Physics-PHY101-Lecture #01

INTRODUCTION TO PHYSICS & THIS COURSE

1.1. Introduction

Welcome to Physics. We will embark on a long journey that will consist of 45 lectures. Nevertheless, I hope will find it interesting and enjoyable. As I continued to study and research in this subject my interest in this subject grew. But before we come to physics, I want to remind all students that physics is the branch of science and must be aware of the fact that our modern world is based on concepts from science, modern machines/equipment rely on science and inventions such as telephones, satellites, etc. are based on science. But in reality, science is a way of thinking that only accepts the rule of reasoning. In which the judgment of truth and falsehood is based on the sets of results from an experiment. So as mentioned earlier physics is the branch of science that is often termed as the "queen" of science and is rightly said to be the greatest science.

The history of science is as old as the story of mankind. When did it start? It is probably tens of thousands of years old. Every civilization has contributed to it. It may have started from the time of Babylon, but after that, the Greeks created great perfection in it, and then Chinese, Hindu and Islamic civilizations advanced it. Physics in its present form is not that much old. It started about three and a half hundred years ago, and it was a time when a great scientific revolution took place in Europe, which is called the Scientific Revolution, and this was the time when great scientists like Newton revolutionized it which is the reason why our present-day world is so different from previous eras.

Physics is related to every worldly thing (actually everything in the whole universe) with its main purpose being to fully understand the whole physical world/universe and it means that everything, no matter how big or small it is. For example, if we look at our solar system (as shown in Figure 1.1), the sun is at the center and planets revolve around it. Human beings have thought a lot over many fundamental questions like, how heat is produced in the sun and then how it reaches the Earth. Why and how does the Earth rotate around the sun? Contrary to this, in general, if anything moves it moves in a straight line but the earth continues to move around the sun in a circular path.

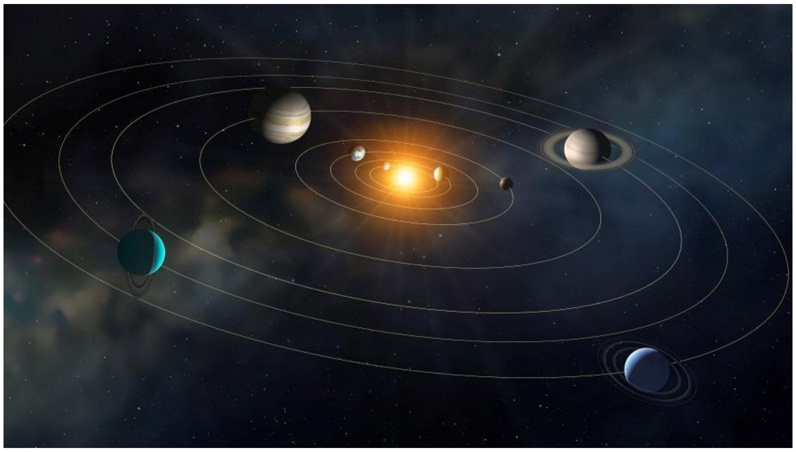

Figure 1.1. Schematic of Solar System. Sun at the center and planets revolving around the Sun.

Atom was considered to be the smallest thing in the world making up all the matter. The atom was considered to be a basic building block but now we know that it can be further broken down as it has a center called the nucleus and electrons revolve around the nucleus as shown in Figure 1.2(a). Upon closer inspection of the nucleus Protons and neutrons can be observed. Interestingly protons and neutrons can be further subdivided into particles called quarks as shown in Figure 1.2(b).

