UNDERSTANDING

PHYSICS FOR EVERYONE

NATURE

VEDANG
SATI

“Physics for everyone”

Understanding Nature

Vedang Sati

Introduction

Physics is an interesting subject but it becomes even more amazing when one recognizes its physical importance. The real joy of physics is attained by living it. This book *Physics for everyone* comes with the perspective to enlighten every human mind with the love of physics. If you know the rules, you can enjoy it too!

Each chapter is easy to read and follow. Your understanding is complemented by numerous real-life examples. Conceptual problems and activities are given at the end of each chapter. Thus, you can be sure that you are going to learn a great deal of physics with a lot of curiosity about your immediate surroundings. This book is not intended to physics students. This book tries to allure all people toward the laws of nature. Don't worry about mathematics. Physics is about observing nature and enjoying its rules and regulations. All that you need is a desire to learn and a bit of curiosity to look around!

What do you need?

You need your eyes wide open. Look around yourself with a bit more passion and a bit more curiosity. This is physics for everyone!

What will you learn?

You will learn about physics in detail and believe me, you will learn it all very easily! You will learn about motion, gravity, heat and energy, about light and electromagnetism, about atoms, about the universe and a lot of amazing physical phenomena!

Why do you need to know it?

Your immediate surroundings are governed by the laws of physics. The devices and technology that you use are because of physics. Our discussion will be very informal, as if we were talking to each other. You will have to know the rules before you start loving physics.

Get ready to learn about how stars make light, how light reflects and refracts, how atomic bombs are made, how lightning occurs and how we use physics in our daily lives!

Vedang Sati

Contents

Chapter 1

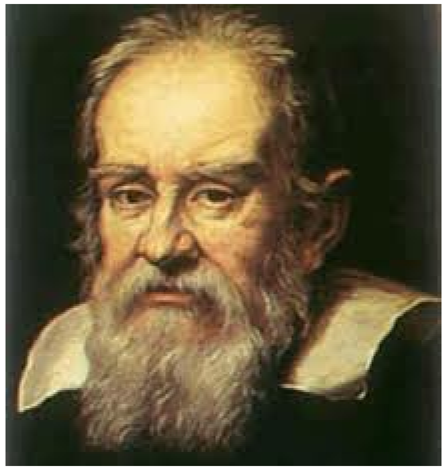
Understanding Motion

Motion is a part of our everyday lives. You often hear people saying how fast a formula one car moves. They appreciate a physical quantity called speed. Speed is how fast an object moves. When bodies move, they have speeds. For example, if a body covers 100 meters in 10 seconds, its speed will be 10 meters per second. But here we get it wrong. We are actually talking about the average speed in this case.

Suppose Allen travels from city A to city B in just 2 hours, travelling a distance of 500 kilometers. His average speed is 250 kilometers every hour, thus covering 500 in 2 hours. But this gives no information about journey at every instant. We do not know about his instantaneous speed. Instantaneous speed and average speed are two different quantities. While average speed sums up the journey, instantaneous speed gives the speed at every moment. In our day to day life, we talk about speed when we want to tell how fast it moves. Our very notion of speed is the distance covered by an object within some time interval. This is speed.

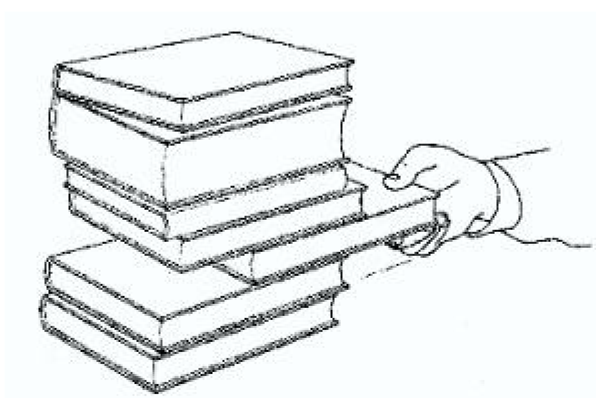
Many of you may have heard about acceleration. If you are very interested in cars, especially super cars, you always read about the acceleration of the car. Some cars can accelerate from 0 meters per second to 100 meters per second in just three seconds. What does this suggest about the car? Suppose the car starts with a speed of zero, then it can pick up the speed of 100 in just three seconds. This is what acceleration means. Acceleration is the rate of change of speeds. Acceleration tells us how quickly the car switches between two speeds.

