Use of Kinematic In Daily Life

Kinematics is a mathematical branch of physics that uses equations to describe the motion of objects (specifically *trajectories*) without referring to forces.

These equations allow you to simply plug various numbers into one of the four basic **kinematic equations** to find unknowns in those equations without applying any knowledge of the physics behind that motion, or having any knowledge of physics at all. Being good at algebra is sufficient to bludgeon your way through simple projectile-motion problems without gaining a real appreciation for the underlying science.

Kinematics is commonly applied to solve **classical mechanics** problems for motion in **one dimension** (along a straight line) or in **two dimensions** (with both vertical and horizontal components, as in **projectile motion**).

In reality, events described as occurring in one dimension or two dimensions unfold in ordinary three-dimensional space, but for kinematics purposes, x has “right” (positive) and “left” (negative) directions, and y has “up” (positive”) and “down” (negative) directions. The concept of “depth” – that is, a direction straight toward and away from you – is not accounted for in this scheme, and it usually does not need to be for reasons explained later.

Physics Definitions Used in Kinematics

Kinematics problems deal with position, velocity, acceleration and time in some combination. Velocity is the rate of change of position with respect to time, and acceleration is the rate of change of velocity with respect to time; how each is derived is a problem you may encounter in calculus. In any case, the two fundamental concepts in kinematics are therefore position and time.

More on these individual variables:

- Position and displacement are represented by an **x, y coordinate system**, or sometimes *θ* (Greek letter theta, used in angles in geometry of motion) and *r* in a polar coordinate system. In SI (international system) units, distance is in meters (m).
- Velocity *v* is in meters per second (m/s).
- Acceleration *a* or

  α

  (the Greek letter alpha), the change in velocity over time, is in m/s/s or m/s^2. *Time t is in seconds.* When present, initial and final **subscripts** (*i* and *f*, or alternatively, *0* and *f* where *0* is called "naught") denote initial and final values of any of the above. These are constants within any problem, and a direction (e.g., *x*) may be in the subscript to provide specific information as well.

Displacement, velocity and acceleration are **vector quantities**. This means they have both a magnitude (a number) and a direction, which in the case of acceleration may not be the direction in which the particle is moving. In kinematic problems, these vector in turn can be broken down into individual x- and y-component vectors. Units such as speed and distance, on the other hand, are **scalar quantities** as they have a magnitude only.

The Four Kinematic Equations

The math needed to solve kinematics problems is not itself daunting. Learning to assign the right variables to the right pieces of information given in the problem, however, can be a challenge at first. It helps to determine the variable the problem asks you to find, and then look to see what you are given for this task.

The four kinematics formulas follow. While "x" is used for demonstrative purposes, the equations are equally valid for the "y" direction. Assume constant acceleration *a* in any problem (in vertical motion this is often *g*, the acceleration owing to gravity near Earth's surface and equal to 9.8 m/s^2).

x=x_0+/frac{1}{2}(v+v_0)t*x*=*x*0+/*frac*12(*v*+*v*0)*t*

Note that (1/2)**(v + v_0)** is the *average velocity*.

v=v_0+at*v*=*v*0+*at*

This is a restatement of the idea that acceleration is difference in velocity over time, or $a = (v - v_0)/t$.

x=x_0+v_0t+\frac{1}{2}at^2*x*=*x*0+*v*0*t*+21*at*2

A form of this equation where initial position (y_0) and initial velocity (v_{0y}) are both zero is the free-fall equation: **$y = -(1/2)gt^2$**. The negative sign indicates that gravity accelerates objects downward, or along the negative y-axis in a standard coordinate reference frame.

v^2=v_0^2+2a(x-x_0)*v*2=*v*02+2*a*(*x*−*x*0)

This equation is useful when you don't know (and don't need to know) time.

A different kinematics equations list might have slightly different formulas, but they all describe the same phenomena. The more you lay your eyeballs on them, the more familiar they will become even while you are still relatively new to solving kinematics problems.

More About Kinematic Models

Kinematic curves are common graphs showing position vs. time (*x* vs. *t*), velocity vs. time (*v* vs. *t*) and acceleration vs. time (*a* vs. *t*). In each case, time is the independent variable and lies on the horizontal axis. This makes position, velocity and acceleration *dependent variables*, and as such they are on the vertical axis. (In math and physics, when one variable is said to be "plotted against" another, the first is the dependent variable and the second the independent variable.)

