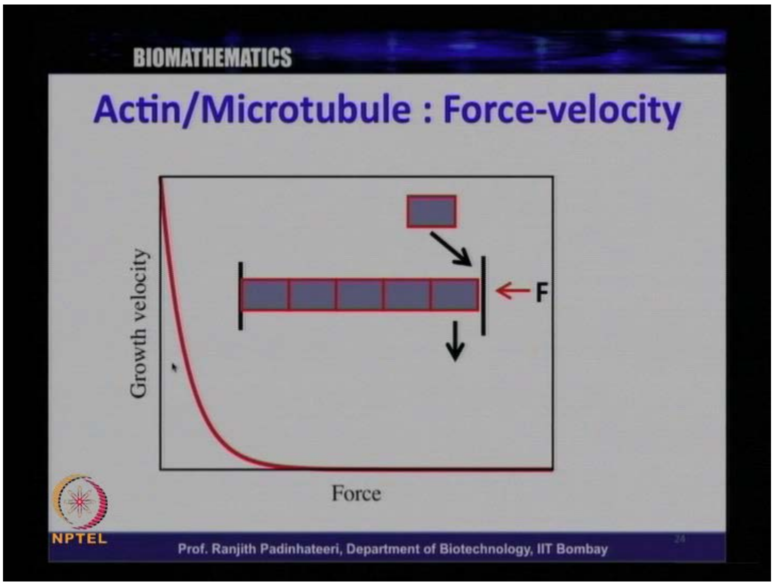

So, again, we can go to the force-velocity relation, again, and we can learn– we can learn how exactly this force-velocity relation varies with… how the growth velocity varies with force.

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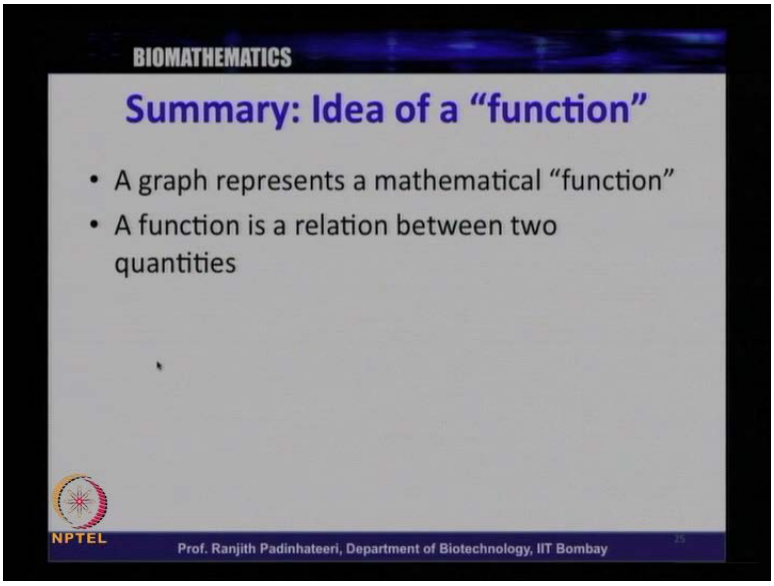

So, these are the examples which we learnt so far, which we had… which we had look at, so far, and the function in each of these examples you will have a closer look. So, to summarize this part of what we said, we studied the idea of a function, so far, and a graph represents, basically, a mathematical function, and the function is a relation between two quantities. So, we had some quantity which we plotted in the X-axis and some other quantity which we plotted in the Y-axis, and the equation basically relates this two quantities, and this what we are basically plotting in a graph.

And while doing in an experiment, we are measuring, basically, two quantities; by varying one quantity, we are measuring some other quantity. So, this relation between these quantities can be described through a mathematical function. So, this is the… basically the idea of a function.

So, now, one can ask– so, we got this idea of a function. Now, the next question is there is many other uses of mathematics in biology. So, another example is if you… they want ask this question– why mathematics? Another example is structure of biomolecules.