Our ancestors have tried to explain motion. Many failed and many survived the test of nature. It was Aristotle who began the discussion. What did Aristotle suggest? He said that bodies moved because they were acted upon by a force. Everyone could see that when they kicked a ball, it moved. Another of Aristotle’s statements was that bodies stopped moving when they get tired. This statement, although stupid, was accepted by people – believing in Aristotle’s authority.

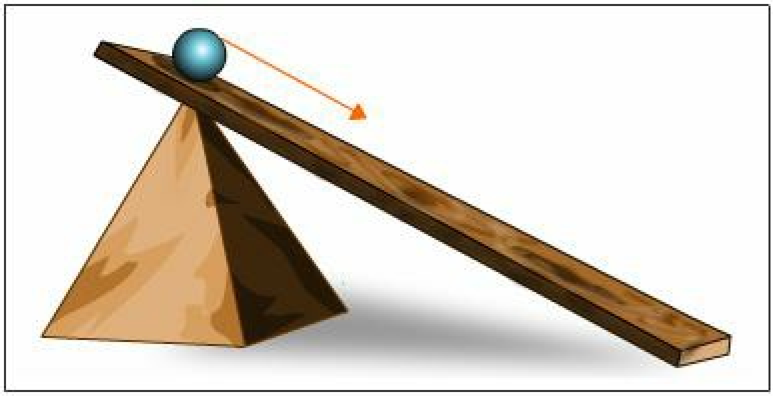


But Galileo was a fine man. He wanted to test Aristotle. He wanted to question each of Aristotle's postulates. The Greek philosopher Aristotle had once said, *if a feather and a stone fell at the same time from some height, the stone would hit the ground first because of greater attraction to the earth.* According to Aristotle, heavier the body, more the pull will be.

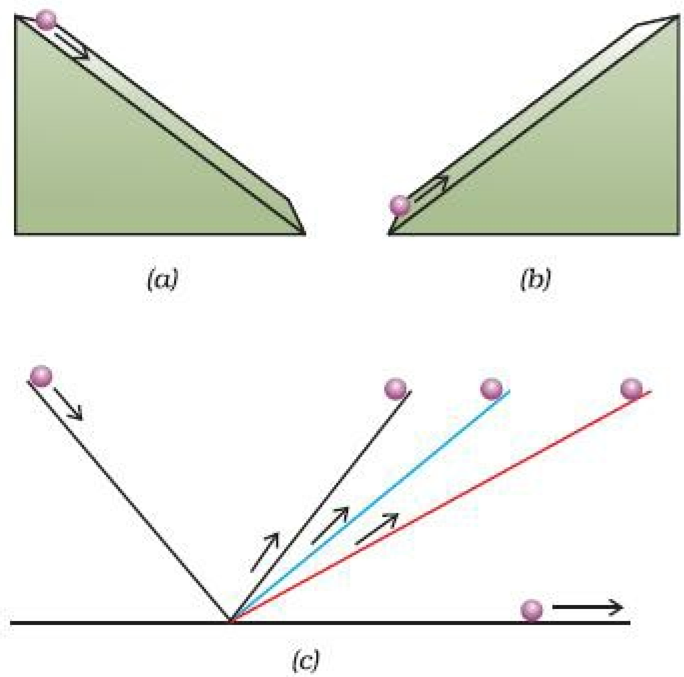
Galileo started from scratch. He asked himself: W*hy do bodies move and why do they stop?* Galileo came up with good answers. He introduced a new term called *inertia.* Galileo told people that each body with mass has inertia. Inertia can be compared with laziness – the more the mass, the lazier the body becomes. It is the tendency to resist changes. A heavier body has greater inertia due to greater mass, thus it will resist any change to its state. If this body is at rest, it would tend to remain at rest forever. If it is in motion, it will tend to remain in motion forever. Every object has inertia, it just so happens that an object with more mass has more inertia. Look at the image following this paragraph. You pull out one of the books, the rest of the books resist change in their states, they tend to remain on the top of the bottom two books, and they thus fall down. But how did Galileo find inertia in the first place? How did he guess its existence?



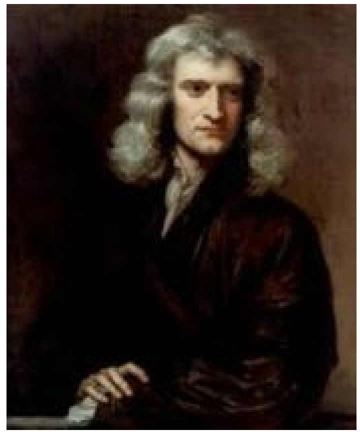
Galileo worked with rolling bodies. He worked with pebbles, round stones and inclined planes. He rolled down marbles from one plane to another and observed the height reached by the marble on the second plane. This is reflected in the image below.



