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BOCES Science Laboratory Investigation

THE “BULLSEYE LAB”

**Introduction**

Whether you are shooting a cannon, a rifle or simply throwing a football around the backyard, it’s important to understand a few basic things about the way that your projectile (football, bullet, cannonball, etc.) is moving. We know that what goes up must come down, and that is due to, of course, the force of Mamma Earth – gravity. We also know that gravity pulls down on everything with the same acceleration, viz. 9.81 m/s/s.

What we don’t often consider is that acceleration can happen in many different directions. Consider, for example, a car moving down a road. If the car speeds up, it is accelerating in the direction of motion, but if it slows down, it is accelerating in the opposite direction. That is, if you consider the velocity of the car in the “backwards” direction, it is increasing, while the velocity in the forward direction is decreasing. So slowing down (or decelerating) is really just accelerating in the opposite direction.

The same thing is true of any of the projectiles that we’ve mentioned above. The only difference is that they’re only going to speed up or slow down at one rate – the acceleration due to gravity, or 9.81 m/s/s. This makes our lives much easier. Consider a ball being thrown straight up in the air. If it is initially going at 9.81 m/s, it is going to slow down at a rate of 9.81 m/s/s. So, it will take one second for the ball to slow down and stop. Now the ball won’t just sit there in the air, it will start to fall again. And we know the rate at which it will fall! It will accelerate at 9.81 m/s/s, so after one second, it will be going 9.81 m/s again, and that’s when it will hit the ground.

The practical upshot of this is that if you throw a ball up in the air and it takes six seconds to land, then you can figure out how fast you threw the ball. Consider this: we know that the ball will accelerate and decelerate at the same rate – 9.81 m/s/s. So it must have taken half of the time to get to the highest point, and half of the time to get back down, because the acceleration on both sides of trip is the same. So it took three seconds to get up, and three to get down (six divided in half is three). And if we know that each second it goes up it decelerates by 9.81 m/s/s, then we can figure out the initial speed by simply multiplying the time in seconds by the acceleration. So, 3 x 9.81 = 29.43 m/s. AND, we know that it was going at exactly that speed when it hit the ground, because it takes three seconds to get from the highest point back down, and the acceleration is still the same! So 3 x 9.81 = 29.43 m/s.

The trickier thing to think about is when you’re throwing something at an angle, like a football. When you throw a football, the ball is moving horizontally AND vertically at the same time. This might seem like it will complicate the math to an aggravating degree, but it’s actually very simple: *The horizontal and vertical motion of any projectile are completely independent*. That’s right, no matter how fast you are going in a forward direction, if you run off a cliff, you’ll still be falling at 9.81 m/s/s. And just because you run off a cliff really fast doesn’t mean that you’ll “hover” in mid-air for a moment, like the coyote in the cartoons; you start falling as soon as there is no longer ground under you. If you’re going fast in a forward direction, you’ll land farther away from the edge of the cliff, but you’ll hit the ground at exactly the same time as if you had simply stepped off the cliff and begun to fall.

So if we are trying to figure out how far away from the cliff you’ll land, we really only need to employ one formula, shown below:

Formula 1: vh = dh/t

Where vh is the velocity in the horizontal direction, dh is the distance traveled in the horizontal direction, and t is the time. Note that this formula, as do all the others in this lab, ignores the effect of air resistance on a projectile, because trying to calculate that really gums up the math.

But if you were trying to figure out how long it would take you to fall, or how fast you might be going when you hit the ground, we need to take into account what is pulling you down, viz. gravity. There are several formulæ that you can use to work in the vertical direction:

Formula 2: vf = vi +at

Formula 3: d = vit + ½ at2

Formula 4: vf2 = vi2 +2ad

Where vf is the final velocity of an object, vi is the initial or starting velocity of an object, a is the acceleration due to gravity, t is the time and d is the distance traveled. Consider the example below:

A car that is going 25 m/s (about 55 mph) rolls off a 700 m tall cliff.



A. How long does it take to hit the ground?

To solve this, you need to consider *only the motion in the up and down (vertical) direction*. So initially, the car is going 0 m/s in the vertical direction. You don’t need to worry about the horizontal direction. We know it will fall 700 m, but how long will that take?

We can use formula 3 from above. We know the distance (700 m), we do know the initial velocity (0 m/s) and we know the acceleration due to gravity (it’s always 9.81 m/s/s). So all we have to do is substitute all that in, and solve for the time, t.

Keep in mind that the car could be going 1,000,000 m/s, and it would still hit the ground at the same time that you calculated. The horizontal velocity simply doesn’t enter into this at all. The only effect it would have would be to make the car land further away from the cliff.

B. How far away from the cliff does it land?

To solve this, we can ignore the vertical information, because it won’t affect the motion in the horizontal direction. N.B. – We can, if we want, use the time that we calculated in part A, because no matter what the horizontal velocity, the car will hit the ground at the same time! That is, the time is the same in both the horizontal and vertical directions. We can use formula 3 again, but this time, we’ll solve for distance. Substitute everything else in that you know, including the time that you’ve already calculated.

So you can see how far away from the cliff it landed depends only on the horizontal velocity.

**Purpose**

The purpose of this lab is for you to investigate a few new formulæ relating to projectile motion, and to try and predict where a ball will land based on measurements that you take yourself.

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**Materials**

PENCIL Ramp

Ball Photogates

LabQuest Meter Stick

Target

**Methods**

1. Incline your ramp using a book or other object. Use tape to secure the ramp in position at the edge of the table so that it will not move.

2. Position the photogates at the edge of the ramp.

3. Measure the velocity of the ball as it exits the ramp.

4. Use the formulæ above to calculate where you need to place the target in order for the ball to hit it right in the middle. You only get one shot!

QUESTION 1: Use the space below to show your calculations. Please be complete, and make sure that no numbers go naked!

QUESTION 2: What was your percent error? That is, how far off were you from the middle of the target?