So, you have… you know that proteins have a three-dimensional structure. So, this sequence– amino acid sequence– specifies the structure of a proteins and it takes up particular structure in 3D– in three-dimensions, and this structure is related to a function. To have a particular function, you have to have a particular structure. So, basically, the structure of a protein is crucial, and to understand this structure, one has to understand some mathematical coordinates, 3D geometry, and so on and so forth.

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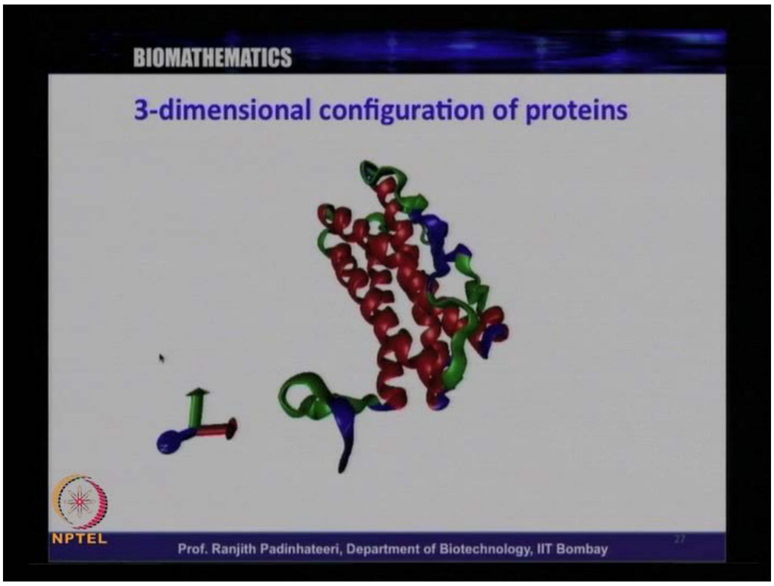

So, this general is a biophysical thing; it is a biophysics… it is a part of biophysics to learn about the structure of a protein, and as you can see in this slide, for example, you have a typical structure of some protein. So, we can see some helices and so on and so forth.

Then you can see the X, Y, Z axis here. So, the 3D geometry, and to understand about the 3D geometry, one has to know some mathematics– some basics of mathematics– the coordinates, Cartesian coordinates, and so on and so forth, and idea of the helix and… and so on and so forth. So, you have plane– planar– and all that. So, basically, what I am trying to say here is that one needs to understand some basic mathematics, again, to understand the 3D structure of the protein. So, that is the example, clearly, where we need mathematics, and another case where we need mathematics is statistics.

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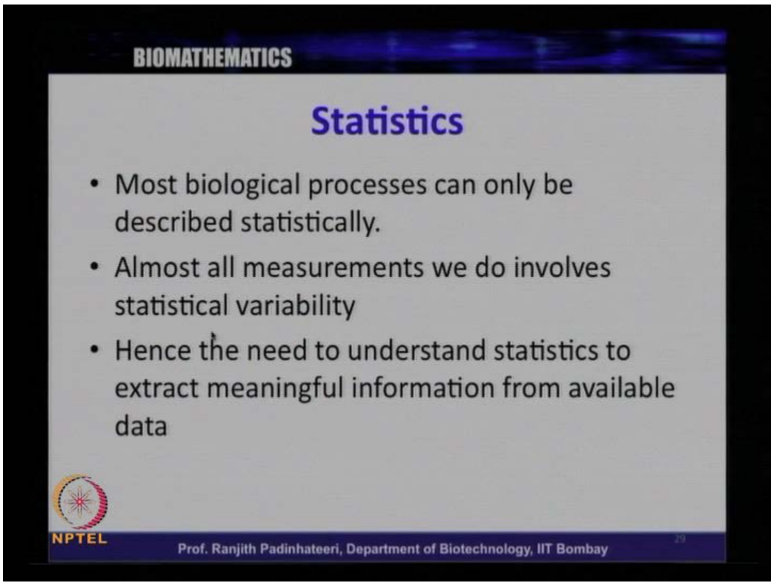

So, as you know that most of the experiments or most of the biological processes can only be described statistically, almost all measurements that we do involves some kind of statistical variability; we saw gene expression, and we will saw this we…. All the statements which I say here– these statements we will explain one… one by one at… at later stage, and we will, at the end of this course, you will precisely… you will understand what all these statements precisely mean, but at this point, just read the statements. So, almost all measurements we do involve statistical variability.

