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SECOND LAW OF MOTION APPARATUS

CAT NO. PH0319

Experiment Guide

GENERAL BACKGROUND

An object is said to undergo free-fall when the only force acting on an object is gravity. Although on Earth, air resistance is an unavoidable factor in calculating the motion of a falling object, for certain situations, air resistance is so small a factor that it can be ignored. This apparatus uses identical steel spheres and relatively low speeds in order to allow us to observe free-fall motion and ignore air resistance.

This apparatus will help challenge students preconceived notions about free fall. Simply ask the students “Which ball will hit the ground first, the one that is launch horizontally or the one that is dropped from rest?”

This simple apparatus will leave no doubt as to the answer of this question. Students will be able to observe that when launched, each sphere will hit the ground at the same time. This stems from the fact that an object propelled horizontally will fall vertically at the same rate as a similar object allowed to fall freely. Because of the effects of air resistance, it is important to point out that the objects must be at least similar in size, shape, density, and velocity. Objects vastly different will have varying amounts of air resistance, which will affect the rate at which they fall.

A sturdy metal platform holds the entire mechanism and it is visible so students can see how the apparatus works. The spring gun offers two tensions. The 25 cm long unit has a 10mm rod. It may be horizontally clamped to a support stand and leveled or rotated to various different launch angles.

KIT CONTENTS

Name of Part	Quantity
Two Dimensional Motion Apparatus	1
Steel Spheres	2

REQUIRED COMPONENTS (NOT INCLUDED)

Name of Part	Quantity
Ring Stand and Post Clamp	1
Meter Stick and Measuring Tape	1
Carbon Paper	1
Computer Graphic Program	1
Safety Glasses	As Needed
Protactor	1
Level	1

SAFE HANDLING OF APPARATUS

- Do not allow students to stand in front of the apparatus when launching spheres. Projected spheres may cause bruising or eye damage. Eye wear is recommended.

ACTIVITY 1: DROPPED VS. LAUNCHED

TEACHER ANSWERS

Purpose

To observe the independence of the horizontal and vertical components of motion.

This activity can be done as a simple classroom demonstration to supplement lecture or as a student driven discovery activity. Pose the following question to students and take a poll on students' hypotheses. “Which hits the ground first, a horizontally launched projectile or an object dropped from the same height?” Urge students to justify their response. An extension of this is to examine whether or not the height at which the projectile is launched/dropped affects the outcome. A student activity sheet and teacher key are included on the following pages.

Basic Principles

An important aspect of two dimensional motions is the independence of the components of motion. For example, the horizontal and vertical components of motion for a projectile are independent of one another. A projectile is defined as an object that is under the sole influence of gravity. Therefore, whether an object is dropped or launched with some initial velocity, the only force acting on a projectile is gravity. Any projectile is considered to be in free-fall. This means that any projectile will undergo an acceleration of about 9.8 m/s^2 (near Earth's surface) in the downward direction.

Now to the question, which hits the ground first, a horizontally launched projectile or an object dropped from the same height? As noted above, each object will have the same acceleration in the vertical direction. Since the force of gravity acts in the downward direction, each object will have no acceleration in the horizontal direction. A force in the vertical direction cannot influence the motion in the horizontal direction. Secondly, each object will have the same initial velocity in the vertical direction. A dropped object has an initial velocity of zero. Regardless of the horizontal velocity at which an object is launched, the initial velocity in the vertical direction will always be zero. Finally, each object has to travel the same distance in the vertical direction. This is independent of how far horizontally the launched object travels. From the equation $d_y = v_{oy} t + ½ a_y t^2$ it can be seen that the time in the air for each object will be the same. It turns out that this outcome is independent of how the mass of each object compare. Since a projectile by definition ignores the effects of air resistance, each object would accelerate at a rate of 9.8 m/s^2.

