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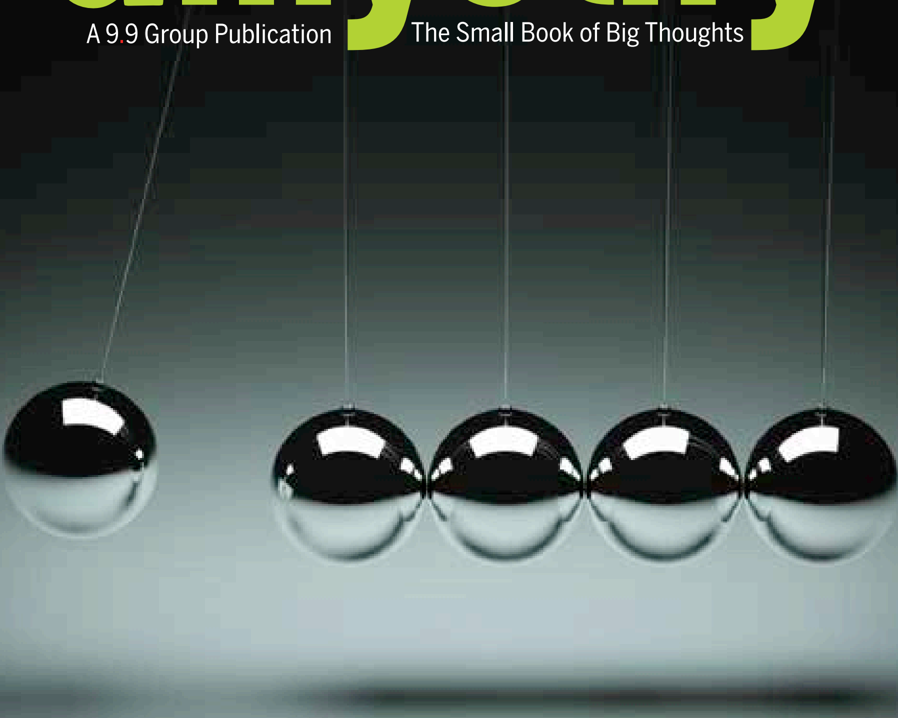
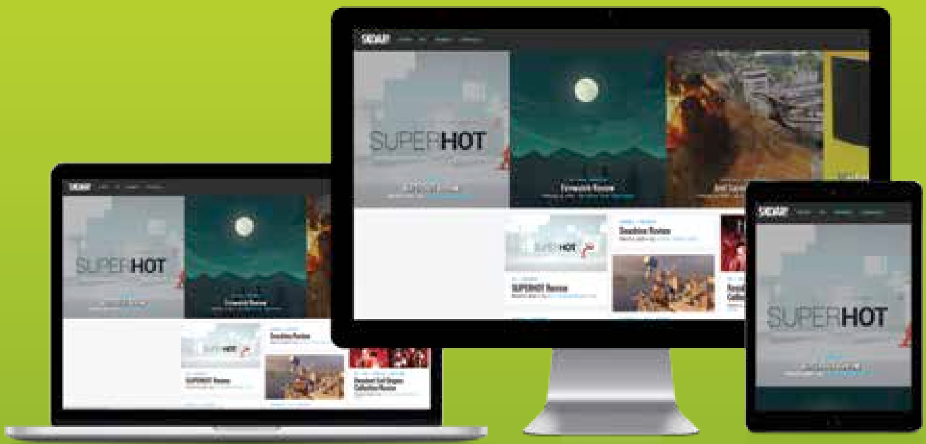
The Small Book of Big Thoughts



MOTION

SICKNESS?


SUPERHOT

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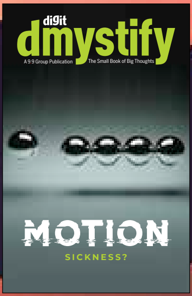
INSIDE

What state?

To move or not to move.
That is the question.



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Moving around - By what virtue?

That is the question that we set out to answer when we started writing this book. Everything moves around us. But, there are very few reasons we know why they behave the way they do when moving. Did you know that when you touch your keyboard to type, the contact between your fingers and keys technically is a collision?

Well, there are several other questions like this around the concepts of motion that we have looked to answer by explaining to you the concepts and theories and making physics a tad bit more enjoyable. Of course, in this small book, you will not get everything that a normal textbook would offer. But, stay assured reading this, even in a hurry, will make you an expert enough that you'd be able to geek out wherever and whenever you want to. ■

Setting things straight

Making strong foundations before facing off against the big three

Motion. What is it? What do you mean by motion? Think about it for a minute. Have an answer? No? Then read and find out.

Drum roll

Like always, there is no concrete answer. Well it sort of depends on where you are while observing motion. Confused? Don't blame us for this. Blame science!

To explain the concept of motion, let's take the example of a person sitting next to you in a car. When you look at the person from the inside, the person looks to be stationary. However, when looked at from the outside, the person looks to be in motion. This shows how important perspectve is when studying motion. Let's take another example.

If you are in a stationary train, you can sometimes feel like you're in motion because of a moving train right next to you. This is a phenomenon most of must have felt at some point. This illusion is also an observation of motion.

As absurd as it may sound, motion has no definitive value without the observer. To put it more scientifically, motion is a combined outcome of a body under observation and the observer. This is where our first term, "the frame of observation"comes in and incidentally will be used quite frequently in this book.

So, Frame of Observation is defined as the fixed point of view of a body being observed. The effect of a frame of observation or reference, as many also call it, on a body's perception of motion is relative. Meaning if the frame of reference changes, then there

He was fined for speeding. To me, it looked like he was stationary.

will be a new definition attached to whether the observed body is at rest or in motion, as we saw in the earlier examples. In the rest of the book, whenever we are explaining concepts, please keep in mind that there is a constant frame of reference throughout, which we will be following to avoid any confusion or unnecessary complications.

Forward and ROTATE!

Whenever a force acts on a body, it either moves forward in the direction of the force being applied or rotates around an axis. From this, we see that there are two fundamental types of motions. They are – rotational and translational (or linear) motion.