These graphs can be used for **kinematic analysis** of motion (to see in which time interval an object was stopped, or was accelerating, for example).

These graphs are also related in that, for any given time interval, if the position vs. time graph is known, the other two can be quickly created by analyzing its slope: velocity vs. time is the slope of position vs. time (since velocity is the rate of change of position, or in calculus terms, its derivative), and acceleration vs. time is the slope of velocity versus time (acceleration being the rate of change of velocity).

A Note on Air Resistance

In introductory mechanics classes, students are usually instructed to ignore the effects of air resistance in kinematics problems. In reality, these effects can be considerable and can slow a particle greatly, especially at higher speeds, since the *drag force* of fluids (including the atmosphere) is proportional not merely to the velocity, but to the square of the velocity.

Because of this, any time you solve a problem including velocity or displacement components and are asked to omit the effects of air resistance from your calculation, recognize that the real values would likely be somewhat lower, and time values somewhat higher, because things take longer to get from place to place through air than the basic equations predict.

Examples of One- and Two-Dimensional Kinematics Problems

The first thing to do when confronting a kinematics problem is identify the variables and write them down. You can, for example, make a list of all of of the known variables such as $x_0 = 0$, $v_{0x} = 5$ m/s and so on. This helps pave the way for choosing which of the kinematic equations will best allow you to proceed toward a solution.

One-dimensional problems (linear kinematics) usually deal with motion of falling objects, although they can involve things confined to motion in a horizontal line, such as a car or train on a straight road or track.

One-dimensional kinematics examples:

*1. What is the **final velocity** of a penny dropped from the top of a skyscraper 300 m (984 feet) tall?*

Here, motion occurs in the vertical direction only. The initial velocity $\mathbf{v}_{0y} = 0$ since the penny is dropped, not thrown. $y - y_0$, or total distance, is -300 m. The value you seek is that of v_y (or v_{fy}). The value of acceleration is –g, or –9.8 m/s^2.

You therefore use the equation:

$$v^2=v_0^2+2a(y-y_0)$$

This reduces to:

$$v^2=(2)(-9.8)(-300) = 5,880 \implies v = -76.7\text{ m/s}$$

This works out to a brisk, and in fact deadly, (76.7 m/s)(mile/1609.3 m)(3600 s/hr) = 172.5 miles per hour. IMPORTANT: The squaring of the velocity term in this type of problem obscures the fact that its value may be negative, as in this case; the particle's velocity vector points downward along the y-axis. Mathematically, both **v** = 76.7 m/s and **v** = –76.7 m/s are solutions.

2. What is the displacement of a car traveling with a constant velocity of 50 m/s (about 112 miles per hour) around a race track for 30 minutes, completing exactly 30 laps in the process?

This is a trick question of sorts. The distance traveled is just the product of speed and time: (50 m/s)(1800 s) = 90,000 m or 90 km (about 56 miles). But displacement is zero because the car winds up in the same place it starts.

Two-dimensional kinematics examples:

3. A baseball player throws a ball horizontally with a speed of 100 miles an hour (***45 m/s****) off the roof of the building in the first problem. Calculate how far it travels horizontally before hitting the ground.*

First you need to determine how long the ball is in the air. Note that despite the ball having a horizontal velocity component, this is still a free-fall problem.

First, use $\mathbf{v = v_0 + at}$ and plug in the values v = –76.7 m/s, v_0 = 0 and a = –9.8 m/s^2 to solve for t, which is 7.8 seconds. Then substitute this value into the constant velocity equation (because there is no acceleration in the x direction) $\mathbf{x = x_0 + vt}$ to solve for x, the total horizontal displacement:

$$x =(45)(7.8) = 351\text{ m}$$

or 0.22 miles.

The ball would therefore in theory land close to a quarter of a mile away from the base of the skyscraper.

Kinematics Analysis: Speed vs. Event Distance in Track and Field

In addition to supplying useful physical data about individual events, data pertaining to kinematics can be used to establish relationships between different parameters in the same object. If the object happens to be a human athlete, there are possibilities for using physics data to help chart out athletic training and determine ideal track event placement in some cases.