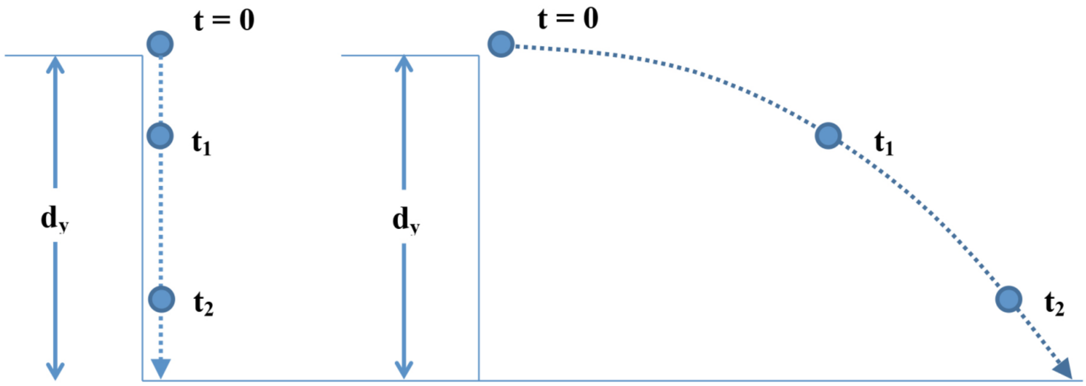


Figure: An object dropped and an object projected horizontally hitting the ground at the same time.

Question

Which hits the ground first, a horizontally launched projectile or an object dropped from the same height?

My Prediction

Student responses may vary. The following is a common student response: The object dropped will hit the ground first.

My Justification

Students responses will vary based on their prediction. Based on the above prediction, a common justification is the object dropped will hit the ground first because the horizontally launched projectile will travel farther so it will take longer for it to hit the ground.

Safety Precautions

Make sure launch area is clear of any breakables or students. Do not stand in front of the apparatus when launching spheres. Projected spheres may cause bruising or eye damage. Eye wear is recommended.

PROCEDURE

Part 1:

1. Secure the apparatus either to a ring stand heavy enough so that the ring stand does not tip upon launching, or to a heavy duty clamp that can attach to a table or lab bench itself. If using a ring stand, secure the apparatus as close to the base as possible to avoid tipping the ring stand over.

2. Use a level to make sure the horizontally launched ball does not have a y-component to its initial velocity.

3. Spring-load the apparatus by pulling the launcher back until the latch clicks into place.

4. Place each sphere on the mounts located on the launcher.

5. Measure the height at which the spheres will launch. Record here: ____________

6. Lift the latch to launch the spheres. Be careful not to jostle the device as this could let loose a sphere prior to launch.

7. Observe the motion of each sphere.

Part 2:

Let's examine if the height at which the spheres are launched has any effect on the outcome. Repeat the steps in part 1 of this activity at different heights. Use tables of various heights, chairs, or books to adjust the height at which the spheres are launched and observe the outcome. No measurements are necessary.

ANALYSIS QUESTIONS

1. Based on your observations, which sphere hits the ground first?

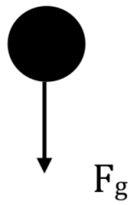
   The spheres hit the ground at the same time.

2. Based on your observations, does the height at which the spheres are launched affect which sphere hits first?

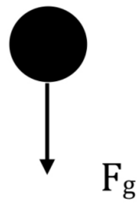
   The height at which the spheres are launched does not affect which sphere hits the ground first. At each of the heights used during the activity, each sphere hit the ground at the same time.

3. Draw a free body diagram of each sphere after it has been launched. Label each sphere appropriately. Ignore the effects of air resistance.

Dropped Sphere



Horizontally Launched Sphere



4. What is the initial velocity in the vertical direction of each sphere?

The initial velocity in the vertical velocity of each sphere is zero.

5. Based on the known information, use a mathematical approach to support your answer to question 1.

Dropped Sphere

$V_{oy} = 0$ m / s

$d_y = 1.2$ m

$a_y = 9.8$ m/s^2

t = ?

$d_y = V_{oy}t + ½\, a_y t^2$

$1.2\text{ m} = (0\text{ m/s})\,t + ½\,(9.8\text{ m/s}^2)\,t^2$

t = 0.49 s

Horizontal Launched Sphere

$V_{oy} = 0$ m / s

$d_y = 1.2$ m

$a_y = 9.8$ m/s^2

t = ?

$d_y = V_{oy}t + ½\, a_y t^2$

$1.2\text{ m} = (0\text{ m/s})\,t + ½\,(9.8\text{ m/s}^2)\,t^2$

t = 0.49 s

CONCLUSION

Which hits the ground first, a horizontally launched projectile or an object dropped from the same height? Based on your observations and answers to the analysis questions, develop an explanation for the stated outcome.