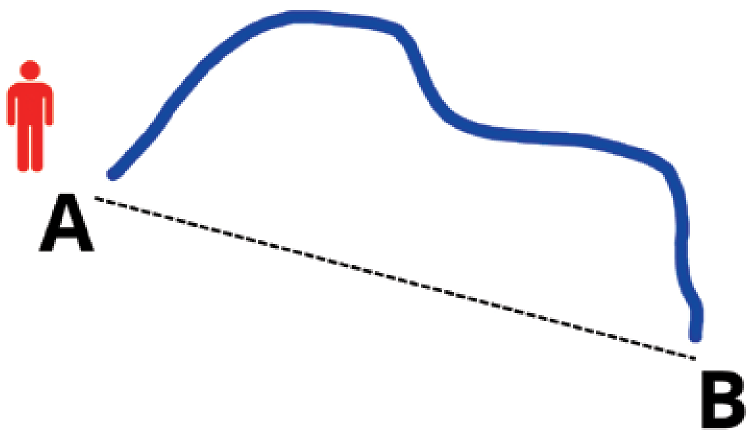
If a force being applied causes a body to move forward in a straight line in the same direction as that of the applied force, then that is called translational or linear motion. If an externally applied force causes a body to rotate around an axis, causing a turning effect on the body, it is called rotational force.

Going forward in this and the following chapters, we will majorly deal with translational motion. The rotational motion will only come into the picture in chapter 4, where we have an entire section dedicated to explaining its concepts. For now, let's focus on translational motion.

From point A to B

In the world of physics, it is the laws that govern every discussion and debate, and not the literal meaning of words. No matter how similar they sound, if the laws say they are different, they are. Take the example of distance and displacement. In conversation, we often tend to use them interchangeably. However, when it comes to physics, the tables turn.

When studying motion, it is important to understand the difference between distance and displacement. Let's start by understanding what the meaning of the term distance is. It is simply the aggregate measure of the path travelled by a body. Coming to displacement, is the absolute separation between the start and finish points of a body that is moving. To better understand this, let us look at the image.



Distance vs Displacement

Here, let us assume that the man is taking the blue path to travel from point A to B. So, the distance travelled by the man would be equal to the length of the path. However, his displacement would just be the measure of the straight dotted line between points A and B. From this, we can draw a conclusion about distance and displacement that will also help you better understand the difference between the two. Since distance is a direction-independent measure, it is a scalar quantity. On the other hand, displacement is dependent on direction, so that makes it a vector quantity.

Now, let's define what speed is, but with the addition of the factors that make it different from velocity.

Zoomin' around

Let's dive into the formal definition of speed. It is the measure of the distance covered by a moving body in a defined time interval. To better say it, speed is the measure of the 'rapidity' of the movement of a body. You must be familiar with the formula to calculate speed, so we will now explain how to calculate a body's instantaneous speed. The speed formula that we know is, distance divided by total time, gives us average speed. But we also know that during motion, there are changes in speed. So, that's why we should know how to calculate the instantaneous speed of a body.

7000 RPM... That's where you've made it

The instantaneous speed of a body is calculated by dividing the change in speed of a body by the time interval in which that change is taking place. Mathematically, it is derived as follows:

$$v_{av} = \Delta s/\Delta t$$

(v_{av} is the average speed, *Ds* distance travelled in the given time interval, *Dt* is the chosen time interval)

Now, if we apply the concept of limits, and make the value of Dt vanishingly small, then we will get a ratio that has a finite limit. That will help us measure instantaneous speed of a moving body. The formula will be:

$$v = \lim_{\Delta t \to 0} \frac{\Delta s}{\Delta t} = \frac{ds}{dt}$$

(v is the instantaneous speed)

Having understood what speed is, we will look at the concept of velocity.

When measuring speed, we looked at the distance travelled by a moving body. However, when measuring velocity, we look at the displacement of a body in a time interval. While the formula of average velocity more or less remains the same, the way it is written mathematically, changes. Mathematically, the formula of average velocity is:

$$\vec{v}_{av} = \frac{\vec{AB}}{t_2 - t_1} .$$

(The arrows represent that the quantities are vector, AB is the displacement)

Just like speed, we also need to know what the instantaneous velocity of a body is. To better understand it, first, we will have to know what is a position vector. As defined by Dr H.C. Verma in his book, Concepts of Physics, "If we join the origin to the position of the particle by a straight line and put an arrow towards the position of the particle, we get the position vector of the particle."

So, the given figure, r_2 and r_1 vectors are position vectors. Using these, we can define the displacement of the particle as:

$$\vec{AB} = \vec{AO} + \vec{OB} = \vec{OB} - \vec{OA} = \vec{r}_2 - \vec{r}_1$$

Now if we have a time interval t_1 to t_2, then the formula for average velocity will be:

$$\vec{v}_{av} = \frac{\Delta \vec{r}}{\Delta t}$$

If we make the value of *Dt* vanishingly small, them mathematically, instantaneous velocity will be defined using the following formula:

$$\vec{v} = \lim_{\Delta t \to 0} \frac{\Delta \vec{r}}{\Delta t} = \frac{d\vec{r}}{dt}$$

Again, if you assume that the size of the body in motion is very small, then the position vector will be along the path of the motion of the body. So, this means that

Dr will be same as the distance travelled. In this case, the magnitude of the velocity will be defined as follows:

$$v = \left| \frac{d\vec{r}}{dt} \right| = \frac{|d\vec{r}\,|}{dt} = \frac{ds}{dt}$$

It is to be noted that instantaneous velocity is often also called 'velocity'. So, going forward, be mindful of this fact.

At high velocity, everything's a blur

At what rate?

When measuring the velocity of a moving body, measuring the rate of change of the velocity of the object is important. That is done by measuring the acceleration of the body. This means that, acceleration is the measure of the rate of change of velocity.