He found that when he released a marble from height H from the first inclined plane, the ball tries to reach the same height H on the second inclined plane. He was not convinced. He used smoother inclined planes and better rolling marbles. He did the experiments again and he found that the marble reached the same heights. The next part of his experiment was to reduce the incline of the second plane as shown below.



The marble moved further distance in order to reach the same height H from where it was released. You will learn in the chapter *Understanding Energy* that since energy is conserved, the marble should reach the same height H. Ultimately, Galileo reduced the incline of the second plane to zero. In this way, he imagined that if the plane surface were frictionless *(actually friction was first identified by Galileo, Aristotle knew nothing about frictional forces – these forces oppose motion, like air drag, ground friction, etc.)* the ball should roll on and on, forever, in order to reach the same height! Thus he found that an object at rest tends to remain at rest and an object in motion tends to remain in motion unless and until, an external agency, an external force causes it to act otherwise. Believe me, this experiment is very beautiful and I have performed this experiment at home. I found results agreeing with Galileo's inertia. The beauty of physics is that Newton used Galileo's discoveries and converted them into three laws of motion.



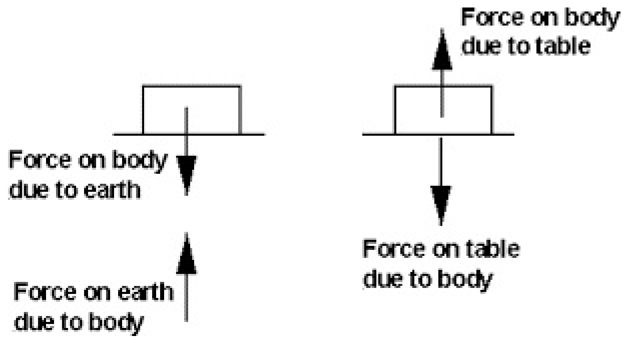
Isaac Newton was an English natural philosopher. The first encounter with physics was the fall of an apple. An apple fell and Newton asked why. That simple question led him to uncover gravitation. He found that the same force with which earth had attracted apple, kept earth around the sun! In fact, Newton found that every object in the universe attracted every other object with a mutual force. Gravity was born. We will discuss about gravity in the next chapter. In this chapter, we will see how Newton explained motion of bodies.

The first law of motion has already been discussed. An object at rest remains at rest forever unless any external act, causes it to act otherwise. A body in motion always remains in uniform motion unless and until an external act causes any change. So far, so good – the object is either at zero velocity or uniform velocity. But Newton's second law shows us what happens when an external force does act on the body.

The body starts to accelerate. Force causes change in speeds. Will the body move without any force? Yes, a body can move without any force acting on it – but it would not change its speed until acted upon by a force, a net force.

Last but not the least, Newton's third law of motion states that every action has an equal and opposite reaction. If you push on a wall, the wall pushed back at you. If you kick a ball, you apply force on the ball, in return, the ball also applied a force on your leg – instantaneously so that there is an action-reaction pair. You will find that action and reaction occur on two different bodies.

For example: An object is kept on a table. There are two forces which are acting on this object. These two forces which are impressed on the object will have their reactions too – according to the third law of motion. The first of these forces is earth's pull – acting downward (object's weight). Earth is pulling this object down! But this object stays where it is – on the table! Why? This is because of the second force being impressed on it. The second force is due to the table – which is an upward force. We know the magnitude of this upward force exerted by the table – it should equal the weight of the object so as to keep the net force zero and to keep the object where it is. You can see the diagram below – which shows the forces impressed ***on*** the object. But the two forces have their reactions too. Earth pulls the object down, but in return, object pulls the earth upward! This is the first action-reaction pair. The second force which was due to the table, also has a reaction. This object exerts a reaction force on the table too! These forces are shown in the diagram below – these are the forces exerted ***by*** the object. Two forces were impressed on the object and two forces were exerted by the object itself, thus forming two action-reaction pairs as shown below. You have a clear understanding of forces now. You know the laws of motion.