When launched simultaneously, an object launched horizontally and an object dropped from the same height will hit the ground at the same time. This is due to the fact that when released, each ball is under the sole influence of gravity and will result in each ball having the same acceleration. And since each ball will travel the same vertical distance with the same initial velocity in the vertical direction, the amount of time in the air for each ball will be the same.

ACTIVITY 2: DETERMINING THE EFFECT OF LAUNCH HEIGHT ON RANGE

TEACHER ANSWERS

Purpose

To examine the mathematical relationship between the height at which a projectile is launched horizontally and the resulting range of the projectile.

Now that students have experience with the independence of the horizontal and vertical components of motion, ask them to come up with a link between the two components of motion. For example, how do the parameters of the vertical motion of a projectile affect the resulting horizontal motion? A student activity sheet and teacher key are included on the following pages.

Basic Principles

Although the horizontal and vertical components of motion are independent of one another during the two dimensional motion of a projectile, there is a common link between the two. That common link is time. When approaching two dimensional motion problems, it is recommended that students separate the information into a table of information for each of the two components of motion. For a projectile, this would be the vertical and horizontal components. An example of this would look like the following:

Horizontal components	
v_x	10 m/s
d_x	?
a_x	0 m/s^2
t	?

Vertical components	
v_{0y}	0 m/s
d_y	3 m
a_y	9.8 m/s^2
v_{fy}	?
t	?

Note that time (t) is the only thing common between the two tables of information. The vertical components of motion will dictate the amount of time the projectile is in the air. Once the time in the air is known, the horizontal distance, or range, can be determined if one knows the horizontal velocity. It is important to note that the horizontal velocity remains constant. Remind students that gravity can only influence the motion of an object in the vertical direction.

Starting with equation $d_y = V_{oy}\, t + \frac{1}{2}\, a_y\, t^2$, setting v_{oy} equal to zero, and solving for t, one would get the following:

$$t = \sqrt{\frac{2d_y}{a_y}} \text{ (Equation 1)}$$

The time in the air for a horizontally launched projectile

Now taking formula $d_x = v_x\, t$ and substituting in equation 1 for t, one would get the following:

$$d_x = v_x\sqrt{\frac{2d_y}{a_y}} \text{ (Equation 2)}$$

The horizontal distance as a function of height

Equation 2 shows that there is a **direct root relationship** between the vertical distance (launch height) and the horizontal distance (range). This means that one would have to quadruple the lunch height in order to double the horizontal distance of a projectile.

Question

What is the mathematical relationship between the height at which a projectile is launched horizontally and the resulting range of the projectile?

My Prediction

Student responses may vary. The following is a common student response: The relationship between launch height and range is direct. If you double the launch height, you double the range.

My Justification

Students responses will vary based on their prediction. Based on the above prediction, a common justification is as the height increases, the time in the air will increase. This will allow the object to travel farther.

Safety Precautions

Make sure launch area is clear of any breakables or students.Do not stand in front of the apparatus when launching spheres. Projected spheres may cause bruising or eye damage. Eye wear is recommended.

PROCEDURE

Part 1:

1. Secure the apparatus either to a ring stand heavy enough so that the ring stand does not tip upon launching, or to a heavy duty clamp that can attach to a table or lab bench itself. If using a ring stand, secure the apparatus as close to the base as possible to avoid tipping the ring stand over.
2. Use a level to make sure the horizontally launched ball does not have a y-component to its initial velocity.
3. Spring-load the apparatus by pulling the launcher back until the latch clicks into place.
4. Place only the horizontally launched sphere on its mount.
5. Fire the launcher by lifting the latch. Take note of where the sphere lands. Place a white piece of paper with carbon paper over the top of it in the vicinity of where the sphere landed.
6. Launch the sphere three times and measure the horizontal distance (range) of each launch. Record this information for each trial in the data table on the following page.
7. Repeat steps 2-6 for four different heights.