So, we will understand what this statistical variability means, and it is important to understand what this variability means– to understand this– understand various systems– and to get some a meaningful information from this data. So, one needs to understand mathematics, and statistics is a subsection– is part of mathematics– and you can understand the data meaningful. To get meaningful information from an experimental data, one needs to get a… one need to understand this in a better way about distributions, probabilities, and all that, and so, let us look at couple of examples where its obvious statistics is in play.

So, let us say the size. So, size of anything– size of, let us take this simplest example: size of a human beings, right? The height– height of a people in a classroom– it is a statistical quality, and it can be size of a protein; it can be size of an organism; it can be size of chromosomes; it can be size of anything, and it will have some kind of a distribution. So, this idea of distribution is of a statistical nature and that distribution conveys a lot of information.

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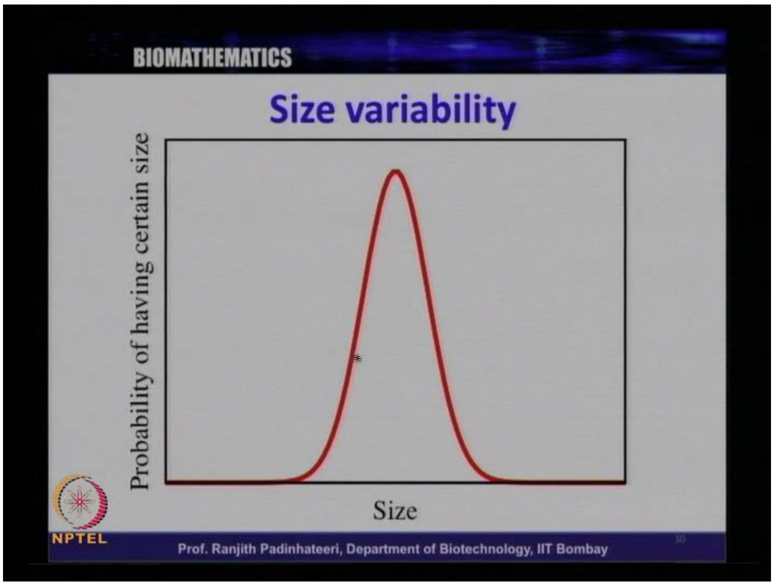

So, let us have look at this slide. One typical distribution called normal distribution is plotted here. So, this normal distribution what…. So, in the X-axis, you have size– let us say, height– and the probability that this many pupils have this size– the probability of having certain size is plotted in the Y-axis and it will have such a curve, and such a curve is basically what describes this probability.

Now, this idea that…. So, the idea variability of size is included where embedded in this graph. So, by understanding the mathematics behind this graph, one gets a lot of information and one can understand what do we mean by variability; what do we mean by average. So, average, standard deviation, etcetera, etcetera, are quantities that we use very often, used to describe experimental data, and one needs to understand statistics basically to understand what we precisely mean by all this.

So, again, we will go if you have a section, we describe statistics and how do we… how to understand this statistical…? How do we statistically interpret biologically… biological data– the experimental data? And another example is probability; you could ask this question– what is the probability? You might have seen in biomathematics; some of you might have seen what is the probability that a particular enzyme binds to the target. So, known the sequence, you can ask this question– what is the probability that this enzyme will bind into a particular sequence?