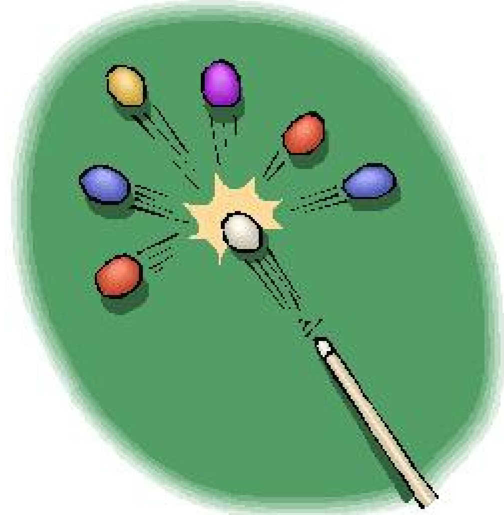
But you still don't know most of the things about motion. We want to ask the following questions:

1. Why do objects move?
2. What happens when a body collides with another body?
3. Why do objects in motion stop?
4. And what exactly motion is?

Let me tell you of what we have been doing so far. We have got only an idea of what motion is. We define motion as movement, right? But there is more to it, as we shall see. We also discussed about how Galileo challenged Aristotle and how he experimented with rolling bodies. We talked about inertia but there is a deeper meaning to it, which we have to understand.

Let us answer the first question. Why do objects move? If you were Aristotle, you would say, *objects move because of the force implied on them.* Then, you would be wrong! Force is not required at all to keep a body moving. A force is required to change how a body is moving – it can speed it up or slow it down. So why do objects move? The answer is *inertia.* Suppose that you are travelling in a car at 30 meters per second. Suddenly, brakes were applied and the car screeches and stops. You tend to fall forward. This is why there are airbags in your car to keep you safe. What if you were travelling at 90 meters per second and there were no airbags in your old car!

The next question is: *What happens when a body collides with another body?* To answer this question, we have to understand a new physical quantity. You have heard about this and you use it in your life. This is called *momentum.* "Oh I wish I could keep the momentum on!" – This is one of the many sentences that we say. What is momentum? Believe me or not, momentum is a very physical quantity, one that has enormous physical significance. You get the idea of momentum when a body collides with another body. What happens when a moving ball collides with a stationary ball? You see that the ball that was once stationary also starts to move. Why does it move?

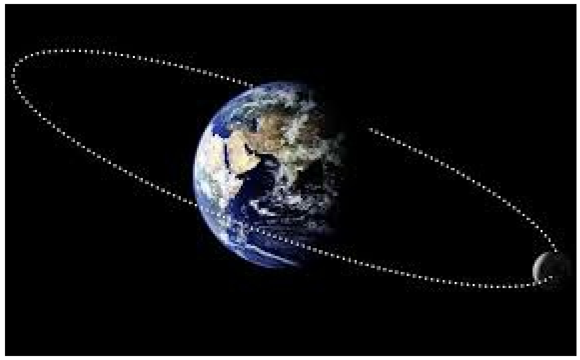


It moves because of transfer of momentum. Momentum is a quantity that an object has and which it can transfer to another body. You cannot transfer speed or acceleration like that – all that you can do is transfer momentum and see what happens. A moving body has momentum – only a moving body. A body which is kept on a table has zero momentum. It is not moving. A boy running at 5 steps per second has momentum too. A truck moving at 30 meters per second has momentum too.

So we were talking about collisions. What would be the consequence of the collision of a truck and a bicycle? Suppose that you are riding a bicycle, at some normal speed. I give you two options, out of which you have to choose one. You have no other choice but to choose out of these two options: You either collide with a car travelling at 20 meters per second or with a fully-loaded truck moving at the same speed. What will you choose? Obviously, if you are clever enough (and if you definitely have no other option left) you will choose to collide with the car. Why? It is obvious that you would get more hurt – or you would die – if you chose to collide with that heavily loaded truck. Two objects with different masses moving at the same speed have different momenta. The one with greater mass is the one with greater momentum. Thus, more momentum would be transferred to you and your puny bicycle. You would be severely injured. You now have the idea of what momentum is and in this way, we have answered the second question.

The third question, however, is a bit trickier. Why do objects stop moving? Aristotle had been fooling around with people by saying that objects stopped because they got tired. Do tennis balls get tired? Actually, he was fooling around with his own mind. It was Galileo who fully realised why objects in motion stopped. Galileo introduced a new term – Friction. Friction is a force, an opposing force. An object moves on a marbled floor. That same object now moves on a rough floor, like that of a playground, with tall grass. It is obvious that it would stop quickly on the rough surface. Roll a ball and you will find the answer.