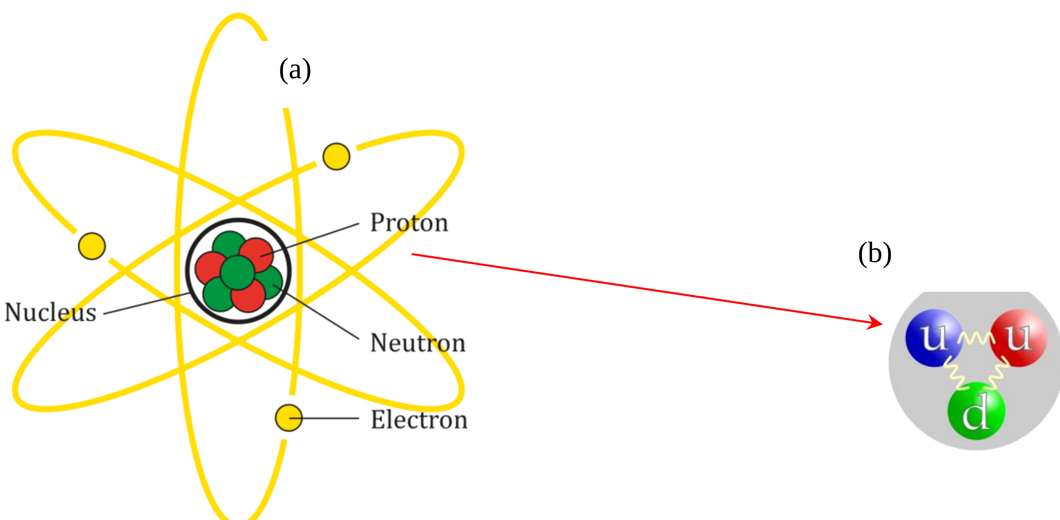

Figure 1.2. (a) Atomic Structure showing nucleus at the center having Proton and Neutron. Electrons revolve around the nucleus. (b) Protons can be subdivided into quarks.

So, on the one hand physics is related to the sun, the solar system, galaxies, and the universe itself, and on the other hand, it is also related to atoms and subatomic particles, and lastly all kinds of entities that come in between these two extremes. These entities can be classified as forms of matter which are as follows

1. Solids
2. Liquids
3. Gases

The first form of matter is called solids in which atoms can't move very far from each other for example table salt. The sodium atom in the salt cannot move away from the chlorine atoms. Atoms are fixed to each other and immobile as shown in Figure 1.3.

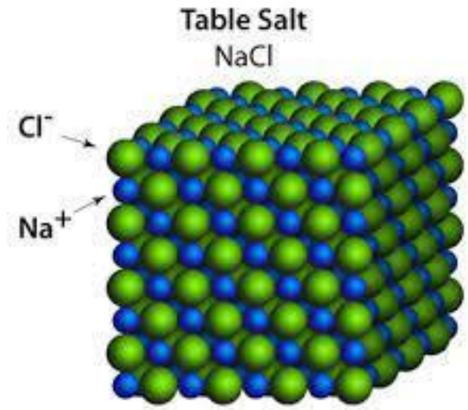

Figure 1.3. Structure of common table Salt (Sodium Chloride, NaCl)

Matter can be in a liquid state and when the substance is in the liquid state, the atoms or molecules that are there can move quite far from each other but still there is some kind of attraction among them confining them. For example, if we put water in a vessel, then this water takes the shape of the vessel and this is a characteristic of the matter when it is in a liquid state. Lastly, there is another situation in which matter can be in a gas state. Well, if the matter is in a gaseous state, then its atoms and molecules can move around freely anywhere and far away from each other. Gases like oxygen, hydrogen, and nitrogen make up our atmosphere and without oxygen, we cannot even breathe.

The purpose of this course is to introduce students to the vast subject of physics. Although even experts in the field only know a fraction of it, we will do our best to learn and gain knowledge related to physics in all 45 lectures. The main goal of this course is to teach problem-solving to students. Science is not just about solving existing problems, but also about understanding and solving new and challenging problems.

To achieve this goal, students must listen to all video lectures, read all materials (such as handouts and referred books) given for this course, and complete the assignments (samples) provided after going through the materials. It's essential to pay attention to the assignments since they will help students to apply the knowledge they have gained.