Given that it is the measure of the rate of change of velocity, this makes it a vector quantity. This also means that if there is a change in the direction or magnitude of the acceleration of a body, then there will be an equal effect on the velocity too. Mathematically, this can be defined as follows:

$$\vec{a}_{av} = \frac{\vec{v}_2 - \vec{v}_1}{t_2 - t_1}.$$

(a_{av} is the average acceleration)

And, now to calculate the instantaneous velocity, we have explained how to derive it. So, now you try and do it yourself.

There is another equation that we want you to understand that will better help you gauge the relation between initial and final speed of a body and the time in which it gained or lost that speed, as we head into a discussion about different types of acceleration.

The equation is written as follows:

$$v = u + at$$

(v is the final velocity of the body, u is the initial velocity of the body,
t is the time taken for that change to come into effect)

This equation means that the final velocity of a body, whether higher or lower than in the initial velocity, is equal to the sum of the initial velocity of the body and the product of the time taken and the acceleration/deceleration.

Now depending upon the rate of change of acceleration, we define the two types of acceleration: uniform and variable. First, let's talk about uniform acceleration. If the change in the velocity of a body is uniform or constant and the change in velocity is taking place at regular intervals, then the body is said to be accelerating uniformly. Now let's move on to talking about variable acceleration.

Final velocity = 0

A body is said to be accelerating variably, if the change in velocity is not the same in the same intervals of time. The best example of this is seen in the movement of a vehicle on a crowded road. If you find a relatively empty stretch, you tend you push the accelerator pedal and your car goes faster. If you encounter an obstacle, you either push the brake or take your foot off the accelerator to reduce the speed, causing the car to decelerate. This is what variable acceleration is. Pit this against a stone dropped from a cliff, falling just due to the influence of gravity. The change in velocity is constant, as it is increasing due to the pull it experiences when under the influence of gravity. This takes us to the next section, which is acceleration due to gravity.

It's gravitational

While we are focused on talking about the physical aspect of motion in bodies, let us take a paragraph or two and understand a bit of the acceleration that bodies in free-fall experience due to gravity. Such an acceleration is called acceleration due to gravity and is denoted by g during calculations. So, if you are ever to mathematically denote the acceleration being experienced by a body in freefall, then you can just write it using +g. The value of acceleration to gravity does not depend at all on the mass of a body. It is the friction in the air surrounding it that makes a difference. This means that if you drop a 100kg and a 5kg block of wood from the same height in a vacuum, both the blocks will reach the bottom at the same time.

Constant freefall

Now, coming to the numerical value of g. For mathematical purposes, the value of g is taken to be 9.8 m/s2. However, due to the shape of the planet, it varies from place to place. On the surface of Earth, the point where you can feel the maximum amount of gravitational pull or acceleration due to gravity is at the poles. And the minimum amount of acceleration due to gravity is at the equator.

Getting graphy

We talked so much about stuff falling under the influence of gravity that we had no choice but to explain how to plot graphs representing such motion. Before that, it is important to know an important term, which is linear or rectilinear motion. A body is said to be in rectilinear motion, if the body is moving in a straight line without any sideways deviation.

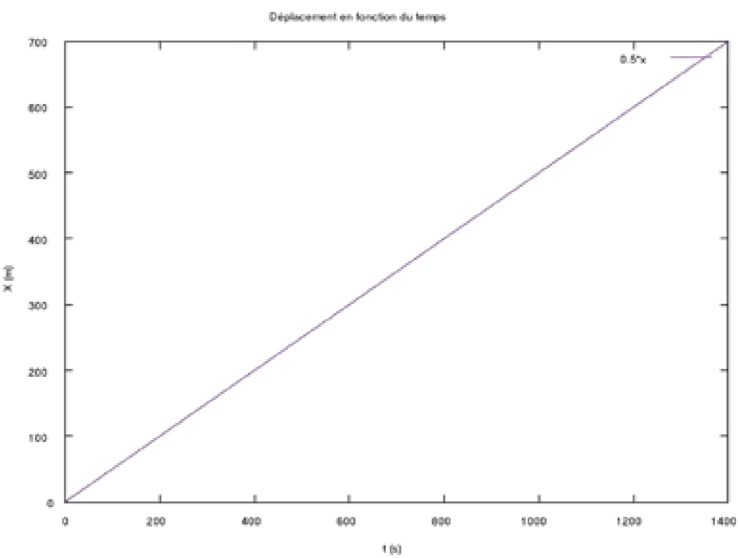
To represent linear or rectilinear motion, there are three types of graphs that can be plotted. They are:

- Displacement-time graph
- Velocity-time graph
- Acceleration-time graph

Each of these three graphs are extremely useful in helping us understand different aspects of linear motion and perform the necessary calculations. Before we go ahead though, we need to let you know that for linear motion, since there is no change in the direction of motion, the displacement-time and velocity-time graphs can be used interchangeably with distance-time and speed-time graphs respectively.

Displacement-time graph

Let's start with the displacement-time graph. Here time is plotted along the X-axis while the displacement is plotted along the Y-axis, and it helps us determine the velocity of



Make your own interpretations

the body. The formula for velocity is simply the ratio of displacement and time. Thus, the slope of this graph is used to calculate the velocity of a body.

Now that we know this, we can draw further conclusions just by looking at the slope of the graph.

- If the slope is positive, this means that the body is moving away from its point of origin.
- If the slope is negative, it means that that the body is moving towards the point of reference or the point of origin.
- If a body is moving with uniform velocity, the displacement will be directly proportional to the time.
- If a body is moving with varying velocity, then the tangent drawn from the given instant of time on the graph can be used to calculate the velocity of the body at that instant.
- If the graph is a straight line parallel to the X-axis, then the body is stationary.
- If the line is straight but at an inclination with the X-axis, then the body is moving with uniform velocity.