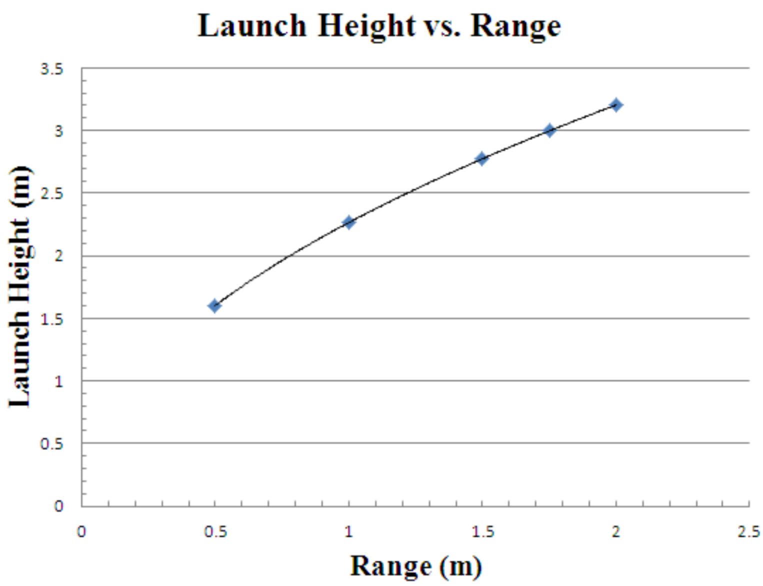
DATA (Sample)

Height (m)	Range (m)	
0.5 m	Trial 1	1.6
	Trial 2	1.7
	Trial 3	1.5
	Average:	1.6
1.0 m	Trial 1	2.3
	Trial 2	2.2
	Trial 3	2.3
	Average:	2.27

1.5 m	Trial 1	2.7
	Trial 2	2.8
	Trial 3	2.8
	Average:	2.77
1.75 m	Trial 1	3.0
	Trial 2	3.0
	Trial 3	3.0
	Average:	3.0
2.0 m	Trial 1	3.2
	Trial 2	3.1
	Trial 3	3.3
	Average:	3.2

DATA ANALYSIS

Compute the average range of each sphere for each trial. Construct a graph of launch height versus range. The use of a computer program is recommended for graphing. Make sure to draw a line of best fit that best represent the data.



ANALYSIS QUESTIONS

1. Based on your data and observations, what is the general relationship between the height at which an object is launched and the range (i.e. as height increases, range __________)?

    As the height of the launch increased, the range of the sphere increased.

2. Since the launch height for a given trial is known, what equation can be used to determine the amount of time an object is in the air? Solve this equation for time.

    $d_y = V_{oy}\, t = \frac{1}{2}\, a_y\, t^2$ setting v_{oy} equal to zero, and solving for t, one would get the following:

    $$t = \sqrt{\frac{2d_y}{a_y}}$$

3. State the equation for determining the horizontal distance (range) of an object, if given the initial horizontal velocity and the time of flight.

    $d_x = v_x\, t$

4. Since we want to relate the horizontal distance (range) to the height at which an object is launched, use your answers to questions 2 and 3 to write an equation that relates these two variables.

$$d_x = v_x\sqrt{\frac{2d_y}{a_y}}$$

5. Does the equation from question 4 fit the constructed graph? Explain.

Yes. The equation from question 4 displays a direct root relationship between the height at which a horizontally launched projectile is launched and the range of the projectile. The constructed graph also shows a direct root relationship between the variables.

CONCLUSION

What is the mathematical relationship between the height at which a projectile is launched horizontally and the resulting range of the projectile? Offer evidence from your data to support your answer.

As the height of a horizontally launched projectile increases, the range of the projectile increases. This is evident from my data. At a launch height of 0.5 m the average range was 1.6 m and at a launch height of 2.0 m the average range was 3.2 m. More specifically, the relationship between launch height and range is direct root. According to my data, if the launch height is quadrupled, the range is doubled. When the launch height is quadrupled from 0.5 m to 2.0 m, the range doubles from 1.6 m to 3.2 m.

EXTENSION FOR ADVANCED STUDENTS

There are several other investigations that can be performed with this apparatus. For more advanced college level students:

How does launch angle affect initial velocity?

- Initial velocity can be found using photogates or photogate sensors.
- Initial velocity can also be found using two dimensional motion formulas and measuring the initial launch angle and the range. Be sure to have the ball land at the same height it was launched at to make calculations easier.

How does launch speed affect overall range?

- There are two different launch speeds to compare and contrast.

Does the launch angle affect the time of flight for the ball?

Which launch angle gives the maximum range of the ball?

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