For example, the sprints include distances up to 800 meters (just shy of a half-mile), the middle-distance races encompass the 800 meters through about the 3,000 meters and the true long-distance events are 5,000 meters (3.107 miles) and above. If you examine the world records across running events, you see a distinct and predictable inverse relationship between race distance (a position parameter, say *x*) and world-record speed (*v*, or the scalar component of *v*).

If a group of athletes runs a series of races across a range of distances, and a speed vs. distance graph is created for each runner, those who are better at longer distances will show a flatter curve, as their speed slows less with increasing distance compared to runners whose natural "sweet spot" is in shorter distances.

Newton's Laws

Isaac Newton (1642-1726) was, by any measure, among the most remarkable intellectual specimens humankind has ever witnessed. In addition to being credited as being a co-founder of the mathematical discipline of calculus, his application of math to physical science paved the way for a groundbreaking jump in, and lasting ideas about, translational motion (the kind under discussion here) as well as rotational motion and circular motion.

In establishing a whole new branch of classical mechanics, Newton clarified three fundamental laws about the motion of a particle. **Newton's first law** states that an object moving at constant velocity (including zero) will remain in that state unless perturbed by an unbalanced outside force. On Earth, gravity is virtually always present. **Newton's second law** asserts that a net external force applied to an object with mass compels that object to accelerate: $\mathbf{F}_{net} = m\mathbf{a}$. **Newton's third law** proposes that for every force, there exists a force equal in magnitude and opposite in direction.

Scalars and Vectors

In kinematics, we can divide physical quantities into two categories: scalars and vectors.

A **scalar** is a physical quantity with only a magnitude.
In other words, a scalar is simply a numerical measurement with a size. This can be a plain old positive number or a number with a unit that doesn't include a direction. Some common examples of scalars that you regularly interact with are:

- The mass (but not weight!) of a ball, textbook, yourself, or some other object.
- The volume of coffee, tea, or water contained in your favorite mug.
- The amount of time passed between two classes at school, or how long you slept last night.

So, a scalar value seems pretty straightforward — how about a vector?

A **vector** is a physical quantity with both a magnitude and direction.
When we say that a vector has direction, we mean that the **direction of the quantity matters**. That means the coordinate system we use is important, because the direction of a vector, including most variables of kinematic motion, will change signs depending on whether the direction of motion is positive or negative. Now, let's look at a few simple examples of vector quantities in daily life.

- The amount of force you use to push open a door.
- The downward acceleration of an apple falling from a tree branch due to gravity.
- How fast you ride a bike east starting from your home.

You'll encounter several conventions for denoting vector quantities throughout your physics studies. A vector can be written as a variable with a right arrow above, such as the force vector F→ or a bolded symbol, such as F. Make sure you're comfortable working with multiple types of symbols, including no denotation for vector quantities!

Variables in Kinematics

Mathematically solving kinematics problems in physics will involve understanding, calculating, and measuring several physical quantities. Let's go through the definition of each variable next.

Position, Displacement, and Distance

Before we know how fast an object is moving, we have to know *where* something is first. We use the position variable to describe where an object resides in physical space.

The **position** of an object is its physical location in space relative to an origin or other reference point in a defined coordinate system.
For simple linear motion, we use a one-dimensional axis, such as the x, y, or z-axis. For motion along the horizontal axis, we denote a position measurement using the symbol x, the initial position using x0 or xi, and the final position using x1 or xf. We measure position in units of length, with the most common unit choice being in meters, represented by the symbol m.

If we instead want to compare how much an object's final position differs from its initial position in space, we can measure the displacement after an object has undergone some type of linear motion.

Displacement is a measurement of a change in position, or how far an object has moved from a reference point, calculated by the formula:

$$\Delta x=xf-xi$$

We measure the displacement Δx, sometimes denoted as s, using the same units as position. Sometimes, we only want to know how much ground an object has covered altogether instead, such as the total number of miles a car has driven during a road trip. This is where the distance variable comes in handy.

Distance is a measurement of the total movement an object has traveled without reference to the direction of motion.

In other words, we sum up the absolute value of the length of each segment along a path to find the total distance d covered. Both displacement and distance are also measured in units of length.