Velocity-time graph

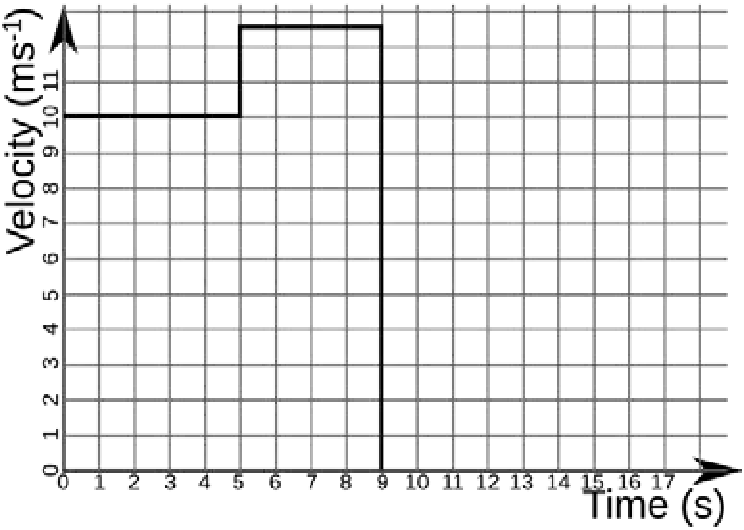
In this type of graph, again time is on the X-axis and velocity takes its place on the Y-axis. There are two uses of a velocity-time graph. The first is that it can be used to calculate the displacement of a body in a given time interval and the second is that it can be used to calculate the acceleration of a body at any instant.

If we are calculating displacement using a velocity-time graph, then the governing formula is – displacement = velocity x time. On the graph, the area enclosed in the plotted line of the graph represents the displacement.

If we are calculating the acceleration of a body using the velocity-time graph, then the governing principle is – Acceleration is the rate of change of velocity in a given time interval. The slope of the graph is what represents the acceleration of a body.

The conclusions that can be drawn from a velocity-time graph are as follows:

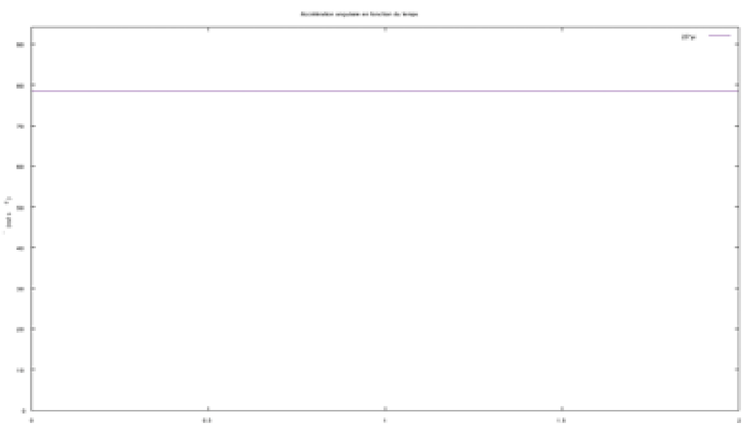
- If the body is moving with a unform velocity, then the graph line is a straight line parallel to the X-axis.
- If the body is moving with constant acceleration, the graph line is inclined with respect to the X-axis.
- If the body is moving with non-uniform acceleration, then the graph line is a curve.
- Positive slope of the graph line, represents accelerated motion.
- Negative slope of the graph line, represents retarded motion.
- Using the acceleration derived at various instants from this graph, one can plot the acceleration-time graph.



Solve this! (Use the notes at the end)

Acceleration-time graph

Just like the other two types of graphs, here too the time is plotted along the X-axis and the Y-axis is occupied by acceleration. Using the acceleration-time graph, we can calculate the change in speed of a moving body in a given interval of time. The governing formula here is – acceleration = speed x time. And, when plotting the



Constant

graph, the area enclosed between the graph line and the X-axis helps us determine the change in speed.

First equations

If you are ever tasked with calculating any of the three basic properties of a body in motion, its initial and final velocity or displacement, and you do not have a graph sheet, then what do you do? Well, the physicists thought this out and created the three basic equations of uniform motion. One of the three - $v = u + at$, has already been explained earlier in this chapter. So, there remain two. Let's have a look at what they are.

Equation to calculate displacement of a moving body:

$$S = ut + 1/2at^2$$

(S is the displacement, v is the final velocity of the body, u is the initial velocity of the body, t is the time taken)

The third equation of uniform motion is as follows:

$$v^2 = u^2+2aS$$

(S is the displacement, v is the final velocity of the body, u is the initial velocity of the body, t is the time taken)

When using these equations, there are certain special cases, which come into effect and change the structure of these equatuons.

If a body is starting from rest, then its initial velocity or u is zero, so the equations will be:

- $v = at$
- $S = 1/2at^2$
- $v^2 = 2aS$

If a body is moving with uniform reduction in its speed (retardation), then the value of a will be negative, and the equations will be:

- $v = u - at$
- $S = ut - 1/2at^2$
- $v^2 = u^2 - 2aS$

Having understood the three types of graphs and the fundamentals of motion, let's move to the next chapter and understand the three laws of motion, which we love to call Newton's Big Three. ■

Newton's Big Three

Every action has an equal and opposite reaction... And we second that motion!

No lecture or book in physics can be complete without a mention of the famous Laws of Motion established by Sir Isaac Newton. That is why we have chosen to call them Newton's Big Three.

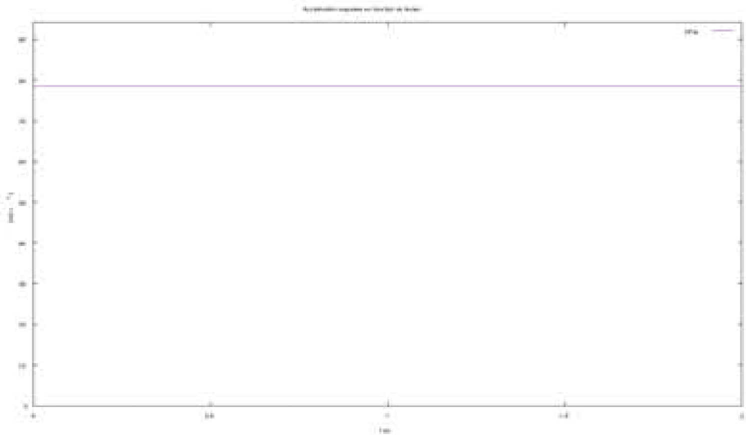
No matter how difficult they seem at first glance, they are intuitive and worded so well by Newton himself that simple observations of the things around us can help easily visualise and understand each of them. So, in this chapter, we go through each of the three laws, understanding their origins, applications, and their significance in our world.

