KINEMATICS

WHAT IS KINEMATICS?

Dictionary definition: the branch of mechanics concerned with the motion of objects without reference to the forces that cause the motion.

In other words, kinematics is a subject within physics that explores an objects motion. Therefore, kinematics can be seen rather often within any sport. However, I'm here today to talk about kinematics within soccer, and only soccer. So let's begin.

THE SPEED OF THE BALL

Calculating the speed of the ball is rather easy, but it can't be done without numbers. In fact with just two numbers that you can simply measure; time and distance. Recently I was at my local soccer field and I passed the ball a total distance of 24 m (metres) until it reached my teammate in 8 s (seconds) . Perfect, I have two numbers right there. Now to calculate the speed I kicked the ball combines both of these numbers. Speed (or Velocity) is calculated in the equation $V= \Delta d/\Delta t$ where Δd represents distance, Δt represents time, and V represents velocity. Therefore the velocity of the ball I kicked was 3 m/s.

THE ACCELERATION OF THE BALL

Now imagine if we went further with the simple concept of velocity. Picture someone kicking the ball into a net. In fact, I did this and got my measurements and calculations. The ball I kicked was traveling at 6 m/s before it sped up and started traveling at 14 m/s. We can see that the ball accelerated by looking at these two numbers because it went from a lower speed to a higher speed, and we can calculate just how much it accelerated by. However we need another variable; distance or time. To prove to you that you can calculate acceleration with both distance and time, I measured both. It took 4 s before the ball changed speed and it was in a distance of 40 m. I calculated this by setting markers in which I start a new timer when the ball reaches the first marker and record the time it takes to get to the final marker. To solve for the acceleration of the ball using the distance looks like this:

The steps I took to solve for the acceleration are as follows:

1. (acceleration)
2. al numbers

$$V_2^2 = V_1^2 + 2a\Delta d$$
$$\frac{V_2^2 - V_1^2}{2\Delta d} = a$$
$$\frac{(14m/s)^2 - (6m/s)^2}{2(40m)} = a$$
$$\frac{196m^2/s^2 - 36m^2/s^2}{80m} = a$$
$$\frac{160m^2/s^2}{80m} = a$$
$$2\ m/s^2 = a$$

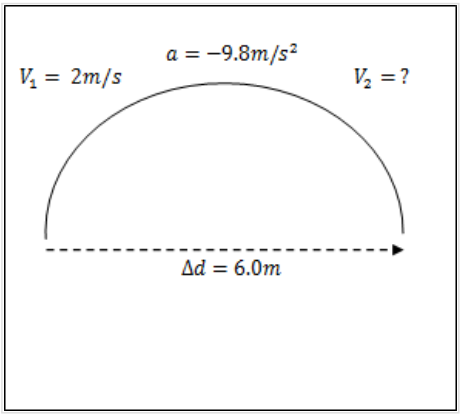
To solve for the acceleration of the ball using the time looks like this:

$$a = \frac{V_2 - V_1}{\Delta t}$$
$$a = \frac{14m/s - 6m/s}{4s}$$
$$a = 2m/s^2$$

The steps I took to solve for the acceleration are as follows:
1. No need to rearrange the equation because a is already isolated
2. Substitute the variables
3. Follow the order of operations

THE MAXIMUM SPEED OF THE BALL

In any sport, when a ball is hit, thrown, or kicked through the air gravity adds an acceleration to the ball. As the ball flies through the air the more and more acceleration due to gravity impacts it. The maximum speed the ball reaches is the amount of velocity it hits the ground with, because gravity is a factor until it reaches a height of 0 m. We can solve for the maximum height of any ball as long as we have a couple variables.

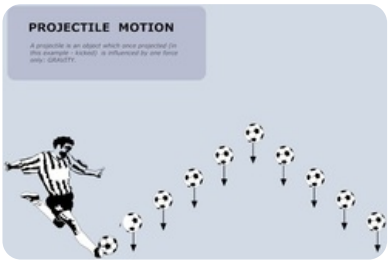


The diagram above shows a situation I was recently in. I was in my backyard when I kicked the ball into the air. I measured the distance it covered, and calculated the initial speed (V= d/t). So I drew up this diagram to show you how to calculate maximum speed in this scenario. First of all, with this diagram I can see the variable I want to solve for which in this case is the final velocity (maximum speed). 9.8 m/s^2 is a constant representing the acceleration due to gravity, and it is negative because it is acting down on the ball when the ball is moving upward.

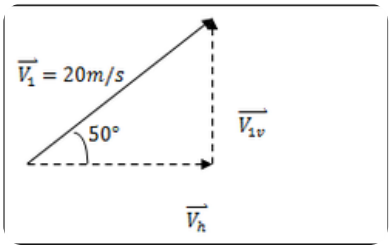
$$V_2^2 = V_1^2 + 2a\Delta d$$
$$V_2^2 = (12m/s)^2 + 2(-9.8\,m/s^2)\,(6.0m)$$
$$V_2^2 = (144\,m^2/s^2) + (-117.6m^2/s^2)$$
$$V_2 = \sqrt{26.4\,m^2/s^2}$$
$$V_2 = 5.\underline{1}38093031m/s$$

before. This could also work for passing between teammates.