Displacement measurements describe how far an object has moved from its starting position, while distance measurements sum up the total length of the path taken,

The most important distinction to remember between these quantities is that position and displacement are vectors, while distance is a scalar.
Consider a horizontal axis spanning a driveway of 10m, with the origin defined at 5m You walk in the positive x-direction from the car to your mailbox at the end of the driveway, where you then turn around to walk to your front door. Determine your initial and final positions, displacement, and total distance walked.

In this case, your initial position xi is the same as the car at x=5m in the positive x-direction. Traveling to the mailbox from the car covers 5m, and traveling towards the door covers the whole length of the driveway of 10m in the opposite direction. Your displacement is:

$$\Delta x=5m-10m=-5m$$

xf=−5m is also our final position, measured along the negative x-axis from the car to the house. Finally, the total distance covered ignores the direction of motion:

$$\Delta x=5m+|-10m|=15m$$

You walked 15m total.
Since displacement calculations take direction into account, these measurements can be positive, negative, or zero. However, distance can only be positive if any motion has occurred.

Time

An important and deceptively simple variable that we rely on for both day-to-day structure and many physics problems is time, particularly elapsed time.

Elapsed time is a measurement of how long an event takes, or the amount of time taken for observable changes to happen.
We measure a time interval Δt as the difference between the final timestamp and initial timestamp, or:

$$\Delta t=tf-ti$$

We record time typically in units of seconds, denoted by the symbol s in physics problems. Time may seem very straightforward on the surface, but as you journey deeper into your physics studies, you'll find that defining this parameter is a bit more difficult than before! Don't worry — for now, all you need to know is how to identify and calculate how much time has passed in a problem according to a standard clock or stopwatch.

Velocity and Speed

We often talk about how "fast" something is moving, like how fast a car is driving or how quickly you're walking. In kinematics, the concept of how fast an object is moving refers to how its position is changing through time, along with the direction it's headed.

Velocity is the rate of change of displacement over time, or:

Velocity=DisplacementΔTime

In other words, the velocity variable v describes how much an object changes its position for each unit of time that passes. We measure velocity in units of length per time, with the most common unit being in meters per second, denoted by the symbol ms. For example, this means that an object with a velocity of 10ms moves 10m every second that passes.

Speed is a similar variable, but instead calculated using the total distance covered during some period of elapsed time.

Speed is the rate an object covers distance, or:

Speed=DistanceTime

We measure the speed s using the same units as velocity. In everyday conversation, we often use the terms velocity and speed interchangeably, whereas in physics the distinction matters. Just like displacement, velocity is a vector quantity with direction and magnitude, while speed is a scalar quantity with only size. A careless mistake between the two can result in the wrong calculation, so be sure to pay attention and recognize the difference between the two!

Acceleration

When driving a car, before we reach a constant speed to cruise at, we have to increase our velocity from zero. Changes in the velocity result in a nonzero value of acceleration.

Acceleration is the rate of change of velocity over time, or:

$\text{Acceleration}=\Delta\text{Velocity}\Delta\text{Time}$
In other words, acceleration describes how quickly the velocity changes, including its direction, with time. For example, a constant, positive acceleration of \(indicates a steadily increasing velocity for each unit of time that passes.

We use units of length per squared time for acceleration, with the most common unit being in meters per second squared, denoted by the symbol ms2. Like displacement and velocity, acceleration measurements can be positive, zero, or negative since acceleration is a vector quantity.

Forces

You likely already have enough physical intuition to guess that motion can't simply occur from nothing — you have to push your furniture to change its position when redecorating or apply a brake to stop a car. A core component of motion is the interaction between objects: forces.

A **force** is an interaction, such as a push or pull between two objects, that influences the motion of a system.
Forces are vector quantities, which means the direction of the interaction is important. Force measurement can be positive, negative, or zero. A force is usually measured in units of Newtons, denoted by the symbol N, which is defined as:

$$1\text{N}=1\text{kg}\cdot\text{ms2}$$

According to our definition of kinematics, we don't need to account for any pushing or pulling interactions that might've kick-started motion. For now, all we need to pay attention to is the motion as it's happening: how fast a car is traveling, how far a ball has rolled, how much an apple is accelerating downward. However, it's beneficial to keep forces such as gravity in the back of your mind as you analyze kinematics problems. Kinematics is just a stepping stone to building our understanding of the world before we dive into more difficult concepts and systems!