Law of Motion and Inertia

A lesson in history

Many know it as Newton's First Law of Motion, but in the inner circles of science, it is better known as Newton's First Law of Motion and Inertia. Did you know that Galileo also played a huge role in getting it to the form Newton worked on and making it what it is? Well, if you didn't, think of this as a little secret that we are letting you in on.

Before Galileo started his commentary on the motion of bodies, everyone believed that a force is needed to initiate the motion of a body and keep the motion going. However, Galileo believed otherwise, and set out to prove his theory, that a body continues to be in a state of motion, until an external force is applied on it. This might sound absurd to you too but let us explain it better using an example.



Infinite inertia

Let us imagine two scenarios. One, where you are skating on a rough road, and the other where you are in a rink. In both the cases, once you have gained enough speed, even if you stop moving your legs, you continue moving. Your skate's wheels do not stop spinning as soon as you stop pushing, right?

Well, that is all that is needed to be proven. If there was no friction, you would have continued moving. This can be proven by the fact that in a skating rink you would tend to cruise further ahead, than you would on a road, just because of the reduced friction your wheels experience. Now, remove other friction inducing factors, and you will have the proof that in absence of an external force, a body set in motion remains in motion. Same is the case with a body in a state of rest. It will remain that way until an external force is applied. This is what is known as Galileo's Law of Inertia.

The Law

Newton further solidified the evidence backing Galileo's Law and formulated, what we know as his First Law of Motion and Inertia. It states that, "If a body is in a state of rest or motion, it will remain in that state until an external force is applied on it." From this emerges a very important term in the world physics: inertia. The other concept that is a part of the definition of the law is, force. Let's start by understanding force.

Helping to move, helping to stop

By definition, force is the external factor that can cause a stationary body to move or change the state of motion of an already moving body. This means, it can either be a motivator or retardant to the motion of a body. From here, we can also draw a few other conclusions about force. The first is that it is a vector quantity, meaning that its direction and magnitude are important. Second, that if there are two or multiple opposing forces, then the body on which they are acting, can have a net force of zero acting on it.

Apple on the head, law in the books

Staying in the state

Having understood what force is, now we will dive into the world of inertia. The definition of inertia is simple. It is the property of an object, by the virtue of which it continues to be in the state that it is in (either motion or rest). It is inherently present in every object that is present around us. A simple example is that of your body on a Sunday morning. It continues to be in bed in a state of rest and completely motionless if you do not apply a force to move it.

While inertia is mostly unaffected by the physical properties of a body, its mass is what affects it. The greater the mass of a body, the greater will be its inertia. For example, it is easier to pick and move a pebble, than it is to move a huge rock. This makes mass, a measure of inertia.

So far, we have iterated several times that a body stays at rest or continues to be in motion because of its inertia. From this statement, we can find the two types of inertia, which are – inertia of rest, and inertia of motion. Both definitions are pretty simple and will sound like a plain repetition of our earlier explanations.

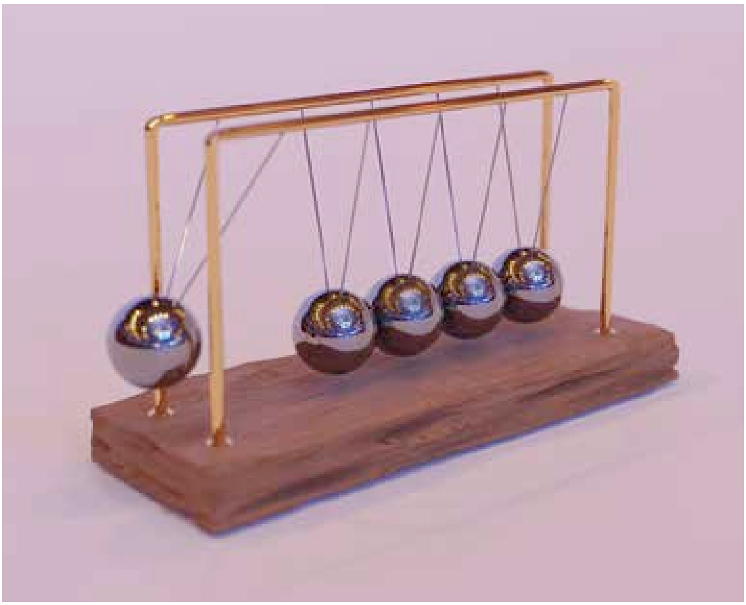
Inertia of rest means that a body at rest, will continue to be at rest, until an external force is applied on it. And as you may have already guessed, inertia of motion means that a moving body will continue moving until an external force is applied on it.

Enough of motion and rest. We are getting sick of it. *insert motion sickness joke* Let's move on to the Second Law and gain back the momentum we lost to inertia.

Shifting momentum every second

It's linear

Before going ahead with the explanation of Newton's Second Law of Motion, you need to familiarise yourself with the concept of linear momentum to understand the law better. After understanding the concept of inertia and its dependence on mass, we know that if the mass of a body is increased, so will be the force required to stop it, if it's moving. To add to it is the speed at which the body is moving. The concept is the same. The higher the speed, the higher the force required to stop it, and vice versa.



Click clack... Click clack... Click clack

So, to establish a formal definition, "Linear momentum of a body is the product of its mass and velocity". It is represented using the letter p and its mathematical formula is:

$$p = mv$$

(p is the linear momentum, m is the mass of the body, v is the velocity of the body)

Often, the word momentum is used in place of linear momentum, so keep that in mind. It is a vector quantity, and its SI unit is kg m/s.