What exactly motion is? This is the last question that we need to answer to fully understand motion. Haven't we done enough? We know that whenever an object changes its position with time, it moves. It moves with certain speed and if it changes its speed, it is accelerating. We found that to accelerate, forces have to be applied. Yet, we do not know the most important thing about motion. Do not worry, I am going to give you a hint. So here is the hint: *Aristotle saw that the sun, the moon, the stars and the planets were crossing earth's sky. They were seen moving, yet he did not see earth to be* *moving. Earth seemed to be static. Thus Aristotle concluded that earth was stationary and that it was the centre of the universe and every other heavenly body revolved around the majestic earth.*



Did you get the hint? Motion is relative. It was Galileo who realised that motion was relative. Actually earth is moving around the sun. So why don't we see it moving? This is because all objects on earth (including earth itself) are moving at the same speed. The pen on your study table, the books on the bed and your TV are static relative to you (you are sitting on a chair) but if someone on moon observed you, he would see you moving – moving at the same speed at which earth is moving!

So if you get a chance, try to move abreast a bus. You move in your car and the bus moves side by side. You see the bus and the bus sees you. Match the speeds and you feel no motion relative to bus. I get amazed whenever I practice this! I get amazed by the relativity of motion. For someone inside the bus, you are stationary, since your speed matches that of the bus. But for someone standing on the ground, you are in motion – only because there is a difference in speeds.

This is motion.

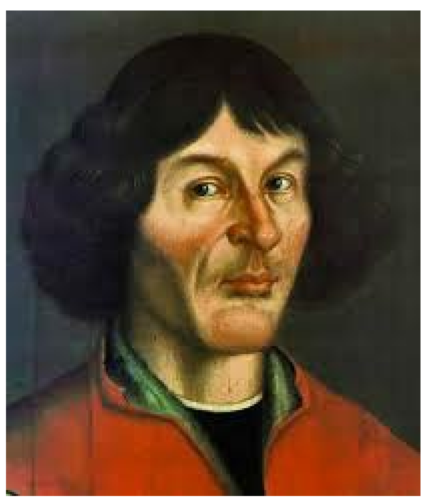
Chapter 2

Understanding Gravity

You are always acted upon by a force called gravity. Gravitation is a universal force and every object in the universe attracts every other body with a force proportional to the product of their masses. The force falls off as the distance increases. How do you know that you are under earth's gravitational pull? Even though you cannot directly see gravity, you can still feel it. Jump up and you will get down. You should not try to fly because you cannot. Gravity pulls you down.

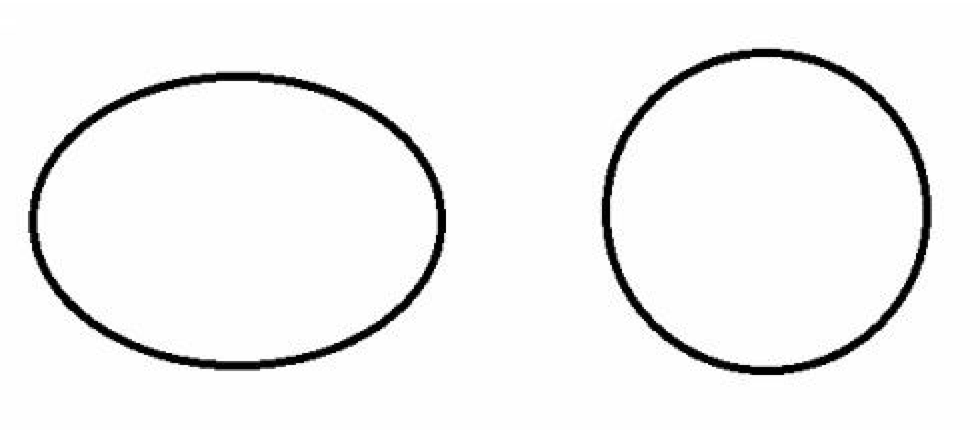
But nature has some boundaries. Earth has a limited gravity. We have learned to overcome gravitational pull and there is a special speed with which if we travel, we could fly into space. If you throw a stone straight up, gravity will eventually bring it down. But if you have enough power to throw this stone at a special speed, and let us assume that the stone continues to travel at the same speed, the stone would fly out into space. This special speed is called escape speed, because it can be used to escape earth – its value is 11.2 km / s directed upward.