Studying physics has multiple purposes, one of which is to gain knowledge for future courses. In every field of engineering, ranging from bridge construction to designing electric components, fundamental physics knowledge is required. However, it is crucial to develop the habit of critical thinking and evaluation based on intellect.

Science relies on reason, logic, and experience to determine the truth or falsehood of a claim. Physics is often considered a difficult subject because it involves mathematics. Calculus is required, but we will develop as much calculus as we need. Knowledge of algebra, trigonometry, linear equations, or quadratic equations is necessary prerequisite knowledge.

1.2. Main Areas of Physics:

Following are the main areas of physics

1. Classical Mechanics
2. Electricity and Magnetism
3. Thermal Physics
4. Quantum Mechanics

First of all, classical mechanics is the field of physics, which is attributed to Isaac Newton. It is related to objects, the movement of objects, momentum, force, and energy, these are all concepts that come under classical mechanics. After this, we will talk about electricity and magnetism. Now, electricity and magnetism are not so different from each other and this is a discovery of James Clerk Maxwell from about 200 years ago. And now all modern technologies in the world (telephone, radio, television etc.) are based on these discoveries. So, we will study electricity and magnetism after classical mechanics. When we have this much background, then we will come to thermal physics, i.e. the physics of heat. Concepts like temperature and entropy will be discussed.

In these three areas, classical mechanics, electricity and magnetism and thermal physics, we will spend a lot of time on them. But there is another field, which is more related to the physics of atoms. We will not be able to spend much time on this because to understand it and to study it correctly, you need special mathematics. So, my advice to those people who want to study physics further is that you should study mathematics separately.

1.3. Dimension:

Just like a house is built with bricks, in every field of physics, everything is built with three types of bricks. These are called dimensions. Dimension is a concept which is about 200 years old and it was proposed by a French scientist named Joseph Fourier. Now, let us focus on the three most important fundamental dimensions[1].

1. Time T
2. Length L
3. Mass M

First of all, there is a dimension of time. What is the reality of time? Now, philosophers have been discussing this for centuries, but scientists and physicists are not very interested in these discussions. In physics, we want to know how to measure a thing or a dimension. There is a method to measure time which is called a clock. Now, clocks can be of different types. For example, my pulse is also a clock although not an accurate one. When I stand here, my pulse moves at one speed but when I run, my pulse increases. But there is a better clock, a pendulum. Now, the pendulum moves to and fro. And every time it moves to and fro, the time duration is the same. The earth rotates around its axis and when it rotates, it comes back exactly to the same position after 24 hours. Similarly, when the earth rotates around the sun, we say that one year has passed. The best clock is called the atomic clock which is based on the regular vibration of an atom. With this, we can measure time with better accuracy than one part in a billion. To measure length, normally we need a ruler but its accuracy is not very good. In modern ways, we measure with the wavelength of atoms. So, accuracy is much better as compared to the ruler. The third fundamental dimension is mass, which tells us how much matter is present in a body. For example, if I have an apple and I add another apple to it, the mass will double (assuming both apples are identical). The more mass

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[1] Fundamental and Derived Dimensions

there is, the more difficult it will be to move. For example, if I put equal force on a rickshaw and a taxi, the rickshaw will move faster and the taxi will move slower. So, mass tells us how much resistance to motion there is.

Now, let us look at dimensional quantities, which are made up of mass, length and time. For example, the dimension of the area is LxL or L^2. For a volume, it will be L^3. For example, for a box, its length multiplied by width multiplied by height will give its volume having the dimension of L^3. We can make another thing from this, which is called density. The dimensions of density will be mass per unit volume or M / L^3. In the same way, we find out the dimensions of frequency. What is frequency? For example, there is a pendulum that completes 2 cycles in a second. So, its frequency is 2. Or, if we consider alternating current (AC) of electricity, which changes its polarity 50 times every second. So, its frequency is 50. Frequency has a dimension of 1/T or T^{-1}. The dimensions of speed are L/T or LT^{-1}. But there are some quantities which have no dimensions such as angle. The angle between two adjacent fingers is dimensionless. Degrees are units not the dimension of the angle[2]. In short, there are seven fundamental dimensions as given in the table. And everything in physics, every other quantity can be constructed in terms of these. Fundamental set dimension is given below in form of table.