When a body is moving, and its velocity changes, there will be a change in momentum. And that is calculated using the following formula:

$$\Delta p = m\Delta v$$

(Δ denotes a small change in quantity)

Here, the mass of the body is assumed to be constant. If it were varying, the equation would have been written as D*p* = D(*mv*). This can be very aptly observed in the motion of a rocket, where the rapid burning of fuel causes a change in the mass of the body.

When working with and around the concept of momentum, it also becomes important to establish the rate at which this change is taking place. For that we must calculate the rate of change of momentum. To get to the mathematical formula, we will have to go through a short derivation process, which is as follows:

Let us assume that the force being applied on the body of mass m is F, for a time t and it brings the velocity of the body from u to v.

Then,

Initial momentum = mu

Final momentum = mv

Change in momentum in time $t = mv - mu = m(v-u)$

Rate of change of momentum = $\{m(v-u)\}/t$

However, we know, acceleration = $(v-u)/t$

Thus,

Rate of change of Momentum = mass x acceleration = ma

WHOAAAAAA!

Now that we have established this relation, let us delve into understanding what Newton's Second Law of Motion is.

The Law

From Newton's first law of motion, we know that force changes the velocity of a body, meaning that it affects its acceleration. So, the second law does the job of relating that force to the rate of change of momentum.

During his experiments, Newton found that the acceleration of a body is directly proportional to the force applied on it (a µ F), and the amount of force that is needed to be applied on a body to bring the same amount of change in its momentum, is also directly proportional to its mass (F µ m). Using these two observations, he established that (if mass remains constant):

$$F = Kma$$

(F is the force, K is a constant, m is the mass of the body, a is the acceleration)

Given the unit of force that has been chosen, the value of K is 1 when a and m are equal to 1. Due to this, the earlier equation takes the following form:

$$F = ma$$

(F is the force, m is the mass of the body, a is the acceleration)

This is how Newton's Second Law of Motion is represented mathematically.

The SI unit of Force is newton. One newton of force is the amount of force required to accelerate a body of mass 1kg by 1 m/s^2. The smaller, CGS unit of force is dyne.

1 newton = 10^5 dyne

Newton's Second Law of Motion can also be expressed in terms of the rate of change of momentum of a body. Here's how:

We know, rate of change of momentum = ma

So,

Dp/Dt = ma (given that the mass is constant)

And $F = ma$

Thus,

$$\Delta p/\Delta t = F$$

The above equation gives us the statement for Newton's Second Law of Motion, that is – The rate of change of momentum of a body is directly proportional to the force applied on it, and it takes place in the direction in which the force is applied.

Relations

There is an interesting relationship that exists between Newton's first and second laws.

Stronger than this

We know that F=ma. So, if the force applied is zero, then the acceleration of the body will be zero. This means that if there is no force applied on a body, it does not move. And that is what the first law also says!

Equal and opposite reactions

If there were ever an award for the most recognised laws of physics, then Newton's Third Law of Motion would surely be a strong contender. While the first two laws tell us the effect and magnitude of force applied to a body during rest or motion, there

Domino effect

remains a void in the explanation of how the force acts on the objects. That is filled in by the third law.

It famously states that "to every action, there is an equal and opposite reaction". This means that in the case of an interaction between two bodies, the magnitude of the force applied on one is equal to the resistive force applied by the other body, but in a diametrically opposite direction.

You may have seen the third law being used in all sorts of ways. In literature and science, there is no need to explain such a concept in further detail. So, let's move on to Chapter 3, where we will discuss different aspects of force and other types of motion.

All around

Moving around, losing speed, and colliding...

Wear and tear

In Newton's First Law of Motion, when giving you an example of an external force stopping a moving body, we mentioned that friction was the external force that is acting between the tyre and the surface on which the skater is moving. Remember, right? Well, in this section we will be exploring this force that causes a lot of damage around us. But it is also the force without which we would never be able to walk on a surface without falling.

Starting off, with the definition. Friction can be defined as the force acting between two touching surfaces, resisting their relative motion, and preventing them from sliding over each other. Basically, when two surfaces, be it fluid or solid, come in contact with each other, their tendency is to slide against each other without any resistance. But, given that we can walk and hold objects in our hands, we know that it is not the case. There is a force that is acting in opposing directions, along the surface of contact. That force is friction. It may seem like it, but friction is not a fundamental force by itself. Depending upon the type of friction, there are different factors and types of forces that give rise to the force of friction.

Visual representation

Two kinds

Based on the virtue of the movement of bodies, friction is basically of two types – Kinetic and Static.

Kinetic friction is the type of friction force that comes in play when two bodies come in contact and move while their surfaces are rubbing against each other. Static friction is the kind of friction which comes in, when the two bodies in contact are not slipping with respect to one another.

However, the direction of kinetic friction is always opposite to the movement of the bodies. So, as shown in the diagram, if Object A is moving forward, then the friction acting on its contact surface will be in the opposite direction.

When talking about the magnitude of kinetic friction, it depends on the normal force acting between the two bodies in contact. A normal force is the force exerted by a surface onto the other when they are in contact. This force acts perpendicular to the surfaces that are in contact with each other. Since the magnitude of kinetic friction is directly proportional to the normal force, the higher it is, the higher will be the friction and vice versa.

Friction action on single object

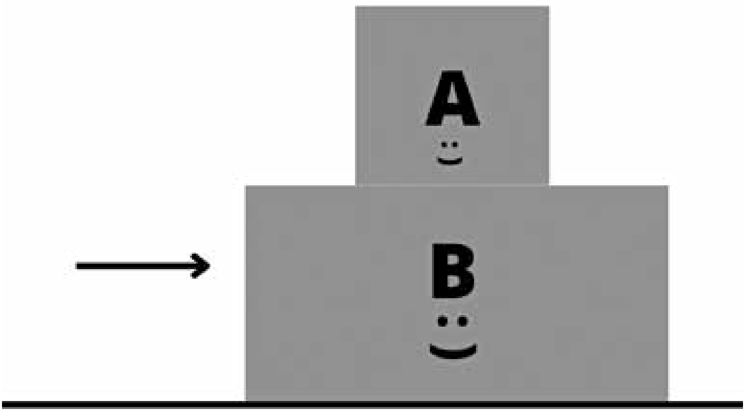
Tale of two stacked boxes – Fiction for Friction

Here's the tale of the two stacked boxes to better understand the concept of friction and clear out some misconceptions that might have slipped in.