We are here to understand gravity. What is gravity? How did we get to know about this force and how did we understand its behavior? It turns out that there are 5 heroes of gravity. They are Copernicus, Galileo, Kepler, Newton and Einstein. They have led to our understanding of the universe as well as gravity. So let us begin the story of gravity.



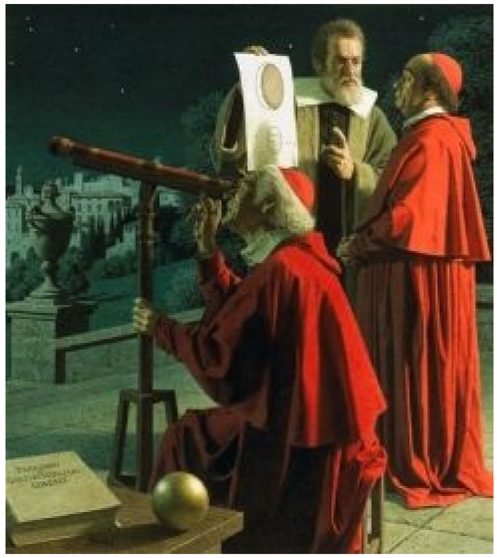
It was Nicholas Copernicus, a Polish priest who predicted that sun was the centre and not the earth. Before him, everybody had believed on the geo-centric model of solar system, i.e. earth was the centre of the universe. This earth-centred model was supported and firmly established by Aristotle and Ptolemy. Thus, it was a daring move to challenge the old theory. Copernicus was punished for his bold proposition.

Copernicus was unlucky because he did not have enough data to explain what he wanted to say. The next hero was Johannes Kepler. He was a German astronomer and mathematician who was keenly interested in geometry and wanted to use geometry to explain celestial motion. He used Tycho Brahe's data – another astronomer of his day and deduced three laws of planetary motion which are called Kepler's laws of planetary motion. Kepler had always supported Copernican theory – every object revolved around the sun. The most important law, however, was that of the shape of the orbits. Copernicus had used circular orbits in his theoretical model but when matched with Brahe's data, only elliptical orbits fit the best. An ellipse is an elongated circle. A circle has a unique centre – on the other hand, an ellipse has two foci. You can think that circle *is an ellipse* in which distance between the two foci is 0, while an ellipse is an elongated circle in which the two foci are separated by some distance. The figure below shows you an ellipse and a circle.



It was Galileo who was the first to realise the existence of a mutual force between heavenly bodies because he found tiny bodies circling the planet Jupiter. He therefore modified the Copernican theory by proposing that *not every object had to directly revolve around the sun.* Galileo also confirmed the Copernican theory because he had proof. He had a special instrument called telescope with which he became the first man to peep into space. He discovered Saturn's rings and was astonished at the beauty of Saturn. Galileo paved the way for Newton to realise the existence of gravity.

Isaac Newton was an extraordinary kid. He was curious about nature, about plants and animals. He soon realised his interest in mathematics and physics. This story is very interesting. He was once sitting under a tree and was accompanied by an apple fall. An apple fell and a quick question popped up: *Why did the apple fall down?* Why didn't it go up? These questions haunted Newton for several years until he came up with an answer. As he fought for his answers, he came up with a new branch of mathematics called calculus. He used his imagination and his knowledge of mathematics to unlock a secret force – the force of gravity. Gravity was born and Newton explained that every object attracted every other within the universe with a mutual force.



We have thus studied about the four heroes so far. One more is left. But before that, we must encounter special and amazing characteristics of gravity. So let us first examine the fall of an apple. When an apple falls, it is pulled by the earth. This force is F, it just so happens that the apple also pulls the earth with the same force F but directed oppositely. Thus, earth pulls the apple down, and the apple pulls the earth upward – very much in agreement with Newton's third law of motion. We see only the apple moving and not the earth because we know that the same force is acting on the tiny apple and the same force is acting on the massive earth. If you try to move a bicycle with a force F and you use the same force to move a mountain, you would hardly succeed. In our example, we have an apple, which is less massive than a bicycle and we have earth, more massive than any mountain. So we won't see the earth moving, we would see the apple fall down. This is obvious but now you also know why it should be obvious.

The second thing that we must know about is *weight*. Mass and weight are two different quantities. Your weight is the direct result of earth's gravitation. If you were on the moon, you would weigh very less than what you weigh on earth but if you were on Jupiter, you would weigh more than the double than what you weigh on earth. Thus, weight is always perceived and it changes from place to place.