Fundamental Quantity	**Dimension**	**SI Unit**
Length	[L]	Meter (m)
Time	[T]	Second (s)
Mass	[M]	Kilogram (kg)
Temperature	[θ]	Kelvin (K)
Electric Current	[I]	Ampere (A)
Amount of Substance	[N]	Mole (mol)
Luminous Intensity	[J]	Candela (cd)

[2] Dimensions refer to the fundamental physical properties that describe a quantity. They are abstract and universal, not tied to any specific measurement system. In physics, there are several fundamental dimensions, such as length (L), mass (M), and time (T). Units, on the other hand, are specific measurements that quantify the magnitude of a physical quantity. Units are used to express how much of a particular dimension is present in a given quantity. Dimensions represent the abstract properties of a quantity, while units are specific measurements that combine a numerical value with dimensions to quantify that property. The combination of dimensions and units provides a complete description of a physical quantity in a specific measurement system.

1.4. Units

As per the previous example, there is an angle between my two adjacent fingers, and measure this angle in terms of degrees or radians. So now we will need a system of units. There are two different unit systems. The first one is called the MKS system. MKS means meter, kilogram, second system. where the length is measured in meters. The mass is measured in kilograms. And the time is measured in seconds. Then there is another system called the CGS system. CGS means centimeter, gram, second system. Here, the length is measured in centimeters. The mass is measured in grams. And the time is measured in seconds, like MKS.

Approximate lengths in meters (m) of a few entities are given below in the table

Distance	**Length (m)**
Tall Person	2×10^{0}
Cricket Ground	3×10^{2}
Radius of Earth	6.4×10^{6}
Earth to Sun	1.5×10^{11}
Radius of Universe	1×10^{26}
Thickness of Paper	1×10^{-4}
Diameter of Hydrogen atom	1×10^{-10}
Diameter of Proton	1×10^{-15}

For very large lengths, scientific notation is required and a power of 10 is used. So, for example, the size of the earth is 6.4×10^{6} meters and the distance of the sun from the Earth is about 1.5×10^{11} meters. Similarly, the universe is very vast, but today we know that it is not unlimited, it is limited and its radius is about 1×10^{26} meters. Now, on the other hand, there are many small things in the world. For example, the thickness of a piece of paper is about 10^{-4} meters and atom, for example, a hydrogen atom, its radius is about 10^{-10} meters. The proton in it is 100,000 times smaller than that and its size is 10^{-15} meters. So, these are different scales of length.

Similarly, there are different scales of time and mass. The approximate time for particular events is given below.

Event	**Time (s)**
Light travels from Earth to the moon	1.3×10^0
One hour	3.6×10^3
One year	3.2×10^7
Age of universe	5×10^{17}
Open/close eyelid	1×10^0
One cycle of radio wave	1×10^{-8}

Light moves at a very fast speed, but light also needs time to go from Earth to the moon and this is about 1.3 seconds, i.e. 1.3×10^0 s. In an hour, there are 3600 seconds, i.e. 3.6×10^3 s. In a year, there are 3.2×10^7 s. Today, we also know that the universe was formed about 15 billion years ago and if written in seconds, then it becomes about 5×10^{17} s. On the other hand, there are such events in which the duration is very short. For example, if you blink your eyes, you can do this twice in a second, i.e. the frequency is 2 per second. For a radio wave (electromagnetic wave) in which the descent and ascent happens 10^8 in a second, i.e. its time duration is 1×10^{-8} seconds.

There are also different scales of mass as listed in the table below.