Displacement Time Graph

The displacement of an object is defined as how far the object is from its initial point. In the displacement time graph, displacement is the dependent variable and is represented on the y-axis, while time is the independent variable and is represented on the x-axis. Displacement time graphs are also known as position-time graphs. There are three different plots for the displacement time graph, and they are given below:

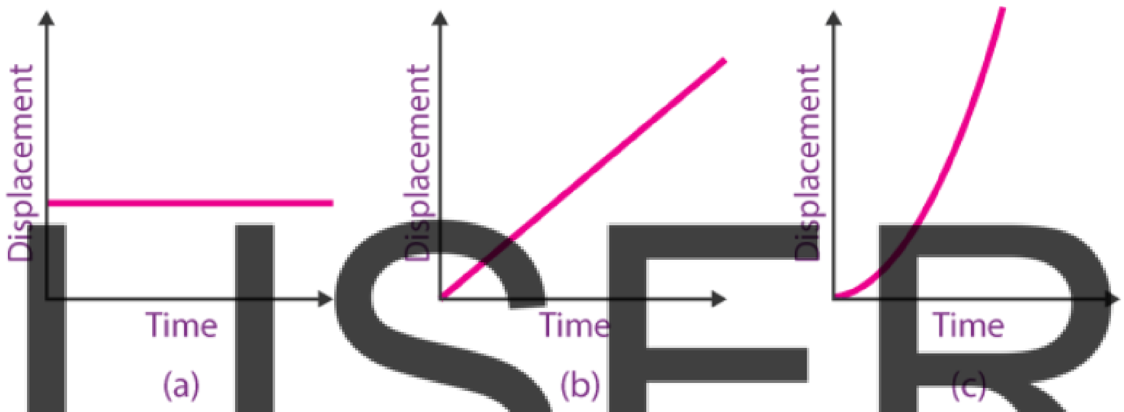
- The First graph explains that the object is stationary for a period of time such that the slope is zero, which means that the velocity of the object is zero.
- the Second graph explains the velocity of the object, and hence the slope of the graph remains constant and positive.

- Third graph explains that the acceleration is constant. The slope of the graph increases with time.

The slope for the displacement time graph is given in the table below:

Therefore, the following are the takeaway from the displacement time graph:

- Slope is equal to velocity.
- Constant velocity is explained by the straight line, while acceleration is explained by the curved lines.
- Positive slope means the motion is in the positive direction.
- Negative slope means the motion is in the negative direction.
- Zero slope means that the object is at rest.

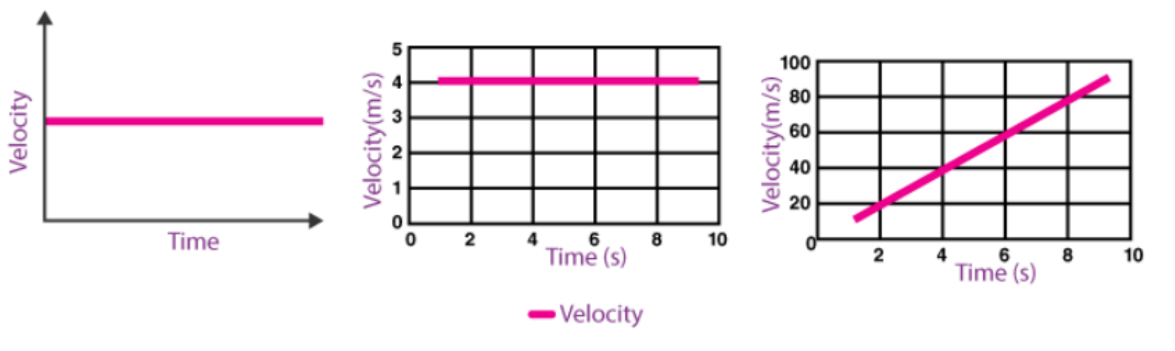


Velocity Time Graph

In the velocity-time graph, velocity is the dependent variable and is represented on the y-axis, and time is the independent variable, represented on the x-axis. The slope of the velocity time graph is given as in the table:

We see that the slope of the velocity-time graph is the definition of acceleration; therefore, it can be said that the slope is equal to acceleration. Therefore, the following are the points understood from the slope:

