Date- Time- Competitor number-

2025 Principles of Engineering-Technology Competition, Kinematics

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Introduction

Kinematics is a fundamental branch of physics that studies the motion of objects. Kinematics comes from the Greek words kine, meaning motion, and matics, meaning study of. That means kinematics is the study of motion. Kinematics is only possible because of Newton's laws of motion, which will be discussed in detail later. Projectile motion, a branch of kinematics, also focuses on the motion of objects; however, projectiles always follow a curved path.

For my technical demonstration, I chose to design and build a catapult. It allows you to launch an object, making it a projectile. It is the most efficient way to show how projectiles work. I also chose to tie a ball to a string and spin it in a circle because that demonstrates circular motion, another branch of kinematics. However, circular motion is the basis for orbital mechanics. Sending objects into orbit is just an extension of projectile motion. Demonstrating circular motion solidifies the concepts used to send objects into orbit.

Discussion

In the 17th century, Galileo Galilei found that any falling object has a constant acceleration regardless of its mass while also ignoring air resistance. He also introduced the idea that the acceleration of a falling object is a constant rate of 9.8 m/s, which we now know as the variable g. These discoveries paved the way for Newton's laws, which are the foundation for every branch of physics. Newton expanded on Galileo's principle of motion into his famous 3 laws: inertia, force, and action and reaction.

Inertia: An object at rest will stay at rest, and an object in motion will stay in motion with the same speed and direction until acted upon by an unbalanced force.

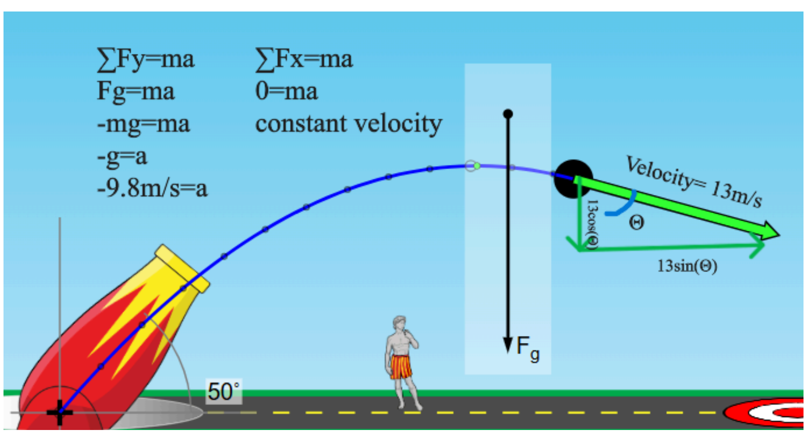
Date- Time- Competitor number-

Force: The acceleration of an object depends on the mass of the object and the amount of force applied. Force= mass x acceleration

Action and Reaction: For every action there is an equal and opposite reaction.

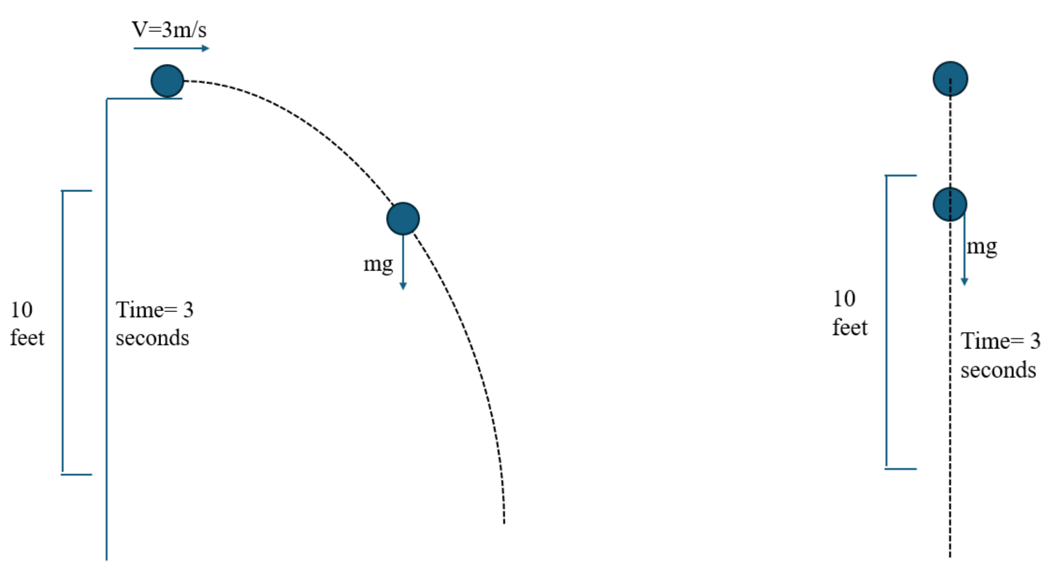
These 3 laws dictate everything we know about motion. Without these laws, most of modern-day science wouldn't be possible. For example, Newton combined his laws with Kepler's law, and he was able to explain why planets have an elliptical orbit rather than a circular orbit. Without that vital discovery, we would not have been able to send any spacecraft into orbit or have any understanding of orbital mechanics.