Object	**Mass (kg)**
Student	7×10^1
Car	1×10^3

Ship	1×10^6
Erath	6×10^{24}
Sun	2×10^{30}
Milky Way (Galaxy)	4×10^{41}
Dust Particle	1×10^{-9}
Oxygen Atom	3×10^{-25}
Electron	9×10^{-31}

For example, the weight of an ordinary person is about 70 kilograms, the weight of a car is about 1000 kilograms, while the weight of a ship is 1000 times more, i.e. 1×10^6 kg. It is worth noting that powers of 10 are used to write very large as well as very small quantities. Earth's weight is 6×10^{24} kg and the sun are about 1 million times heavier; its weight is 2×10^{30} kg and if we calculate the weight of our galaxy, then that is about 4×10^{41} kg. Dust particle barely weighs 1×10^{-9} kg. An atom of oxygen is much lighter than this as its weight is about 3×10^{-25} kg and an electron is 1000 times lighter than that, and its weight is 9×10^{-31} kg.

1.5.Conversion of Units

Going from a one-unit system (like MKS or CGS) to another system is called conversion of units. There are some useful conversion factors i.e. 1 inch is equal to 2.54 centimeters and 1 meter is equal to 3.28 feet. Sometimes it is required to convert other quantities as well. For example, converting miles per hour (mi/hr) into meters per second (m/s). 1 mile per hour (mi/hr) can be easily converted to meter per second (m/s) using only two following conversions and cross multiplications:

$$1\,mi = 5280\,ft \rightarrow 1 = \frac{5280\,ft}{1\,mi}$$

$$1\,m = 3.28\,ft \rightarrow 1 = \frac{1\,m}{3.28\,ft}$$

$$1\,hr = 3600\,s \rightarrow 1 = \frac{1\,hr}{3600\,s}$$

So, multiplying all the above unities by $1\frac{mi}{hr}$

$$1\ \frac{mi}{hr}.1\ .1.1 = \left(1\ \frac{mi}{hr}\right).\left(\frac{5280\ ft}{1\ mi}\right).\left(\frac{1\ m}{3.28\ ft}\right).\left(\frac{1\ hr}{3600\ s}\right)$$

By cancelling units, we get

$$1\ \frac{mi}{hr} = \frac{5280}{3.28 \times 3600}\ \frac{m}{s} = 0.477\frac{m}{s}$$

This was also an example of dimensional analysis. Even though units were of miles per hour on the left side and meters per second on the right side, both were length over time [L/T]. So, the dimensions were equal in both cases. So, it becomes very important that the dimensions on the left side should be on the right side in every equation. If this is not the case, then it means that the equation cannot be correct.

For example, let's assume the following equation

$$d = vt^2$$

Where d is distance, v is velocity and t is time. Dimension on the left side of the equation is [L] and on the right side, it is $[LT^{-1}]\ [T^2] = [LT]$ which is not equal to the left side so this equation is incorrect. Explain whether the following equation(s) could possibly be right or wrong based on Dimensional analysis.

$$v^2 = u^2 + at$$
$$v^2 = u^2 + 3a^2t^2$$

Here *v* and *u* are velocities, *a* is acceleration, and *t* is time.

1.6. <u>Rules of Dimensions</u>

Dimensions (M, L, and T) can be considered as algebraic quantities. Likewise, symbols and dimensions can be added and subtracted but rules differ from conventional algebraic rules. Multiplication and division are applicable to dimensions. For example, in the case of length divided by length [L/L] dimension will cancel and the result will be a dimensionless quantity. Dimension for speed can be simplified to $[LT^{-1}]$ based on division. So [M], [L] and [T] can be divided and multiplied but cannot be added or subtracted from each other. For example, [L] + [T] is physically not realizable. Even [T^2] cannot be added to [T]. So, addition and subtraction of the same dimension is only possible.

1.7. Accuracy

Whenever we measure a quantity its accuracy cannot be 100%. For example, if a certain length is measured using a conventional ruler to be 2.95 centimeters (cm), it cannot be measured as 2.952467 cm. This is because of the fact that measuring equipment always has inaccuracy associated with it so significant figures become relevant. It is not advised to do calculations using certain equipment that misrepresents their accuracy.