Once there were two stacked boxes, A and B, resting on each other on a fairly rough surface. B was on the bottom, and A was resting on top of it. When a small force was applied on B parallel to the resting surface, there was no movement. This was because static friction was higher than the force being applied. However, when the magnitude of the force increased, both the boxes started moving together and did not slip along the surface because kinetic friction was acting on B. Did you notice something strange?

You might believe that friction often stops bodies from moving. But here, friction helped box B to carry box A forward. When force was applied to B, the friction between box B and A helped it stay on top of B, and they moved forward together.

Moral of the story: Friction does not always hinder movement; it often assists it!



They look happy!

Going round and round

Let's just cut to the chase here. In this section, we will be talking about Uniform Circular Motion, hence the subhead. The formal definition of Uniform Circular Motion goes as follows: "When a particle moves with a constant speed in a circular path, its motion is said to be uniform circular motion."

If an object is in uniform circular motion, this means that it will travel a fixed distance along a circular path in a given time interval, over and over again. However, if there is a continuous change in the direction of the object's motion, it would mean that its motion is accelerated, because the body's velocity is constantly changing (increasing or decreasing). In such a motion, if we track the movement of a single point on the object, then as opposed to forming a perfect circle, it will form a spiral (assuming that there is a constant decrease or increase in the velocity).

During uniform circular motion, the direction of velocity of the body is along the tangent drawn from that instant in the circular path. It is to be noted, that during uniform circular motion, the circular motion can be accelerated, even though the speed is uniform.

The force is pulling and pushing you

When a body is in circular motion, there are two primary forces acting on it – Centripetal and Centrifugal. You might be familiar with the concept of these forces already. Nevertheless, here's a short explanation of the two.

Centripetal force is the force that acts on a body while it is in circular motion, causing the body to move inwards towards the centre of the circular path that it is

No one's tapping into this centrifugal force

following. On the other hand, centrifugal force is the force acting on a body in circular motion, that causes it to move away from the centre of the circular path. It is considered to be a fictitious force. It is only an observed force, which comes in due to the presence of centripetal force. During circular movement, there is no centrifugal force as such, but when the motion is observed, centripetal force's effect often translates into centrifugal force.

In day to day observations, it is easier to see centrifugal force compared to centripetal force, even though it is fictitious/virtual. The best application of this can be seen in the clothes dryers. The water molecules move away from the clothes when the drier tub rotates. This is often attributed to centrifugal force. But, it cannot be, as it is not a force.

In perfect harmony

In this chapter we have so far read about friction and how it isn't what we often think it is, and a uniform circular motion which includes a force that isn't even real. But harmonies are something that we hadn't discussed so far. So, the next topic is simple harmonic motion.

As musical as it may sound, that artistic tinge is only limited to the name, as simple harmonic motion is nothing but a body moving in the same way over and over again in a given time period. To put it in a way that would get an 11th grader marks in his physics exam, "When a body exhibits a repeated pattern of motion in fixed intervals of time, it is said to be in simple harmonic motion (SHM)." Here, the time in which one round of motion is completed, is called... *Time Period!* And, if the body after starting to move from a resting position is moving to and fro along the same path over and over again, then it is said be oscillating.

Going up, coming down

That dangling thing from the grandfather clock?

When studying simple harmonic motion, the best way to understand the concept is to look at a pendulum. You may be familiar with the common definition of a pendulum, which attributes the term to the that dangling stick from those huge old clocks, with a circular disc at the end. While, that is not wrong, there are other systems that can be called pendulums as well in the world of physics.

A pendulum can be defined as – Any rigid body that has been suspended from a fixed support. This means that if you are to tie a rock to a string and suspend it from a wall, it can be called a pendulum.

If you are familiar with the working of the old grandfather clocks, then you might have already figured how SHM dictates time in those clocks. For the ones not familiar, in the clocks, the pendulum, given it is exhibiting SHM, meaning that the clock's gears will turn in a fixed pattern throughout the day, and you will get accurate readings. If the pendulum goes out of SHM, the clock's mechanism will go astray, and you will not be getting accurate readings.

No kaboom?

In the world of physics, any instance where two bodies exert forces on each other when in contact, in a short amount of time, is called collision. So far you may have used the term to define an instant where two bodies come together with great force. However, when taken in a scientific context, collision has nothing to do with the magnitude of force at all.

An example of collision would be your foot landing on the ground every time you take a step or every time a dog or a cat's paw touches the grass, whenever they are

Shouldn't have tested it on the track

trotting around. It's that simple. The only thing that can be used to define a type of collision is the amount of kinetic energy that is dispersed during that process.

Based on the amount of kinetic energy discharged or transmitted between two bodies, collisions are divided into two categories – Elastic and Inelastic.

A collision is considered to be perfectly elastic, if upon the contact, there is no loss of kinetic energy taking place. Actually, this is not completely true, as during a collision there is always some amount of kinetic energy that is lost at the macroscopic level. However, given the contextual insignificance of the total energy exchange or rather the lack of it, that it is neglected. A pool table is a great place to observe nearly elastic collisions. The interaction between pool balls when they hit each other is nearly elastic.

The other type of collision, which is inelastic collision, is defined as a type of collision during which, upon contact there is a loss of kinetic energy. And, in accordance with the law of conservation of energy, the lost kinetic energy gets converted into other forms of energy. We generally get to see this energy being dissipated in the form of heat, light, or sound. ■

Things that remain

Final touchups

Whatever we have covered so far, is enough for passing an exam. But to geek out, it won't do the trick. To complete your understanding of the topic of motion, here's what remains that will help you transcend from being a well-educated person in terms of knowledge of motion, to a semi-geek. Everything from the leftover concepts to real life applications are present in this chapter. Read on...