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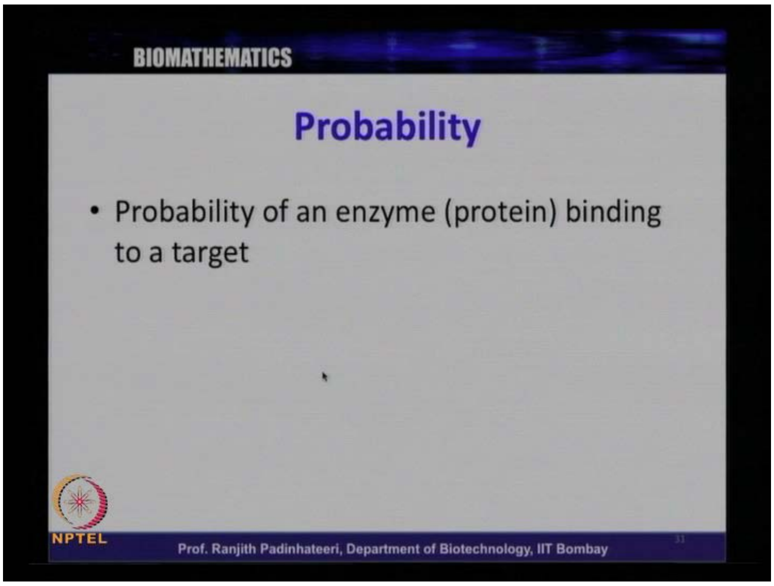

Again, this is a question of probability. So, one need to know statistics. So, again it is mathematical in nature, and this is the idea of mutation itself has– it is a mutation is the random event, and the randomness and statistics and randomness are very closely related with each other. So, as we go along, we will go into this idea of how the mutation leads to variability, and how should be… how do we understand this, and how it is important in the biological context.

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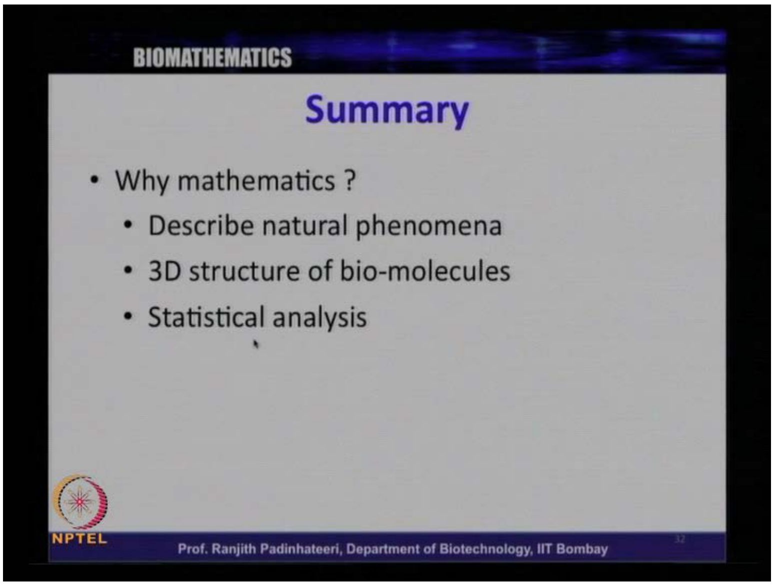

So, in in… to summarize, we had this question– we started with this question– why mathematics? So, mathematics describes natural phenomena; it can describe 3D structures of biomolecules and one needs to have mathematics to describe 3D structure of biomolecules, and one needs to learn… learn statistics to do… one needs biomathematics to do statistical analysis.

So, there are lot of… it is very clear–it is very evident– that one needs mathematics to understand, if you want to meaningfully understand some set of data, and if you want to gain more insights to some experiments; if you want to extract maximum information from some experiments, one needs to understand mathematics and use mathematics so that we can get lot of information.

So, as we go along in this course, we will see… in this course, we will learn how to use mathematics to understand different biological systems, and how we… and we will learn basic fundamentals of mathematics. So, we will start with functions– simple functions– in the next… next class, and we will describe simplest functions like linear function, exponential functions, and all that, and when we describe, we will not use a typical… you will not do this like a mathematics course, like a typical mathematical course– mathematics course in a mathematics department.

On the other hand, we will take a biological example, where for example, where exponential function appears, and we will explain how this function– how, how this particular function is useful– and how, how does this particular function describes this experimental data, and we will go ahead. So, today, we will stop here, and the next class, see you in the next class.