A projectile is an object that falls through the air in the path of a parabola, with the only force acting on it being gravity. Projectiles are completely dependent on Newton's Laws of motion, these concepts are essential when analyzing projectiles. Without them, we would not be able to understand the mechanics of projectile motion. Projectile motion is analyzed in two dimensions, the x and y. As said before, the only external force is gravity, which is measured in the y dimension, also commonly written as Fg. However, if you apply Newton's second law (F=ma) and then sum up the forces in the y dimension, which is just gravity, you find the force acting on the projectile is equal to the mass times acceleration. Instead of writing Fg for the force of gravity, it is beneficial to write mg or mass times gravity. If you substitute mg in for fg in F=ma, it simplifies to -mg=ma (Mg is negative



because on a free body diagram, gravity points in the negative direction.) Mass cancels out from both sides, leaving you with -g=a. While solving projectiles, it is important to note that all the x and y forces are independent of each other, meaning when you sum up the forces, you should have two separate columns, one for the y and one for the x. On the other hand, upon examining the projectile in the x dimension, you will notice there is no external force, meaning F=0. Substituting that into F=ma results in 0=ma. This means there is a constant velocity and a balanced force. To have balanced forces, there must be constant velocity, which occurs when there is no acceleration. But if F=0, how is the projectile still moving horizontally? The projectile starts with an initial velocity that propels it horizontally, but velocity is a vector quantity, not a force, so it cannot be included in the summation of forces.

If an object is launched horizontally and another object is dropped vertically, both from



the same height, they will reach the ground at the same time. This phenomenon occurs because they both have a vertical acceleration of 9.8. And as previously stated, the x and y forces are independent of each other, so even if it has a force in the x dimension, it doesn't matter because gravity is still the only y force acting on it.

Calculating projectiles is not very difficult; there are 4 main equations, and they are derived from velocity-time graphs. They use 5 variables: **υ** final velocity, **a** acceleration, **t** time, **Vo** initial velocity, and Δx displacement. When you are solving a projectile problem, you will need to make an x and y column because the two forces are independent of each other. For example, if you wanted to solve for velocity, you would first have to solve for the x and y velocity values using component vectors. However, there is one exception to this rule, and that is time. Time is the same value for x and y because a projectile moves in both dimensions simultaneously. The most challenging part of solving these problems is keeping the x and y values separate.

	υ	a	t	V_o	Δx
$v = at + V_o$	X	X	X	X	
$x = V_o t + \frac{1}{2}at^2$		X	X	X	X
$^2 = v_o + 2a\Delta\chi$	X	X		X	X
$v = \frac{\Delta\chi}{t}$	X		X		X

For the technical demonstration, I decided to demonstrate two different concepts. For the first demonstration, I decided to design a catapult out popsicle sticks and rubber bands because those items are common household items so anyone can build it. A catapult is also the most efficient way to demonstrate projectiles There are a multitude of ways to manipulate how a projectile can travel, including manipulating launch angles to affect the distances traveled. For example, 70° gives you a longer vertical distance while 30° gives you a longer horizontal distance traveled. I will put the projectile into the catapult, then describe which launch angle it will be launched with and how that will affect the path. Then I will launch it and discuss the forces involved. I will repeat this 3 times with a different angle each time to emphasize the importance of launch angles. For the second demonstration, I will have a ball attached to a string and I will spin it in a circle. This is a simple way to demonstrate circular motion. It is crucial to understand circular motion because it lays the foundations for the concepts involved in orbital mechanics. Orbital mechanics are essentially an extension of projectile motion because to send an object into orbit, you have to launch it into the atmosphere, which then follows a curved path, thus making it a projectile.

Projectile motion applies to many everyday scenarios. For example, if you chip a soccer ball, once it is kicked into the air, it becomes a projectile because it follows a curved path and the only force acting on it is gravity. Another common example of a projectile is a slingshot. When you pull back the elastic, you are building up elastic potential energy, and when you release the elastic, that energy converts to kinetic energy. Kinetic energy launches it forward, making it a projectile. Both of these examples follow Newton's third law: for every action, there is an equal and opposite reaction. They also follow the law of conservation of energy, energy can neither be created nor destroyed. For example, the elastic energy doesn’t get lost, it simply converts into kinetic energy. Another example of projectiles is planes, satellites, missiles, and meteors. These are all excellent examples, however, they are impractical to demonstrate as they are too big and expensive. When you think of a satellite, you don’t think of it as a projectile, but it is. It gets launched with an initial velocity, and the only external force is gravity. Even in space, it can technically be counted as a projectile because the only external force is still gravity; gravity is what keeps it in orbit. It is also still following a curved path, except it's just curving around the

Earth in the shape of an ellipse. This is circular motion, gravity acts as the centripetal acceleration, which is what keeps it in orbit. Or if you look at the path of a plane, even though it is self-propelled, it still follows the path of a parabola. Missiles are also a really good example because to launch missiles, the launch angle has to be incredibly precise because the launch angle has a very low tolerance. If it is even off by a hundredth of a degree, it could land in the completely wrong area.

Kinematics is the study of motion, and projectiles are a branch of kinematics. Projectiles are when an object is launched and follows the path of a parabola, where the only external force acting is gravity. Newton's first, second, and third laws all apply to projectile motion and are the foundations of projectiles. Through the technical demonstration, we prove the relationship between the fixed variables, acceleration, time, initial velocity, final velocity, and displacement. We also demonstrate the importance of launch angles and how they affect the trajectory of a projectile. It proved that the larger the angle, the greater the vertical distance, and a smaller angle results in a smaller horizontal distance. They are inversely proportional. By understanding how these variables interact with each other, you can manipulate them to your benefit. Whether this means making the perfect slingshot shot, or launching a satellite into space. Understanding projectile motion is key and provides the base for achieving high-level accomplishments.

Date- Time- Competitor number-

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orbital mechanics.