- Steep slope represents the rapid change in velocity.
- Shallow slope represents the slow change in velocity.
- If the slope is negative, then the acceleration will also be negative.
- If the slope is positive, then the acceleration will also be positive.
- The area under the velocity represents the displacement of the object

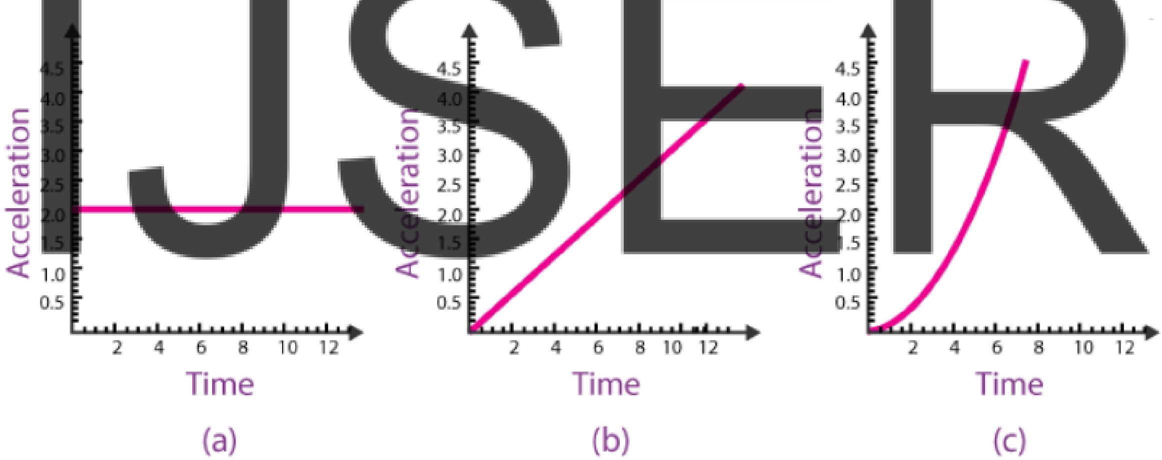


Acceleration Time Graph

In the acceleration time graph, acceleration is the dependent variable and is represented on the y-axis, and time is the independent variable and is represented on the x-axis. The slope of the acceleration time graph is as given in the table:

The slope of the acceleration time graph is known as jerk. The following are the points understood from the graph:

- If the slope is zero, then the motion is said to have constant acceleration.
- The area under the graph represents the change in velocity.



Kinematic Equations in Physics

The kinematics equations, also known as equations of motion, are a set of four key formulas we can use to find the position, velocity, acceleration, or time elapsed for the motion of an object. Let's walk through each of the four kinematic equations and how to use them.

The first kinematic equation allows us to solve for the final velocity given an initial velocity, acceleration, and time period:

$$v=v0+a\Delta t$$

where v_0 is the initial velocity, a is the acceleration, and Δt is the time elapsed. The next kinematic equation lets us find the position of an object given its initial position, initial and final velocities, and elapsed time:

$$x=x0+(v+v02)\Delta t, \text{or} \Delta x=(v+v02)\Delta t$$

where x_0 is the initial position in the x-direction. We can substitute x for y or z for motion in any other direction. Notice how we've written this equation in two different ways — since the displacement Δx is equal to $x-x_0$, we can move our initial position variable to the left side of the equation and rewrite the left side as the displacement variable. This handy trick also applies to our third kinematic equation, the equation for the position given the initial position, initial velocity, acceleration, and elapsed time:

$$x=x0+v0t+12a\Delta t2, \text{or} \Delta x=v0t+12a\Delta t2$$

Again, we can always substitute the position variables with whichever variable we need in a given problem. Our final kinematic equation allows us to find the velocity of an object with only the initial velocity, acceleration, and displacement:

$$v2=v02+2a\Delta x$$

All four of the kinematic equations assume that the **acceleration value is constant**, or unchanging, during the time period we observed the motion. This value could be the acceleration due to gravity on the surface of Earth, another planet or body, or any other value for acceleration in another direction.
Choosing which kinematic equation to use might seem confusing at first. The best method to determine which formula you need is by listing the information you've been given in a problem by variable. Sometimes, the value of a variable may be implied in the context, such as zero initial velocity when dropping an object. If you think you haven't been given enough details to solve a problem, read it again, and draw a diagram too!