For example, if you are asked to measure the weight of 3 apples and then calculate the average weight. Its average weight cannot be measured at 550.234 grams. This is not possible because the equipment being used to measure weight is not 100% accurate. For this reason, we need to be aware of the fact that what level of accuracy is required for the measurement of an algebraic or an arithmetic quantity. Only an appropriate and reliable number of digits should be used for the measurement process.

If length is being measured by a ruler, then there can be at most 1% accuracy, not more than that. Some general rules should be considered for calculations. For example, when two numbers are added together if one number has an accuracy of 95.9 and the other has an accuracy of 39.32, then you add them together and it becomes 135.22. But it would be more appropriate to call its accuracy 135. So, there is no point in adding the decimal figures to it. It would not be of any benefit. When subtracting when multiplying and when dividing, for example, multiplying, one number has an accuracy of one figure of decimal i.e. 105.8 and the other has an accuracy of 31.4. If we multiply both, then we have six figures. But we should round off this. This means that after the decimal figure, the 0.12 does not have any meaning. We should leave it. So, if we divide 105.8 by 31.4, then we will get many decimal figures. But it would be appropriate to cut it off at 3.37 because the two numbers are known only to one decimal figure of accuracy. Therefore, 5 decimal figures after 3 do not give much information.

1.8. Orders of Magnitude:

Order of magnitudes means that we want to approximately calculate a quantity. In physics, it is often not possible to do exact calculations. Either we do not have enough information or the problem is very difficult or whatever. So, it is extremely important that we can estimate. Now, we would like to discuss the order of magnitude. Order of magnitude means that when we write in powers of 10, then if it is written near the nearest power of 10. Let us give you an example. A man's weight is approximately 100 kilograms. Now, I agree that 100 kilograms is of very few people. Usually, it is half of that. But writing it as 10 to the power of 2 kilograms can be useful in some situations. Similarly, if we take the weight of a child, then it can be approximately 10 kilograms. And if you take a cricket ball, then its weight is approximately 1 kilogram. Now, here we have only talked about the closest powers of 10. So, we are not saying that this is accurate, but as mentioned earlier, whenever an estimate is required, we can use this method.

Let’s have a look at an example. How many seconds are there in a person's life? Let's calculate it. If a person is 80 years old, then you can calculate it from 365 days per year. Next, there are 24 hours in a day. And there are 60 minutes in an hour. And there are 60 seconds in a minute. So, calculate by multiplying these conversion factors (i.e. 80 x 365 x 24 x 60 x 60). As a result, we will get 2.5 x 10^9 seconds. On the other hand, if we estimate it, then assume a person's life is 100 years for the purpose of approximation. There are 365 days in a year but we assume 100 days per year which is the closest power of 10 and so on as shown in the table below. Upon multiplication of all conversion factors, we get 10^9 seconds. On one hand, we did a very accurate calculation to get 80 years which is equivalent to 2.5 x 10^9 seconds. And on the other hand, if we make these coarse estimates, then there is not much difference. In both cases, we get 10^9 seconds only. Although in one calculation we get 2.5 and in the other we get unity. But this difference is very small. Approximate reasoning sometimes gives us very useful results.

Conversion Factor	**Closest Power of 10**	**Closest Power of 10 (scientific notation)**
80 yr	100 yr	10^2 yr
365 days/yr	100 days/yr	10^2 days/yr
24 hr/day	10 hr/day	10^1 hr/day
60 min/hr	100 min/hr	10^2 min/hr
60 s/min	100 s/min	10^2 s/min

