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Kinematics/Projectile Motion Laboratory Activity

Part 1 – Determination of Acceleration Due to Gravity

Prerequisite knowledge: 1. Be familiar with the *ScienceWorkshop* data collecting and graphing program. 2. Understand how to use a photogate and what it measures.

A penny dropped from 10 feet above ground would be almost harmless to anyone below, but a penny dropped from the Sears Tower could be potentially life threatening.

An astronaut wearing his space suit on earth would be burdened with over 300 pounds of heavy material, but, on the moon, the space suit seems almost six times lighter.

Both of these phenomena are a result of acceleration due to gravity. In this part of the experiment, you will determine the magnitude of the earth's acceleration due to gravity (g).

Goal Q: What is the magnitude of g?

Note: The following is intended to be a set of guiding questions to help you successfully complete this laboratory activity. These questions need not be responded to in the lab report unless specifically mentioned.

How can you tell visually if something is accelerating?

How is acceleration mathematically defined?

What are the units of acceleration?

If velocity is plotted on the y-axis and time on the x-axis, what would be the units of the slope of the graph?

Graphically, the value of the slope of a function is known as its derivative. Therefore, acceleration is the derivative of the function of v(t). (By using calculus and finding the limit as change in time goes to 0:

$$\frac{d}{dt}v = a$$

You have been given the following materials:

- Picket fence
- Photogate
- Computer with a data collecting and graphing program

Using the computer program, set *ScienceWorkshop* to read the velocity of the picket fence as it free-falls through the photogate. Using the computer, graph the velocity (y-axis) versus time (x-axis).

What does the shape of the graph suggest about the change in velocity over time? (Does the velocity increase, decrease, or stay the same?)

If there are any y or x – intercepts, what could they represent?

What is the value of the derivative (slope) of the best-fit line to the velocity vs. time graph?

After t seconds, what is the velocity of the picket fence? (Use the definition of acceleration and solve for velocity).

After t seconds, what is the acceleration of the picket fence?

If you give an initial downward or upward push to the picket fence before it falls through the sensor, how will it affect the value of g?

If you give an initial downward or upward push to the picket fence, how can this be accounted for in the equation for velocity = acceleration * time?

How does your value of acceleration compare to the accepted local value of g as 9.81 m/s^2?

What is the percent error of experimental acceleration to the accepted value of g?

What might account for the difference in the experimental and accepted values?

Part 2 – Derivation of Kinematics Equations

Prerequisites: 1. Understand how to draw and analyze force diagrams. 2. Understand vectors and vector components.

On the way down Splash Mountain at Disney World, you realize that you started at the top of the ramp very slowly, but at the bottom of the ramp your speed was notably increased.

Preparing to sled down a nearby hill covered in snow, you choose the part of the hill with the greatest incline to assure a more exhilarating ride.

Both of these situations are related to kinematics and the nature of "speeding up" as we travel downwards on an incline. In this part of the laboratory experiment you will determine the relationship between the acceleration due to gravity on inclined planes, the velocity, and displacement of an object travelling down the plane.

Goal Q: On a plane inclined at an angle θ to the horizontal, how fast will an object be going after d units of displacement?

Is there any acceleration on a ball going down an inclined plane?

Where does this acceleration come from? (Draw a force diagram of a ball on an inclined plane. Then, make your x-axis parallel to the plane and find the component vectors of each force.).

What is the value of acceleration on a plane of θ degrees? (Express this in terms of a trigonometric function and g).

What is the theoretical value of acceleration on your plane at 10 degrees?

What is the velocity of a ball going down the plane of θ degrees after t seconds (with the ball having started from rest)? (Use the definition of acceleration and solve for velocity.)

You are given the following items:

- Plane at an angle of 10 degrees
- Metal ball
- Timer
- Meter stick
- Computer with a graphing program

Calculate the average velocity of the ball versus the average time it takes the ball to travel from the top edge to the bottom edge of the inclined plane. Repeat this process at least five times, and calculate the final velocity and total time.

Graph the average value of velocity (y-axis) versus the average time (x-axis). (This will be a graph with only one point). Using the equation of the area of a triangle (1/2 * base * height), find the area of the triangle bounded by the function, the x-axis and the line formed by the point on the graph that is perpendicular to the x-axis).

The area bounded by a function, the x-axis, and the line perpendicular to the x-axis containing the maximum x-value is known as the <u>integral</u> of the function. Measure the distance traveled by the ball from the top to the bottom edge of the inclined plane. Compare the values of the function’s integral and the distance traveled by the ball.

So, by using calculus we can say that :

$$\int (v)dt = d \qquad\qquad \frac{d}{dt}d(t) = v$$

$$y(t) = d = \frac{1}{2}at^2$$

What was your starting velocity of the ball on the plane?

What was your ending velocity of the ball on the plane?

What if the ball started not from rest, but with a little push?

How can this push be represented in the mathematical relationship?

Part 3 – Derivation of Projectile Motion Equations

You are a general in a battle. You have a cannon on top of a hill directly opposite your opponent's fort. Shooting your last cannonball horizontally, you must hit the fort on the first try.

A stunt artist is standing on a high cliff, and must jump over a wide chasm and onto a cliff a meter below. He must carefully calculate the minimum horizontal velocity with which he must jump to avoid falling into the chasm.

Both of the above situations relate to projectile motion. In this part of the laboratory activity you will derive the projectile equations so as to solve the dilemma of the battle general.

Goal Q: In projectile motion, where and when will the projectile fall?

As a general, you must use your cannonball (metal ball) to hit the fort (plastic cup). Working with your military men and women, you must determine how far away the cannon (inclined plane system) and the fort must be to make a successful hit.

You have been supplied with a number of items:

Inclined plane (part of cannon set up)
Metal ball (cannon ball)
Timer
Plastic cup (opponent's targeted fort)
Meter stick

The inclined plane is situated on top of a table, a few feet from the edge (the muzzle of the cannon is parallel to the floor). The cannonball must start at the top of the inclined plane with no initial push.

Graphically, considering the edge of the table to be the origin, in what two directions will the ball move after the moment of its release from the cannon?

Are these two directional motions independent of one another in terms of time they take to fall? Conduct an experiment to verify your presumption. (Use the device in your physics laboratory that makes one ball fall with a horizontal component and another ball fall directly downward).

Consider the vertical component of the cannonball:

- What is the initial value of vertical velocity?
- What is the value of the vertical acceleration?
- How far will the ball fall vertically?
- How long will it take for the ball to fall the vertical distance?

Consider the horizontal component of the cannonball:

- What is the initial value of the horizontal velocity?
- What is the value of the horizontal acceleration? (Neglect air resistance and spin.)
- What factor determines how far the ball will fly horizontally?
- How long will it take for the ball to fly its maximum range?
- What will the distance of the maximum range be?

How far away from the edge of the table must the fort (the plastic cup) be placed for a successful hit with the cannonball?