PROJECTILE MOTION



First of all, what is projectile motion? Projectile motion is a type of motion that is under the influence of gravity and is not self powered. Projectile motion is seen very often in sports. With projectile motion the vertical and horizontal components act independently of each other, an object will travel at a constant vertical acceleration of 9.8m/s^2 [down] (acceleration due to gravity), there will always be a constant horizontal velocity, and the only factor that the horizontal and vertical components share is the time it takes for the object to travel through the air. Considering the projectile motion questions are separated between horizontal and vertical components the values are vector. Vector is a quantity that has both size and direction. Therefore one of the first steps of solving a projectile motion question is to differentiate which two directions are positive (one in the vertical and one in the horizontal).
I kicked a soccer ball from 40m away from the goal. The ball traveled at an initial velocity of 20m/s [50 degrees above the horizontal] and then the goalie caught it. I want to calculate for the final velocity the ball had before the 1.7m tall goalie caught it. To start solving this question I'm going to draw a right-angled triangle of the horizontal velocity, the vertical velocity, and the velocity travelling diagonally of both.



As you can hopefully see by the triangle, we can solve for the initial velocity in the vertical, and the velocity in the horizontal using SOH CAH TOA.

(I am not going to solve for them just yet because I do not want to deal with decimals until I solve for something.)

The next step is to differentiate between the horizontal and vertical components and define which directions are positive.

Horizontal [→] = +ve	Vertical [↑] = +ve
$\overrightarrow{V_h} = 20m/s\,(cos50°)$ $\overrightarrow{\Delta d_h} = 40m$	$\overrightarrow{V_{1v}} = 20m/s\,(sin50°)$ $\overrightarrow{V_{2v}} = need$ $\overrightarrow{\Delta d_v} = 1.7m$ $\vec{a} = -9.8\ m/s^2$

The chart to your left shows what we know/what is given, and what we NEED to solve for in order to solve for the final velocity. To get the final velocity we need the final velocity in the vertical.
Therefore we must solve for this velocity like this:

$$\overrightarrow{V_{2v}^2} = \overrightarrow{V_{1v}^2} + 2\vec{a}\overrightarrow{\Delta d}$$

$$\overrightarrow{V_{2v}^2} = [20m/s(sin50°)]^2 + 2(-9.8m/s^2)(1.7m)$$

$$\overrightarrow{V_{2v}^2} = (234.7296355m^2/s^2) + (-33.32m^2/s^2)$$

$$\overrightarrow{V_{2v}} = \sqrt{201.4096355m^2/s^2}$$

$$\overrightarrow{V_{2v}} = 14.19188626m/s\,[\downarrow]$$

N city we can solve for the final velocity of the ball diagonally. To do this we need the final hc elocity in the horizontal for projectile motion question is constant. In other words, it will

$$a^2 + b^2 = c^2$$

$$\overrightarrow{V_{2v}^2} + \overrightarrow{V_h^2} = \overrightarrow{V_2^2}$$

$$(14.19188626m/s)^2 + [20m/s(cos22°)]^2 = \overrightarrow{V_2^2}$$

$$201.4096356m^2/s^2 + 165.2703645m^2/s^2 = \overrightarrow{V_2^2}$$

$$\sqrt{366.6800001m^2/s^2} = \overrightarrow{V_2}$$

$$19.14889031m/s = \overrightarrow{V_2}$$

all the initial velocities of the ball. Now that I have the final velocities I have each side length of my new triangle and can solve for the angle the final velocity is above the horizontal.

$$\sin\theta = \frac{\overrightarrow{V_{2v}}}{\overrightarrow{V_2}}$$

$$\sin\theta = \frac{14.19188626m/s}{19.14889031m/s}$$

$$\theta = \sin^{-1} 0.741133613m/s$$

$$\theta = 47.82807174°$$

Now I have the whole vector value. I have the magnitude and the direction of the speed. ∴the final velocity of the soccer ball is 19 m/s [48° above the horizontal].

For a soccer player, knowing the physics of soccer can help their play. Considering we know the acceleration due to gravity that acts on the ball, a smart soccer player can take that into consideration when they kick the ball. Along with the distance they are trying to reach. For example when a soccer player takes a penalty kick, they are 12 yards away from the keeper and the net. When they are this close to their target, it is not smart to hit the ball up because the distance is so small. What I mean is that the ball will be decelerating in the air until it reaches it's peak height in which the goalie can catch it. It is very hard for a soccer player to kick the ball into the air and then it be accelerating downwards toward the net in a penalty kick. This is why most players shoot with the ball remaining on the ground. The benefit of this is that the ball is not travelling a great distance which means it won't be decelerating. This is because the only thing stopping the ball would be the goalie or the back of the net.