Turning force

As said in the first chapter, most of what we have dealt with so far, has had to do with translational motion. The turning effect of force has not been talked about. In this section, let's do that!

The more scientific term for the turning effect of force is torque. It is also known as a moment of a force, but we will stick with torque for now. As the name suggests, torque is responsible for bodies to turn when a force is applied on them. Its presence can be observed anywhere. From the turning of a wheel when stroked, or the opening of doors or the screens of the foldable smartphones; there's torque playing its role everywhere.

To get to the mathematical formula of torque, which would help us gauge to what extent a body will turn if a certain magnitude of force is applied to it, we will first look at the factors affecting it. They are:

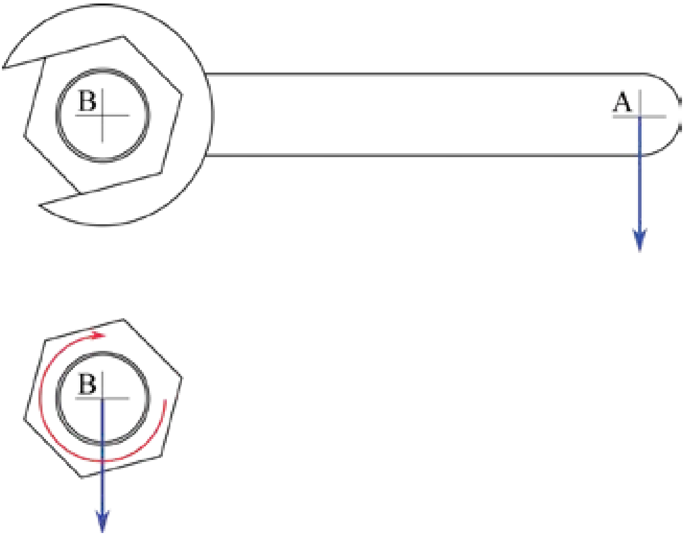
- The magnitude of force being applied on the body.
- The distance between the axis of rotation, and the point at which the force is being applied.

The best kind of wrench

Having this in mind, we now move on to mathematically determining the value of torque. It can be done using the product of the magnitude of force being applied and the distance between the point of application of force and the axis of rotation. The SI unit assigned to torque is Nm (newton x metre).

Turning forces

Don't get confused by the subhead. It's not a mistake.



Makes sense?

While torque is just a single force acting on a body, causing it to move, a pair of forces acting on a body causing it to rotate, is called a couple. It is made up of two forces of equal magnitude acting in opposite directions. It might not be obvious, but everything from turning a key to a car wrench needs a couple to be executed.

Momentary? I don't think so

You may think that there are virtually no similarities between torque and couple. However, there is one. Just like torque, it also has a property connecting it with moment. It's called the moment of couple. Moment of couple is the simple product of one of the two forces and the perpendicular distance between the two points where the force is being applied at.

Constant state of...

When there are multiple forces acting on a body, causing no change in its current state of motion or rest, the body is said to be in a state of equilibrium. As you may have guessed, having read so much of the book, there are two types of equilibrium – static and dynamic. When talking about either kind of equilibrium, the direction of the forces being applied does not matter, as long as they are making the body stay in equilibrium.

A body is said to be at static equilibrium, when it remains under the state of rest, despite the presence of multiple forces acting on it. When the forces acting on a moving body, help keep it in the same state of motion, then it said to be in a state of dynamic equilibrium.

In space and time

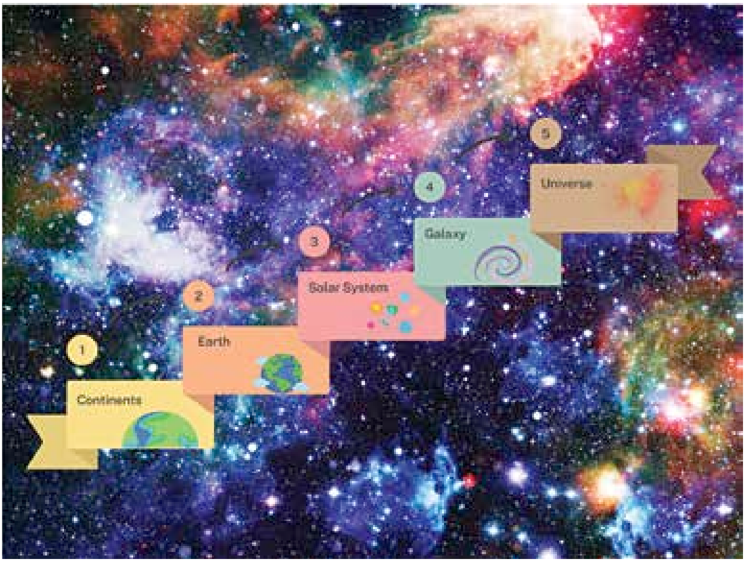
Well, there is a scope of making a joke about the motion of time if you see the hands of a clock, but we will not make it here. We serve you facts and that is what will happen.

You might not feel it, but even when stationary, you are moving. Remember the concept of frame of reference? It's time to apply it.

When talking in the context of the entire universe, as you move one step ahead in the observation bubble, you will see how each layer seems stationary but isn't. Look at the picture and try to observe each listed entity from a third-person perspective.

From the atmosphere, you can gradually see the continents move. From space, you can see Earth move. From outside the solar system, you can see it moving. From outside the Milky Way, it also seems to move. And, we know for a fact that the universe is moving and expanding. Yet, if you are present on the observed entity, you feel that you are not moving.

Were you able to visualise it? Interesting right?



Well, that was all that we had to serve you in this book about motion. It started with the fundamentals, then we understood the laws, then some more concepts came in, before the final context setting example, that would have brought everything in context.

If you feel we skipped out on anything that could have made this book better, or have any feedback about it, feel free to write to us at *editor@digit.in* d


Zipping around in the skies
https://dgit.in/Zoommm