There once a news that armed men robbed 10 crore rupees (100 million rupees) from shopkeepers and ran away on a motorcycle. Now the question arises, can such a large amount be put on a motorcycle or not? To find out, let us do a small experiment. A balancing scale (as shown in the video lecture) is used to measure the weight of 10 currency notes each having a value of 1000 rupees. As seen in the video lecture, the weight of 10,000 rupees (10 notes x 1000 rupees/note) is 20 grams. This means that the weight of 100,000 rupees is 200 grams, which is equal to 0.2 kilograms. And the weight of 1 crore rupees is 20 kilograms. The weight of 10 crores is 200 kilograms. Now 200 kilograms is equal to the weight of 3 people. And it is not possible that such a large amount can be put on a motorcycle other than two people riding it. Therefore, there is something doubtful about the whole incident. This was a very ordinary example of scientific methodology. However, we will see in the upcoming lectures that this methodology is used in every field of physics, and it is called the scientific method.

Observations are made based on which an initial thought is created. After that, the hypothesis is born in the mind. For now, we do not know whether this hypothesis is right or wrong. Now, to test it, its predictable outcome has to be compared with more observations. It has to be experimentally verified. When a law is tested again and again and it is seen again and again that it is successful, means the hypothesis combined with the observations and they connect, then it gets the status of scientific theory. We will give you an example of Newton's theory of gravitation and Newton's theory of motion. Now, we will see in the next lectures, those lectures which are related to classical mechanics and which are associated with Newton's theory, what phenomena are achieved by those. But as we know, Einstein who came after Newton proved that Newton's theory cannot be completely correct. So, does this mean that Newton's theory is wrong? No, this does not mean at all. Now, if you apply Newton's theory to any particle, as long as that particle is not moving close to the speed of light, that is, it is not moving at this extreme speed, then Newton's theory can be used very easily and effectively. For example, when we send a spacecraft to a planet far away from the Earth, then we use Newton's laws. We do not need to use Einstein's laws. The theory of relativity created by Einstein is used only in those cases where particles’ speed is close to the speed of light. For example, in research of particle physics particle accelerators are used and electrons move at a speed close to the speed of light.

Finally, I will say something which may seem a little strange to you. In this lecture, I emphasized that physics is related to the material world and that its purpose is to find out the rules and laws that are the basis of our universe. So, we are talking about materialistic things. But on the other hand, the concepts of physics are abstract and only exist in our minds. These concepts are the creation of our minds. Now, we would like to clarify this a little. In the upcoming lectures, you will hear again and again that this is a free particle, a free body, that this is a point, that this is a straight line. But there is no such thing as a free body. We say that there is nothing free on Earth because gravity pulls that body towards the Earth. So, take it a little farther from Earth, take it to the outer atmosphere. How far should we take it? Take it 1 crore miles away from the earth. Take it 100 crore miles away. But that will not be enough because there will always be a minute force that pulls that body towards the earth.

And if we take it too far, then there are galaxies and other planets, therefore, a completely free body does not exist. It exists only in one place and that is in our brains. And similarly, if we talk about a dot. We assume that a dot is a very tiny thing and we can make it by putting a pencil on paper. But if we look at it under a microscope, the higher the magnification bigger the dot we will observe. Now a pencil's tip cannot be made so fine because a pencil's tip itself is made up of atoms and atoms themselves are not dots. Therefore, there is no dot in the world and there is no straight line either. The point is that the concepts of physics are in one’s mind. Therefore, these concepts are created and evolve, which is why physics is a progressive discipline. In which there is progress all the time. And this is the most interesting thing about physics. So, I hope that in the next lectures, you will feel that this is an interesting topic. That there is progress in it and that it invokes thinking. To learn this subject, you will have to work a little hard. As long as you do not solve problems by yourself. You have to believe that you can solve every problem by yourself. And the more problems you solve, your physics skills will increase accordingly. Secondly, do not assume that you will be able to solve all your problems with a single course be it this course or any other course. There is a vast ocean of knowledge in this world and we can pick up a drop of it at one time. It is a lifelong effort to understand physics and science. And we hope that you will also be a part of this effort. The journey of physics will continue in the next lecture. We will meet again at that time. With your permission, goodbye.