Types of Kinematics

Though kinematics in physics broadly includes motion without regard to causal forces, there are several types of recurring kinematics problems you'll encounter as you begin your studies of mechanics. Let's briefly introduce a few of these types of kinematic motion: free fall, projectile motion, and rotational kinematics.

Free Fall

Free fall is a type of one-dimensional vertical motion where objects accelerate only under the influence of gravity. On Earth, the acceleration due to gravity is a constant value we represent with the symbol g:

$$g=9.81ms2$$

Free fall motion occurs in only the vertical direction, starting at a height h naught above the ground, In the case of free fall, we don't consider the effects of air resistance, friction, or any initially applied forces that don't fit in with the definition of free-falling motion. An object undergoing free fall motion will descend a distance of Δy, sometimes called h0, from its initial position to the ground. To get a better understanding of how free fall motion works, let's walk through a brief example.

Your calculator falls off your desk from a height of 0.7m and lands on the floor below. Since you've been studying free fall, you want to calculate the average velocity of your calculator during its fall. Choose one of the four kinematic equations and solve for the average velocity.

First, let's organize the information we've been given:

- The displacement is the change in position from the desk to the floor, 0.7m.
- The calculator begins at rest just as it begins to fall, so the initial velocity is $vi=0ms$.
- The calculator is falling only under the influence of gravity, so $a=g=9.8ms2$.
- For simplicity, we can define the down direction of motion to be the positive y-axis.
- We don't have the duration of time for the fall, so we can't use an equation that depends on time.

Given the variables we do and do not have, the best kinematic equation to use is the equation for velocity without knowing the duration of time, or:

$$v2=v02+2a\Delta y$$

To make our math even simpler, we should first take the square root of both sides to isolate the velocity variable on the left:

$$v=v02+2a\Delta y$$

Finally, let’s plug in our known values and solve:

v=0ms+(2·9.8ms2·0.7m)v=13.72m2s2v=3.7ms

The average velocity of the calculator is 3.7ms.
Though most free fall problems take place on Earth, it’s important to note that acceleration due to gravity on different planets or smaller bodies in space will have different numeric values. For example, acceleration due to gravity is considerably smaller on the moon and significantly greater on Jupiter than what we’re used to on Earth. So, it isn’t a true constant — it’s only “constant” enough for simplifying physics problems on our home planet!

Projectile Motion

Projectile motion is the two-dimensional, usually parabolic motion of an object that has been launched into the air. For parabolic motion, an object’s position, velocity, and acceleration can be split into horizontal and vertical **components**, using x and y subscripts respectively. After splitting a variable of motion into individual components, we can analyze how fast the object moves or accelerates in each direction, as well as predict the position of the object at different points in time.

An object with projectile motion launched at an angle will have velocity and acceleration in both the x and y directions,

All objects experiencing projectile motion exhibit symmetric motion and have a max range and height — as the classic saying goes, “what goes up must come down”!

Rotational Motion

Rotational motion, also known as rotational kinematics, is an extension of the study of linear kinematics to the motion of orbiting or spinning objects.

Rotational motion is the circular or revolving motion of a body about a fixed point or rigid axis of rotation.
Examples of rotational motion exist all around us: take the planetary orbits revolving around the Sun, the inner movement of cogs in a watch, and the rotation of a bicycle wheel. The equations of motion for rotational kinematics are analogous to the equations of motion for linear motion. Let’s look at the variables we use to describe rotational motion.

Variable	Linear Motion	Rotational Motion
Position and Displacement	x	θ (Greek *theta*)
Velocity	v	ω (Greek *omega*)
Acceleration	a	α (Greek *alpha*)

Conclusion

Kinematics is a field of mechanics concerned with the study of a body's motion without considering the source of the motion. Kinetics is the part of classical mechanics regarding the relations between motion and its causes, specifically forces and torques, in physics and engineering. The influence of forces and torques on the motion of massed bodies is studied in kinetics it is a branch of classical mechanics. It is also known as "dynamics." Kinetics and Kinematics are two disciplines of Mechanics that are very essential. kinetics explains concepts such as torques, various forces, and so on. kinematics explains topics such as acceleration, the end position of a moving object, speed, and so on.